A short history of CP violation with neutral kaons

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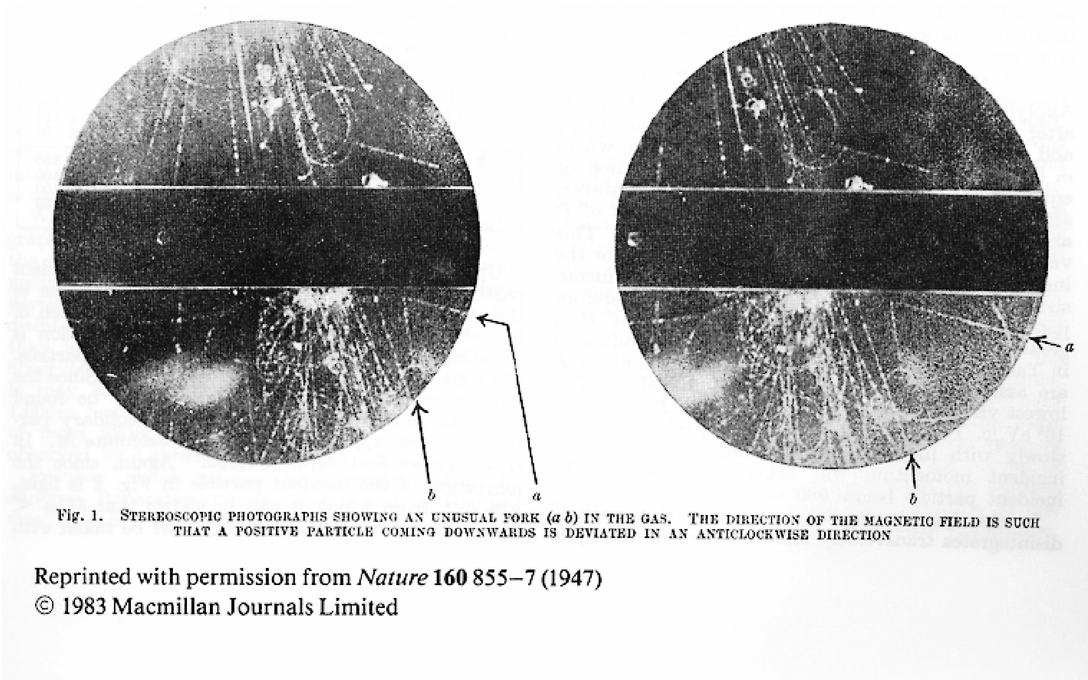
Outline

- Introduction: reminder of $\not{C}P$
- Discovery at BNL ? e
- Search for direct $\not{C}P$: e'/e
- Results from CERN and FNAL
- Conclusions

The story starts in the 1940's



- strangeness
- Quark model
- t-? Puzzle
- K^0 - $\overline{K}^0$ mixing

V particles in cloud chamber

K_L prediction by Pais + Gell Man

CP violation in K decays

Weak and CP eigenstates:

$K_S \sim K_1 + \varepsilon K_2$ $\quad$ $CP(K_1) = +1$ $\quad$ $K_1 = (K_0 + \overline{K}_0)/\sqrt{2}$

$K_L \sim K_2 + \varepsilon K_1$ $\quad$ $CP(K_2) = -1$ $\quad$ $K_2 = (K_0 - \overline{K}_0)/\sqrt{2}$

Indirect CP violation comes from mixing of CP eigenstates K_1 and K_2 in weak eigenstates K_S and K_L ? ***mixing*** parameter $\varepsilon = (2.28 \pm 0.02) \mathrm{x} 10^{-3}$

Direct CP violation results from asymmetric decay amplitudes
$\Gamma(K_0 \rightarrow \pi\pi) \neq \Gamma(\overline{K}_0 \rightarrow \pi\pi)$? parameter e'

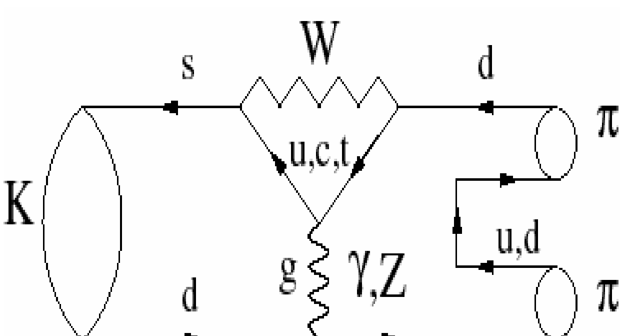
CP violation parameters:

$$h^{+-} = \frac{\mathbf{A}(\mathbf{K}_L \rightarrow p^+ p^-)}{\mathbf{A}(\mathbf{K}_S \rightarrow p^+ p^-)} = e + e'$$

$$h^{00} = \frac{\mathbf{A}(\mathbf{K}_L \rightarrow p^0 p^0)}{\mathbf{A}(\mathbf{K}_S \rightarrow p^0 p^0)} = e - 2e'$$

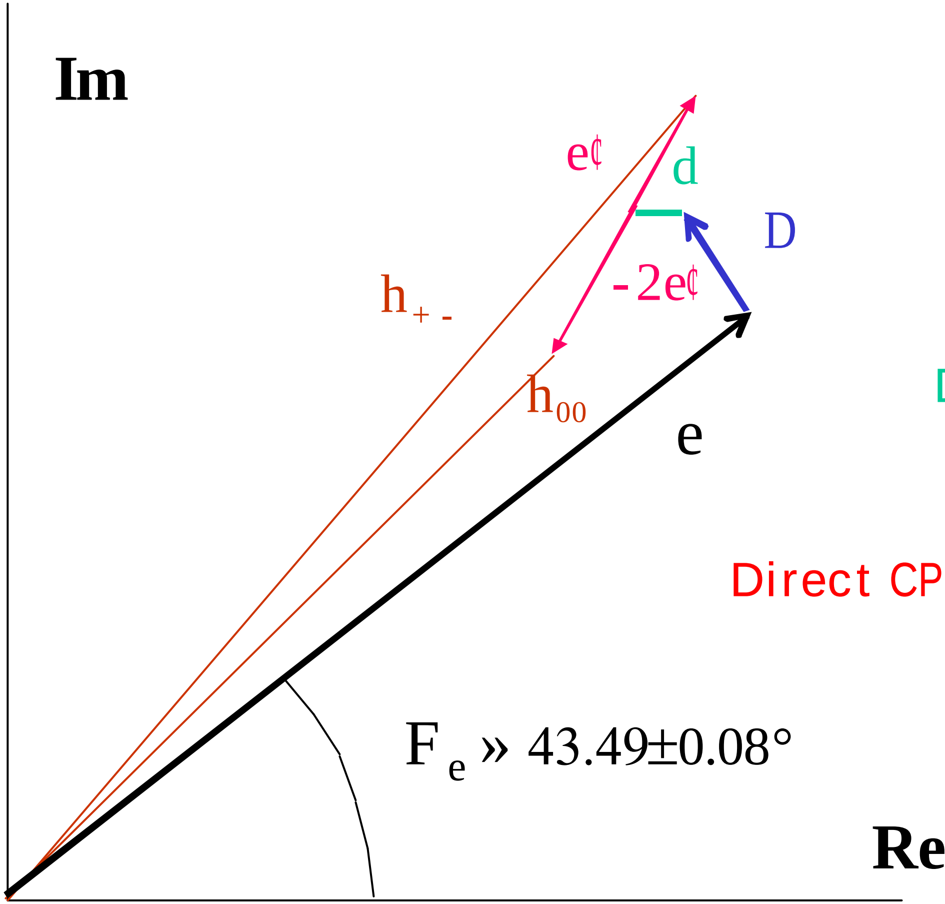
Direct CP violation e' = penguin diagrams in SM

$$e' = \frac{\mathbf{i}}{\sqrt{2}} \mathrm{Im}\left(\frac{\mathbf{A}_2}{\mathbf{A}_0}\right) \exp^{\mathbf{i}(d_2 - d_0)}$$



Theoretical calculations of ε'/ε within SM range $[4\text{-}30] \mathrm{x} 10^{-4}$

CP and CPT violating parameters



Direct CPT violation Þ $d = \frac{A_0 - \overline{A}_0}{A_0 + \overline{A}_0}$

Direct CP violation Þ $e' = \frac{1}{\sqrt{2}} \frac{A_2 - \overline{A}_2}{A_2 + \overline{A}_2} e^{i(d_2 - d_0)}$

$h_{+-} = (e + D + d) + e¢$

$h_{00} = (e - D + d) - 2e¢$

e : ~~CP~~ , **CPT** in K°- $\overline{\text{K}}$° mixing

D : ~~CP~~ , ~~CPT~~ in K°- $\overline{\text{K}}$° mixing

CP violation: is it a mystery?

- Unexpected phenomenon
- Disturbing discovery of K_L? pp at BNL by Christenson, Cronin,Fitch,Turlay
- Kobayashi and Maskawa give a modern explanation
- Sakharov's conjecture for baryon asymmetry of the universe
- CP violation = matter-antimatter asymmetry $\sim 3\times10^{-10}$
- Need also thermal non-equilibrium and processes with ΔB?0
- CP violation from CKM not sufficient
- Phase transition not strong enough
- CKM too cool
- New source(s) needed

BNL 1963: proposal

APPENDIX

PROPOSAL FOR K^o_2 DECAY AND INTERACTION EXPERIMENT

J. W. Cronin, V. L. Fitch, R. Turlay

(April 10, 1963)

I. INTRODUCTION

The present proposal was largely stimulated by the recent anomalous results of Adair et al., on the coherent regeneration of K^o_1 mesons. It is the purpose of this experiment to check these results with a precision far transcending that attained in the previous experiment. Other results to be obtained will be a new and much better limit for the partial rate of $K^o_2 \to \pi^+ + \pi^-$, a new limit for the presence (or absence) of neutral currents as observed through $K_2 \to \mu^+ + \mu^-$. In addition, if time permits, the coherent regeneration of K_1's in dense materials can be observed with good accuracy.

II. EXPERIMENTAL APPARATUS

Fortuitously the equipment of this experiment already exists in operating condition. We propose to use the present 30° neutral beam at the A.G.S. along with the di-pion detector and hydrogen target currently being used by Cronin, et al. at the Cosmotron. We further propose that this experiment be done during the forthcoming μ-p scattering experiment on a parasitic basis.

The di-pion apparatus appears ideal for the experiment. The energy resolution is better than 4 Mev in the m^* or the Q value measurement. The origin of the decay can be located to better than 0.1 inches. The 4 Mev resolution is to be compared with the 20 Mev in the Adair bubble chamber. Indeed it is through the greatly improved resolution (coupled with better statistics) that one can expect to get improved limits on the partial decay rates mentioned above.

-2-

III. COUNTING RATES

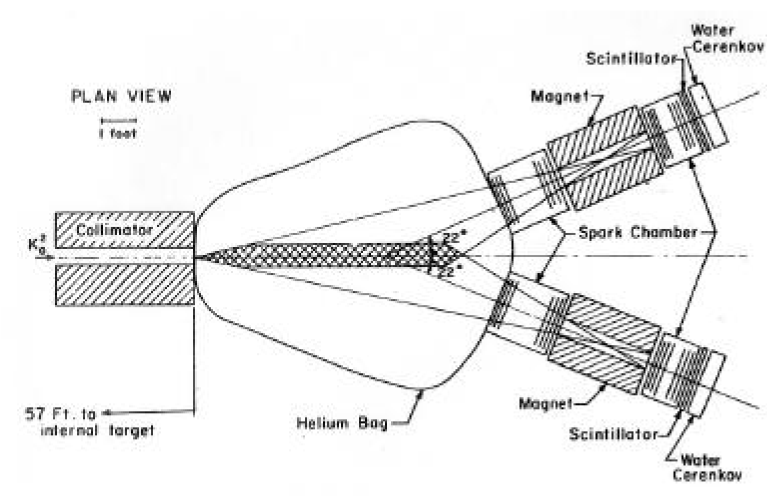
We have made careful Monte Carlo calculations of the counting rates expected. For example, using the 30° beam with the detector 60-ft. from the A.G.S. target we could expect 0.6 decay events per 10^{11} circulating protons if the K_2 went entirely to two pions. This means that one can set a limit of about one in a thousand for the partial rate of $K_2 \to 2\pi$ in one hour of operation. The actual limit is set, of course, by the number of three-body K_2 decays that look like two-body decays. We have not as yet made detailed calculations of this. However, it is certain that the excellent resolution of the apparatus will greatly assist in arriving at a much better limit.

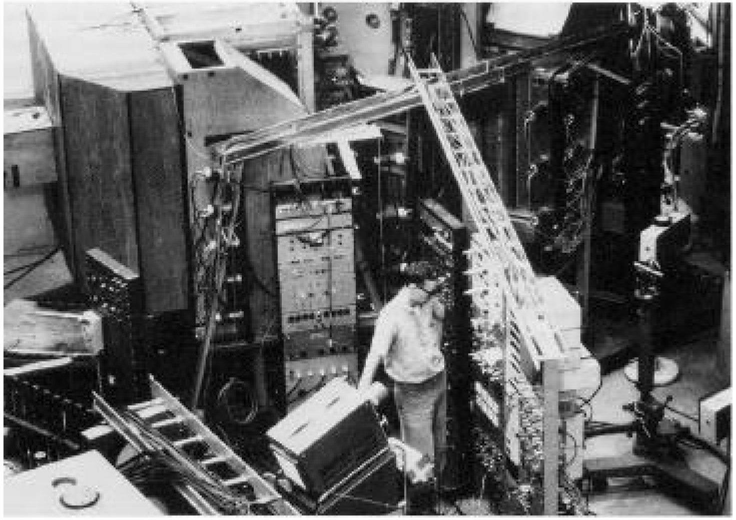
If the experiment of Adair, et al. is correct the rate of coherently regenerated K_1's in hydrogen will be approximately 80/hour. This is to be compared with a total of 20 events in the original experiment. The apparatus has enough angular acceptance to detect incoherently produced K_1's with uniform efficiency to beyond 15°. We emphasize the advantage of being able to remove the regenerating material (e.g., hydrogen) from the neutral beam.

IV. POWER REQUIREMENTS

The power requirements for the experiment are extraordinarily modest. We must power one 18-in. x 36-in. magnet for sweeping the beam of charged particles. The two magnets in the di-pion spectrometer are operated in series and use a total of 20 kw.

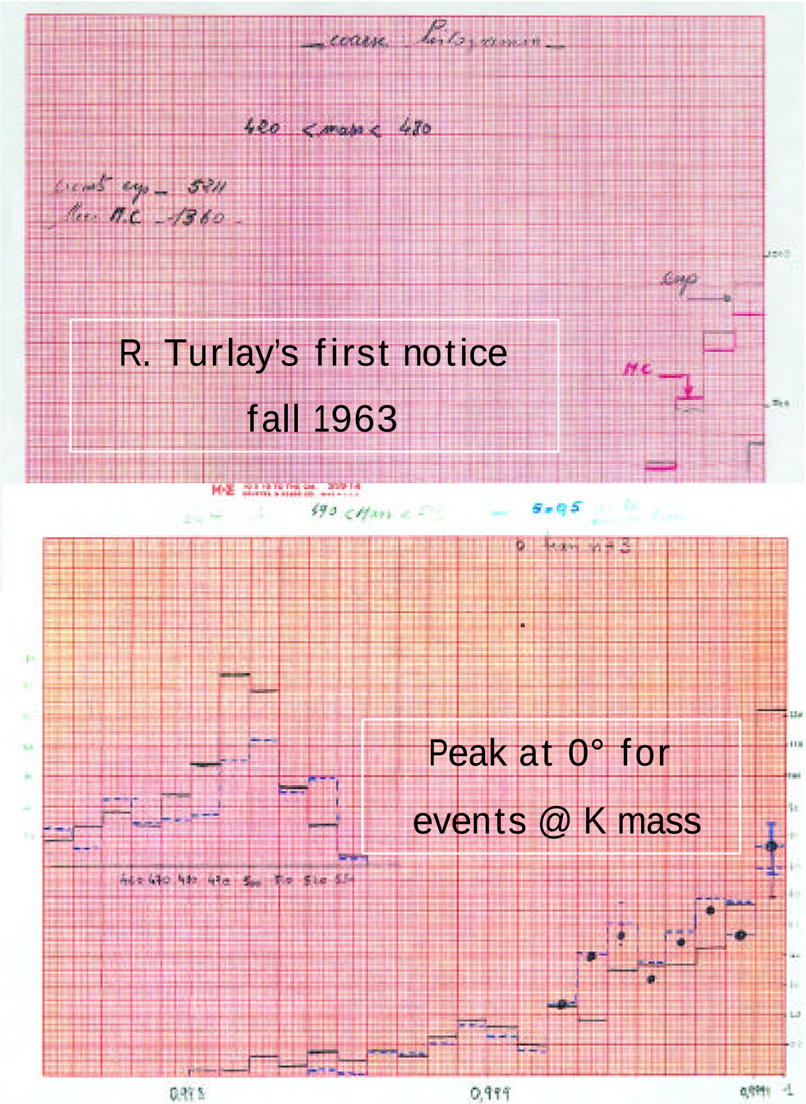
BNL 1963: the experiment

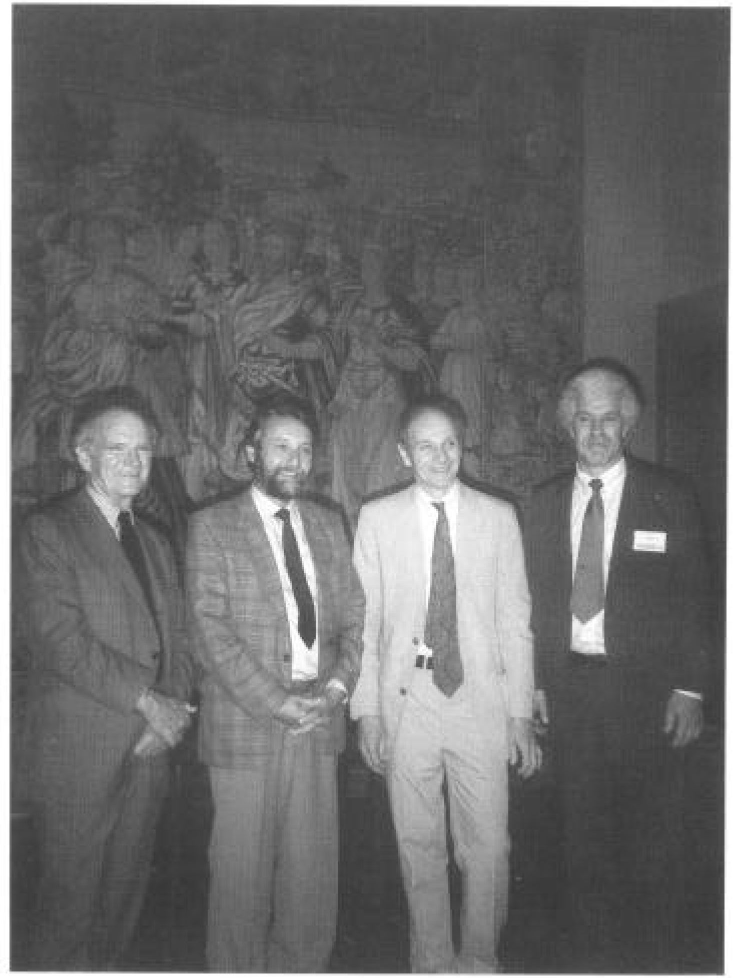




- Letter of Intent by J. Cronin, V. Fitch, R. Turlay: April 1963
- Agreement of BNL directorate: May 1963
- Apparatus ready: June 2nd 1963
- 40 days of running: end of July 1963
  - 1- regeneration on C, Cu, Pb 70000 triggers
  - 2- CP limit 47000 triggers
  - 3- Adair effect on H2 23000 triggers

BNL 1963: the first hint





From left : Val Fitch, René Turlay, Jim Cronin and Jim Christenson. Château de Beauregard. Courtesy of Count du Pavillon.

BNL 1963: the experiment

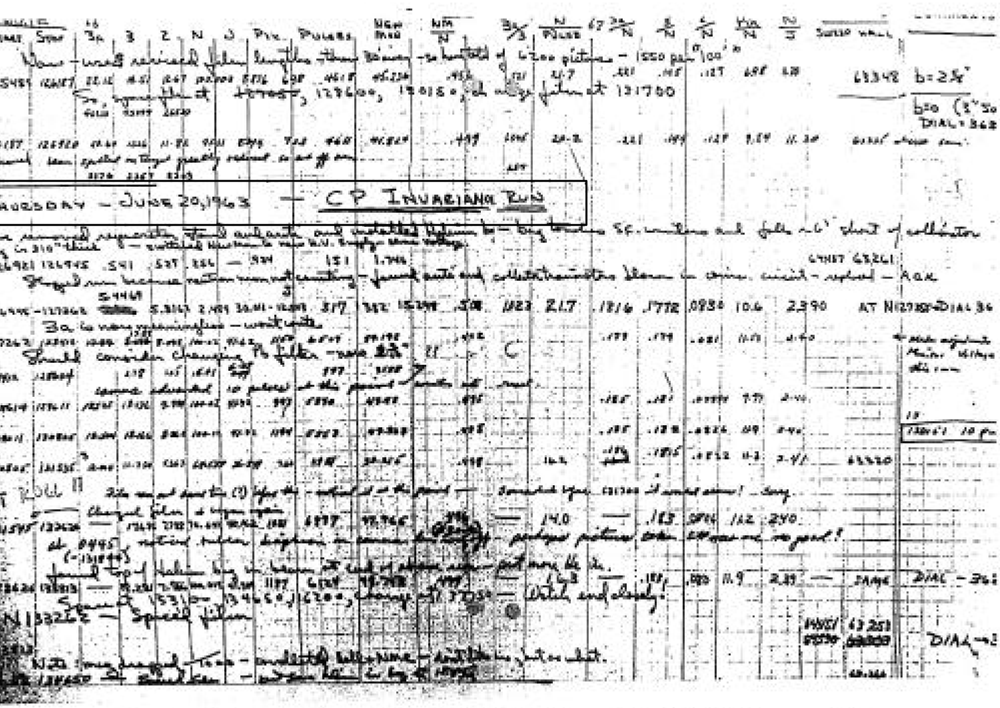


Figure 7: Page from the data book at the beginning of the CP violation run, June 1963

Page from data book @ beginning of CP violation run

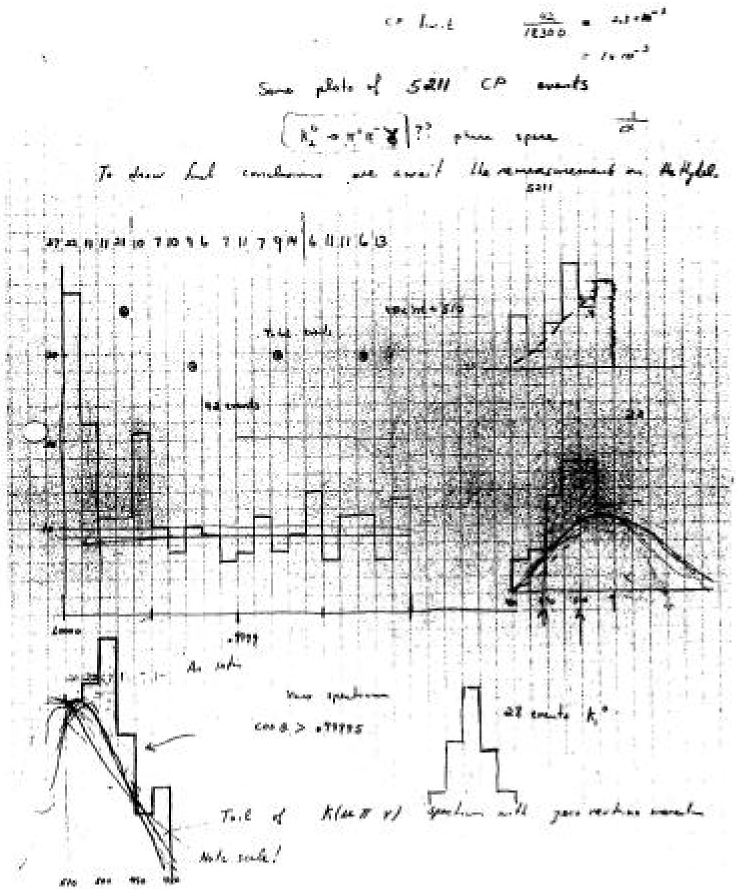


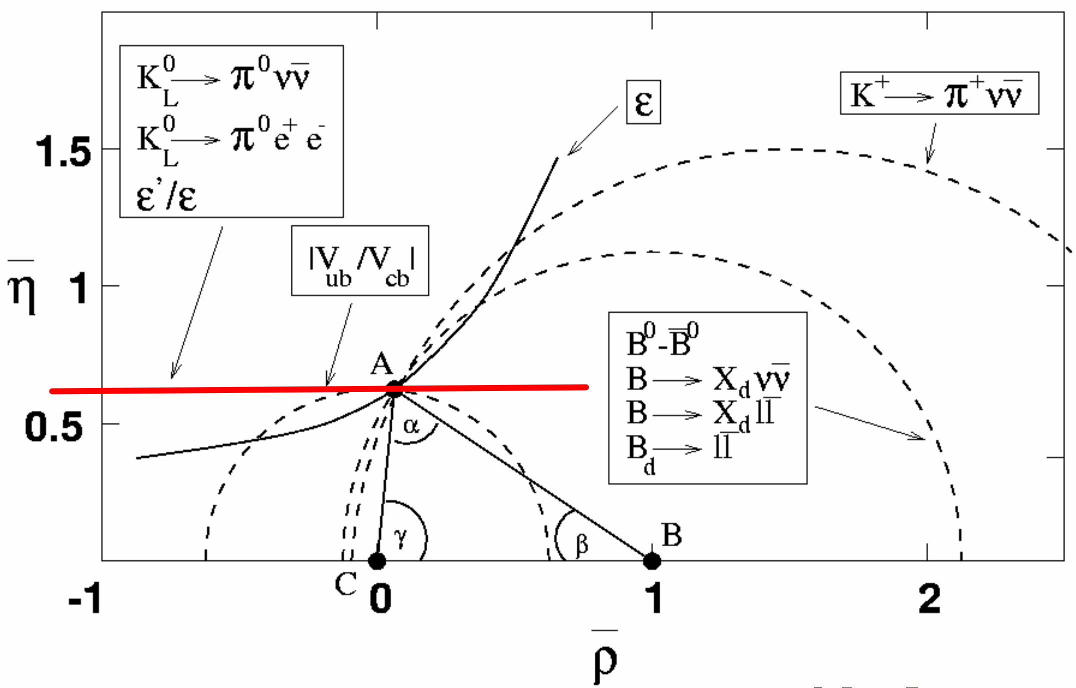
Figure 9: Page from notebook of J. W. Cronin with comment on the first results of the analysis of the CP events measured with the angular encoder.

Short bibliography on C~~P~~ discovery and early experiments

- V.L. Fitch, A personal view of the discovery of CP violation, Proc. Int. Conf. Symmetries in Physics, San Luis de Guixols, 1983.
- R. Turlay, CP Violation, Int. Conf. on History of original ideas and basic Discoveries in Particle Physics, Erice. Plenum (1996) Nato ASI B352
- J. W. Cronin, The experimental Discovery of CP violation, Nishina Memorial Foundation, september 1993.
- V.L. Fitch, The discovery of charge-conjugation parity asymmetry. Rev. Mod. Phys. 53,367, 1980.
- J. W. Cronin, CP symmetry violation-thye search for its origin. Rev. Mod. Phys. 53,373, 1980.
- R.K. Adair, CP-Nonconservation-The early experiments.
- A. Pais, CP-violation: the first 25 years.
- J. Steinberger, experimental status of CP violation.

} 25th Anniversary of CP violation discovery Blois May 1989.

Why measure e'/e?



Unitarity triangle

Constraints on models

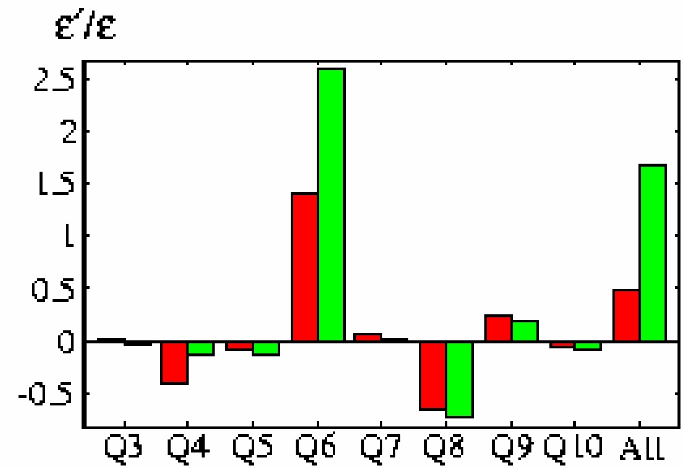
(SM, SUSY …)

$$??^5 A^2 = \mathrm{Im}(V_{td} V_{ts}^*)$$

$$\frac{\varepsilon'}{\varepsilon} = \frac{\omega G_F}{2|\epsilon| Re(A_0)} Im\lambda_t \left[(1-\Omega_{\eta+\eta'}) y_6 \langle Q_6\rangle_0 - \frac{1}{\omega} y_8 \langle Q_8\rangle_2 + \dots\right]$$

Approximate '*pedagogical*' formula *(Buras-Munich)*

$$\frac{\varepsilon'}{\varepsilon} \propto Im\,\lambda_t \left(\frac{110\ MeV}{m_s(2\ GeV)}\right)^2 \left[0.75\cdot B_6 - 0.4\cdot B_8 \left(\frac{m_t}{165 GeV}\right)^{\frac{5}{2}}\right] \frac{\Lambda^{(4)}_{\overline{MS}}}{340\ MeV}$$



E617 at Fermilab 1980-1985

January 1979: Proposal

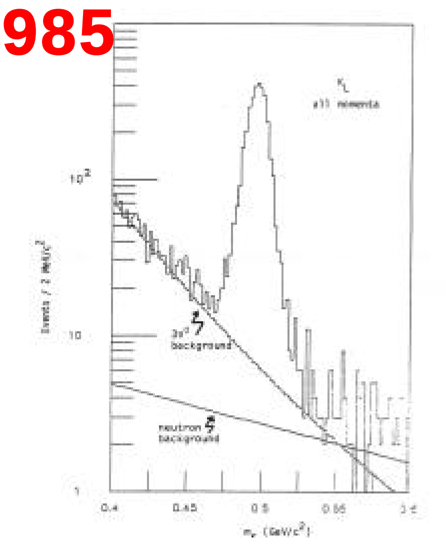
A Study of Direct CP Violation in the Decay of the Neutral Kaon via a Precision Measurement of $|\eta_{00}/\eta_{+-}|$

R. Bernstein, J.W. Cronin, and B. Winstein
University of Chicago, Enrico Fermi Institute, Chicago, Illinois
B. Cousins, J. Greenhalgh, and M. Schwartz
Stanford University, Department of Physics, Stanford, California
D. Hedin and G. Thomson
University of Wisconsin, Department of Physics, Madison, Wisconsin

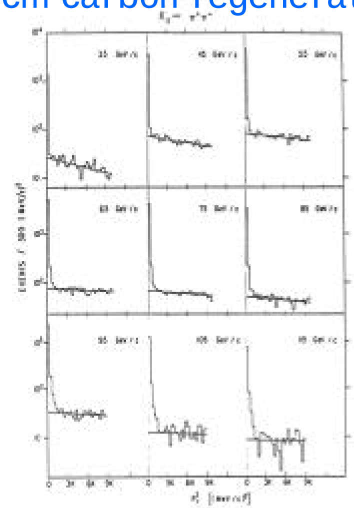
ABSTRACT

In this proposal, we describe an experiment to measure the ratio R of the CP violating amplitudes $|\eta_{00}|$ and $|\eta_{+-}|$ to a precision of better than 1% thereby improving the present results by about one order of magnitude. If the CP violation is confined to the mass matrix, R = 1.0 exactly. Recent theoretical considerations which unify the CP violating interaction with the CP conserving weak and electromagnetic interactions among six quarks predict R differing from 1.0 by sizable amounts.

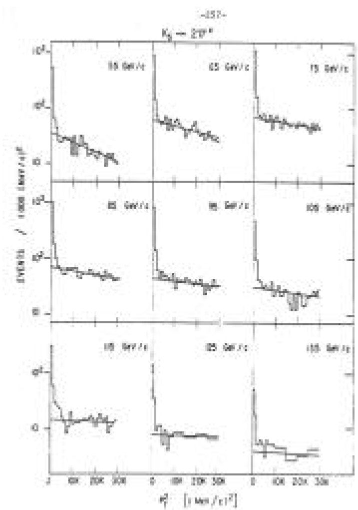
4x25.4cm carbon regenerator



K_L? $2\pi^0$ mass peak BKG ~8%



K_S? $\pi^+\pi^-$ inelastic BKG ~1.7%



K_L? $2\pi^0$ inelastic BKG ~14.6%

Basic principles

E731 uses regeneration

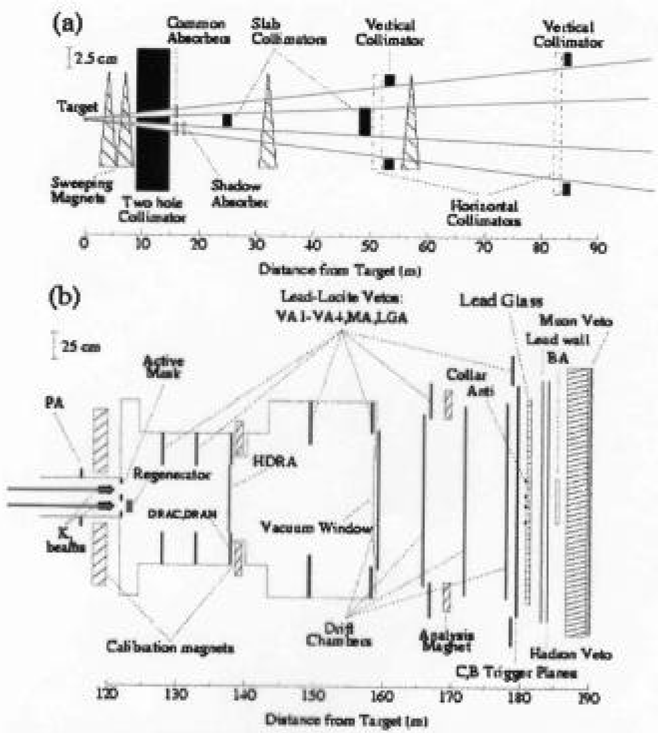
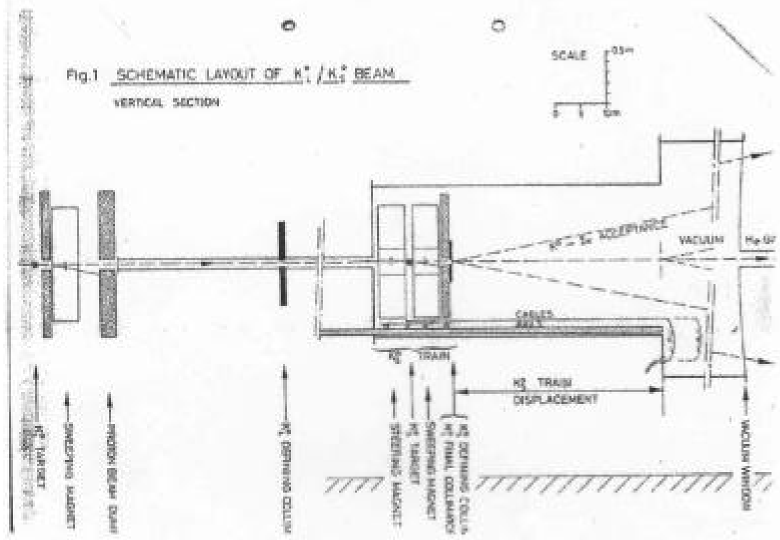


FIG. 2. Illustration of the apparatus used in this experiment. (a) is an elevation view o layout of the collimation and sweeping system used to produce the two neutral beams. (b) a the apparatus used to detect the kaon decay products.

NA31 uses movable target



NA31: Measurement of $|\eta_{00}|^2/|\eta_{+-}|^2$

CERN-Edinburgh-Mainz-Orsay-Pisa-Siegen Collaboration

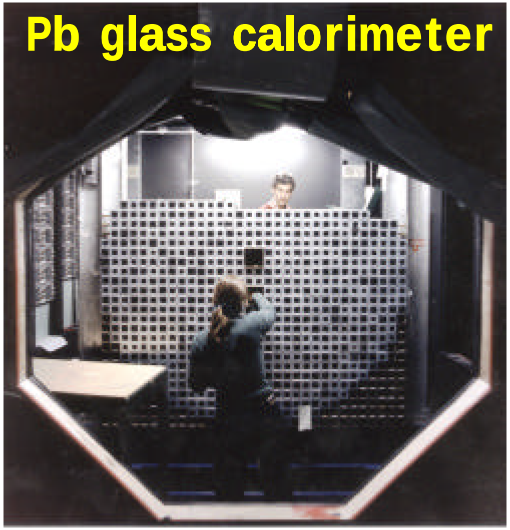
Proposal 22 Dec 1981

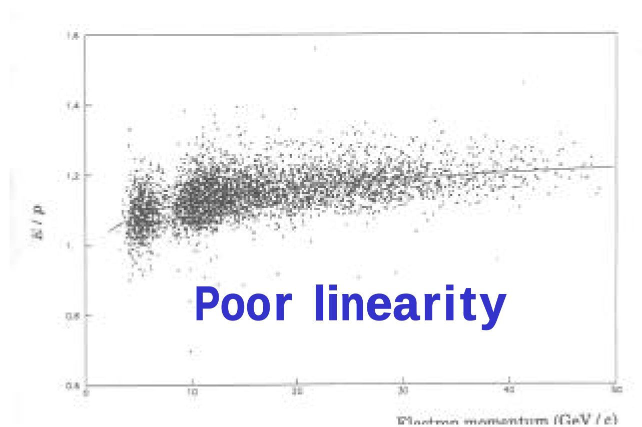
Approved 16 Sep 1982

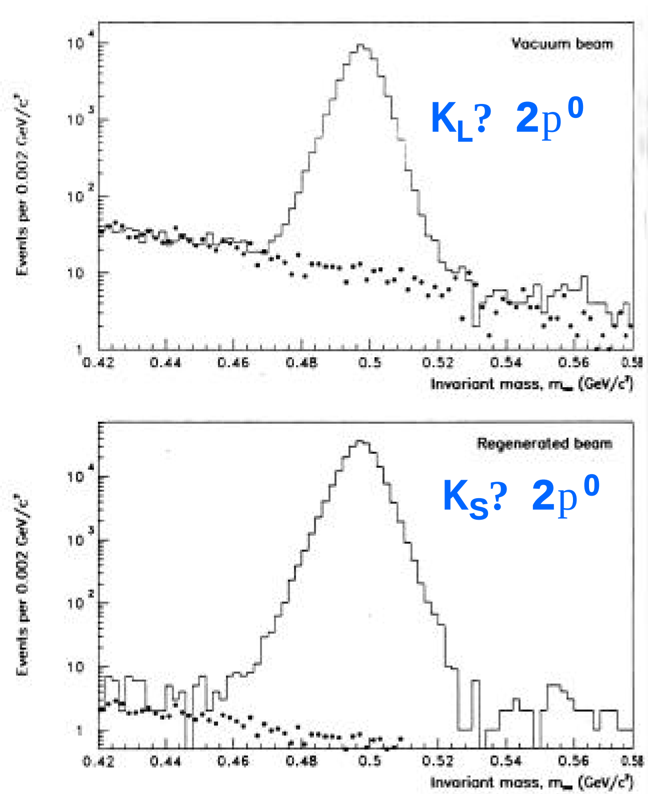
Data taking 1986 – 1989

Final result 1993

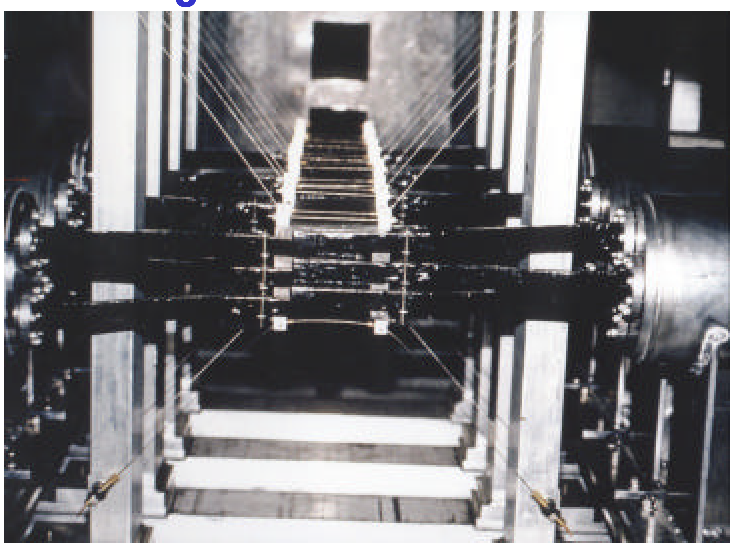
E731 at Fermilab 1985-1990



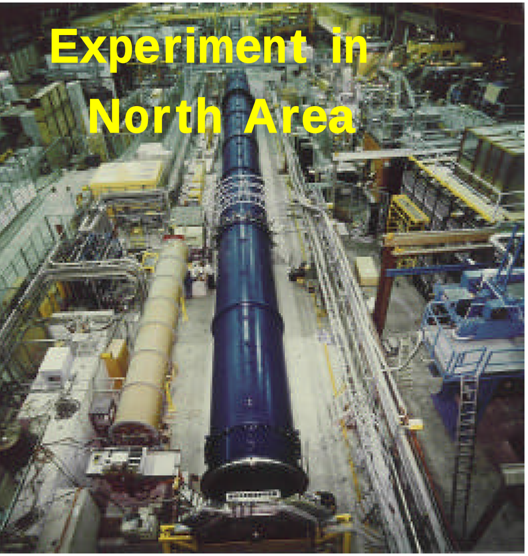




Regenerator in vacuum



NA31 at CERN 1982-1990



December 1980: Proposal

5 December, 1980

M E M O R A N D U M

To: CERN-Dortmund-Heidelberg-Saclay Collaboration

From: J. Steinberger and H. Wahl

Subject: $|\eta_{00}|/|\eta_{+-}|$ experiment

As is well known, SU(2) × U(1) with six flavours provides a "natural" way to CP violation, and deviations from 1 in $|\eta_{00}|/|\eta_{+-}|$ of the order of ~1%, and consequently of the order of 2% in the double ratio

$$\frac{\Gamma(K_S \to 2\pi_0)/\Gamma(K_S \to \pi^+\pi^-)}{\Gamma(K_L \to 2\pi_0)/\Gamma(K_L \to \pi^+\pi^-)}$$

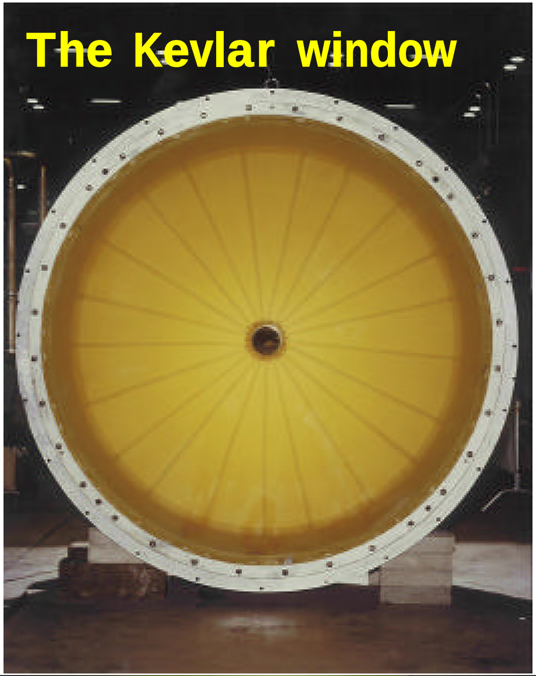
can be expected[1]. An experiment by Cronin et al. to measure this accuracy is in progress at FNAL.

We have been thinking about how one might best do this measurement and think we have found a way in which one might hope to get an accuracy of the order of ~0.002 in $|\eta_{00}|/|\eta_{+-}|$. The general idea is shown on the sketch. Neutral and charged rates are measured simultaneously in a detector which consists of:

a) proportional chambers to measure the charged directions;
b) a γ calorimeter with $\Delta E/E \sim 0.1/\sqrt{E}$, and $\Delta x, \Delta y \sim 3$ mm;
c) a hadron calorimeter with $\Delta E/E \sim 0.6/\sqrt{E}$, and rather coarse grain;
d) muon counters.

It is intended to work in the range $120 \lesssim E_K \lesssim 200$ GeV. Short and longlived kaons are obtained alternately by a change in target position.

The chief background for the neutral mode is the $3\pi^0$ decay, and the position and energy information should be sufficient to get rid of all these. The resolution of the reconstructed K^0 in z should be no worse than ~ 0.1 K_S lifetimes, and the resolution in the reconstructed K^0 mass for the neutral decay should be ~1%. The background for the charged mode is presumably chiefly Ke_3 and $K\mu_3$ decay. It should be possible to reject



Status in 1989

CP violation: where we stand 25 years later

$$\epsilon'/\epsilon = (33 \pm 11) \times 10^{-4} \text{ (NA31)}$$

$$\epsilon'/\epsilon = [(-10 \text{ to } 10) \pm 15] \times 10^{-4} \text{ (E731, very preliminary)}$$

The E731 result does not confirm the non-zero result of NA31 nor does it significantly disagree with it.

What are we to conclude from these experiments? The most important conclusion is that they must be continued to still higher accuracy. The point is not to find the exact value of ϵ'; the point is to make absolutely sure that ϵ' is non-zero. The NA31 experiment has wounded the superweak theory. The time has come to really kill it. I remember in 1968 in Moscow discussing the death of the superweak theory based on an experiment ... The superweak theory does not die easily.

L. Wolfenstein, Concluding talk

CP violation in particle physics and astrophysics, Chateau de Blois 1989

Final results in 1996

ε'/ε **Status:** ... The final results from NA31 and E731 are well known:

$$\text{NA31: } \mathrm{Re}\,\varepsilon'/\varepsilon = (23 \pm 6.5) \times 10^{-4},$$
$$\text{E731: } \mathrm{Re}\,\varepsilon'/\varepsilon = (7.4 \pm 5.9) \times 10^{-4}.$$

The NA31 result is more interesting in that it tends to disagree with the latest predictions from the Standard Model. On the other hand, the E731 result is in the range favored by the Standard Model and as well it doesn't quite rule out the Superweak Model ($\mathrm{Re}\,\varepsilon'/\varepsilon = 0$) with any confidence. The results differ by about two standard deviations; nevertheless, the conclusions are sufficiently different that it would not be appropriate to average the results prior to the establishment of a non-zero effect.[HW]

B Winstein, Summary (Experiments)
Workshop on K physics, Orsay 1996

CP LEAR LOI 1984

2. Letters of Intent concerning CP/CPT violation (Basle-Stockholm-Thessaloniki PSCC/83-28/I65; Delft-Ljubljana-Pennsylvania-Birmingham-Oxford PSCC/84-9/I66 and 84-10/M180)

R. Turlay reviewed the status of our present knowledge on CP/CPT violation for the kaon case. A new interest has arisen in recent years in connection with the successful 6-quark Kobayashi and Maskawa model (which includes CP violation in a "natural" way) and with astrophysics problems. The two planned experiments, at CERN and Fermilab, aim for $\sim 10^5$ events in 1985-87 with an accuracy of $\sim 0.1\%$ on $|\varepsilon'/\varepsilon|$, whereas in 1974 the errors were at the level of 1%. Why then LEAR? In the referee's opinion LEAR can do as well in the $|\varepsilon'/\varepsilon|$ measurement or better in other parameters. Even if the statistical accuracy is comparable, the systematic errors would be of a completely different origin. Also one would explore the kaons in K^0 and $\bar{K}^0$ states with the possibility to study the K_{e3} channel and improve the measurement on CP and CPT. However, one should go for a long-term programme (~ 5 years); the experiments are interesting, but very difficult.

The Committee agreed that a CP/CPT experiment could be an interesting ingredient in the second-generation LEAR programme, but in view of the large effort involved it was clearly too early to take any commitment.

CP LEAR

$$\bar{p}p \to \begin{cases} K^+ K^0 p^- \\ K^- \bar{K}^0 p^+ \end{cases}$$

Strangeness K° ($\bar{K}$°) signed at t=0 by $K^+(K^-)$

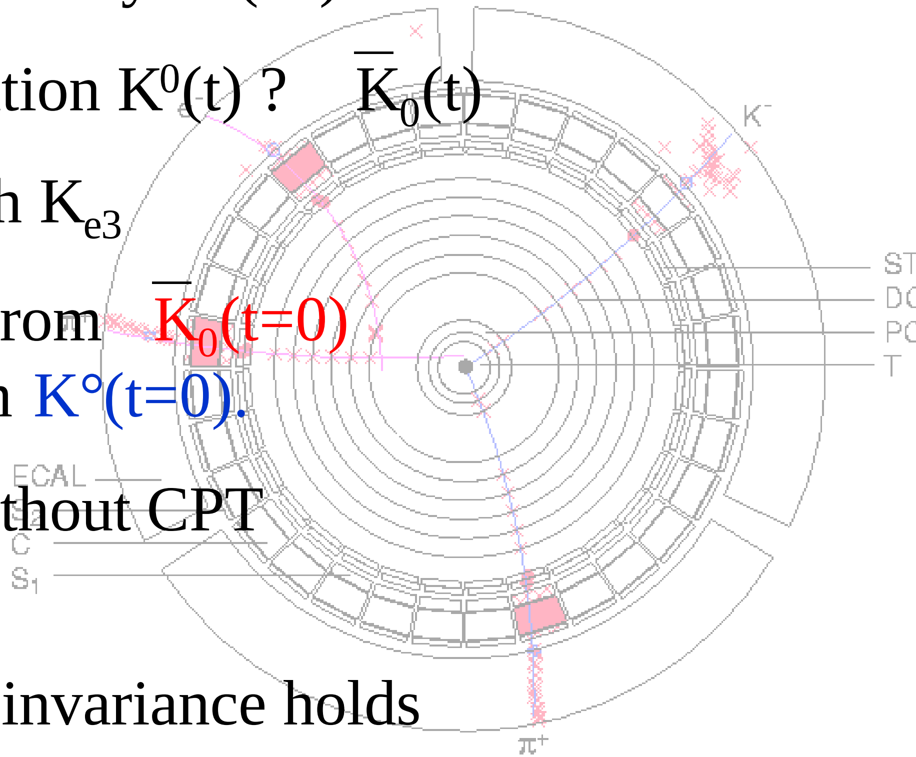
Direct observation of time evolution $K^0(t)$? $\bar{K}_0(t)$

Strangeness of decay signed with K_{e3}

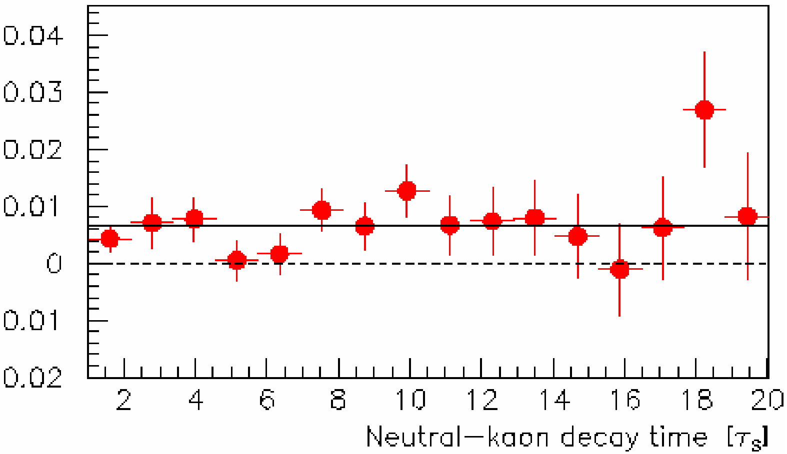
T invariance ⇒ K°(t) observed from $\bar{K}_0(t=0)$
identical to $\bar{K}_0(t)$ observed from K°(t=0).

Measurement of T invariance without CPT hypothesis

T violation: $A_T \approx 4Re(\varepsilon)$ if CPT invariance holds



CP LEAR



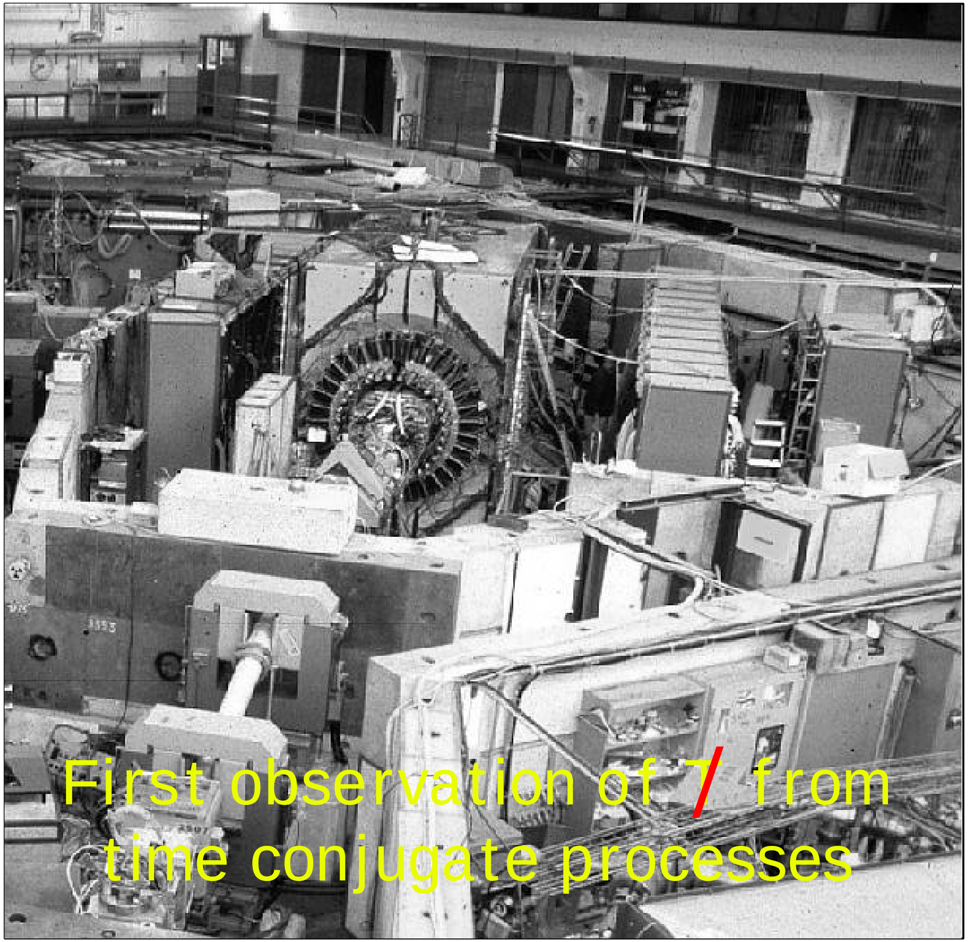
$$A_T^{exp}(t) = \frac{\eta N(\bar{K}^0_{t=0} \to e^+\pi^-\nu_{t=\tau}) - \xi N(K^0_{t=0} \to e^-\pi^+\bar{\nu}_{t=\tau})}{\eta N(\bar{K}^0_{t=0} \to e^+\pi^-\nu_{t=\tau}) + \xi N(K^0_{t=0} \to e^-\pi^+\bar{\nu}_{t=\tau})}$$

$$\langle A_T^{exp} \rangle_{(1-20)\tau_S} = (6.6 \pm 1.3) \times 10^{-3}$$

$$\chi^2/\text{d.o.f.} = 0.84$$

Systematic errors on $\langle A_T^{exp} \rangle$

Source	$\langle A_T^{exp} \rangle$ $[10^{-3}]$
background level	± 0.03
background asymmetry	± 0.02
ξ	± 0.2
η	± 1.0
decay-time resolution	negligible
regeneration	± 0.1
Total syst.	± 1.0



CPLEAR Results

CP Violation

$K^0 \to \pi^+\pi^-$	PLB 458 (1999) 545
$\lvert\eta_{+-}\rvert = (2.264 \pm 0.023_{stat} \pm 0.026_{syst} \pm 0.007_{\tau_S}) \times 10^{-3}$	
$\phi_{+-} = 43.19^\circ \pm 0.53^\circ_{stat} \pm 0.28^\circ_{syst} \pm 0.42^\circ_{\Delta m}$	
$K^0 \to \pi^0\pi^0$	PLB 420 (1998) 191
$\lvert\eta_{00}\rvert = (2.47 \pm 0.31_{stat} \pm 0.24_{syst}) \times 10^{-3}$	
$\phi_{00} = 42.0^\circ \pm 5.6^\circ_{stat} \pm 1.9^\circ_{syst}$	
$K^0 \to \pi^+\pi^-\pi^0$	EPJ C5 (1998) 191
$Re(\eta_{+-0}) = (-2 \pm 7_{stat}\ {}^{+4}_{-1}{}_{syst}) \times 10^{-3}$	
$Im(\eta_{+-0}) = (-2 \pm 9_{stat}\ {}^{+2}_{-1}{}_{syst}) \times 10^{-3}$	
$K^0 \to \pi^0\pi^0\pi^0$	PLB 425 (1998) 391
$Re(\eta_{000}) = 0.18 \pm 0.14_{stat} \pm 0.06_{syst}$	
$Im(\eta_{000}) = 0.15 \pm 0.20_{stat} \pm 0.03_{syst}$	

T Violation

$Re(\varepsilon) = (1.65 \pm 0.33_{stat} \pm 0.25_{syst}) \times 10^{-3}$	(direct)	PLB 444 (1998) 43
$Re(\varepsilon) = (1.649 \pm 0.025) \times 10^{-3}$	(unitarity)	PLB 456 (1999) 297

CPT Violation

$Re(\delta) = (3.0 \pm 3.3_{stat} \pm 0.6_{syst}) \times 10^{-4}$	(direct)	PLB 444 (1998) 52
$Im(\delta) = (-1.5 \pm 2.3_{stat} \pm 0.3_{syst}) \times 10^{-3}$	(direct)	PLB 444 (1998) 52
$Im(\delta) = (-2.4 \pm 5.0) \times 10^{-5}$	(unitarity)	PLB 456 (1999) 297
$M_{K^0K^0} - M_{\overline{K}^0\overline{K}^0} = (-1.5 \pm 2.0) \times 10^{-18}$ GeV		
$\Gamma_{K^0K^0} - \Gamma_{\overline{K}^0\overline{K}^0} = (3.9 \pm 4.2) \times 10^{-18}$ GeV		

- Other parameters of the neutral kaon system

$\Delta m = (529.5 \pm 2.0_{stat} \pm 3.0_{syst}) \times 10^7 \hbar/s$	PLB 444 (1998) 38
$\Delta S = \Delta Q$ rule:	
$Re(x) = (-1.8 \pm 4.1_{stat} \pm 4.5_{syst}) \times 10^{-3}$	PLB 444 (1998) 38
$Re(x_-) = (0.2 \pm 1.3_{stat} \pm 0.3_{syst}) \times 10^{-2}$	PLB 444 (1998) 52
$Im(x_+) = (1.2 \pm 1.9_{stat} \pm 0.3_{syst}) \times 10^{-3}$	PLB 444 (1998) 43
$BR(K_S \to \pi^+\pi^-\pi^0) = 2.5^{+1.3}_{-1.0}{}_{stat}\ {}^{+1.5}_{-0.6}{}_{syst}) \times 10^{-7}$	PLB 407 (1997) 19
$BR(K_S \to e^+e^-) < 1.4 \times 10^{-7}$	PLB 413 (1997) 23
Kaon scattering amplitudes in Carbon	PLB 413 (1997) 42

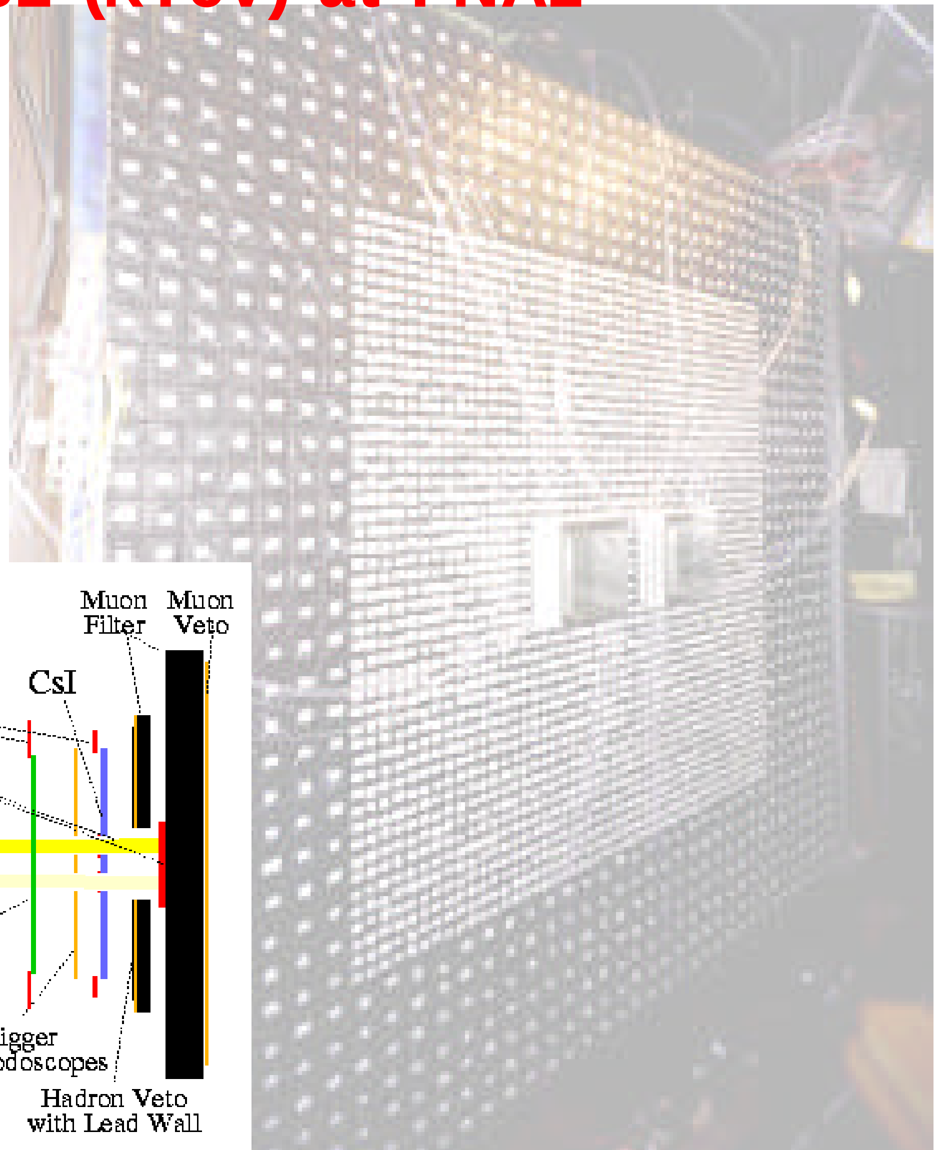
- Other tests of fundamental physics

Test of quantum mechanics coherence	PLB 364 (1995) 239
EPR test with $\bar{p}p \to K^0\overline{K}^0$	PLB 422 (1998) 339
Test of equivalence principle	PLB 452 (1999) 425

KTEV

Kaons at the Tevatron

E832 (KTeV) at FNAL



Double K_L beams (<p>=70 GeV/*c*)

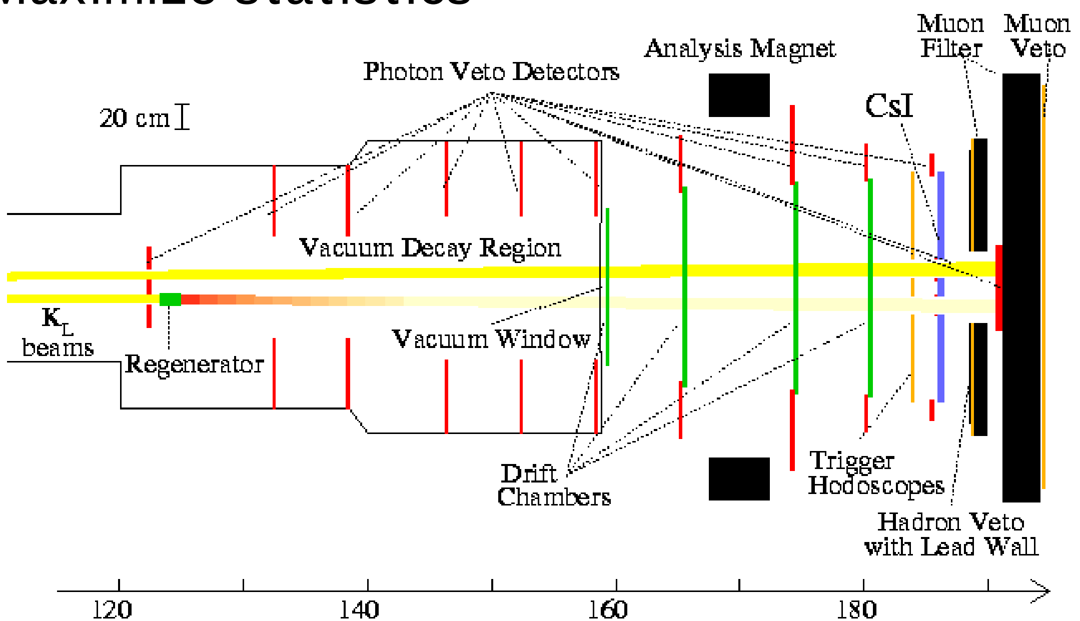
Regenerator for K_S

Pure CsI calorimeter

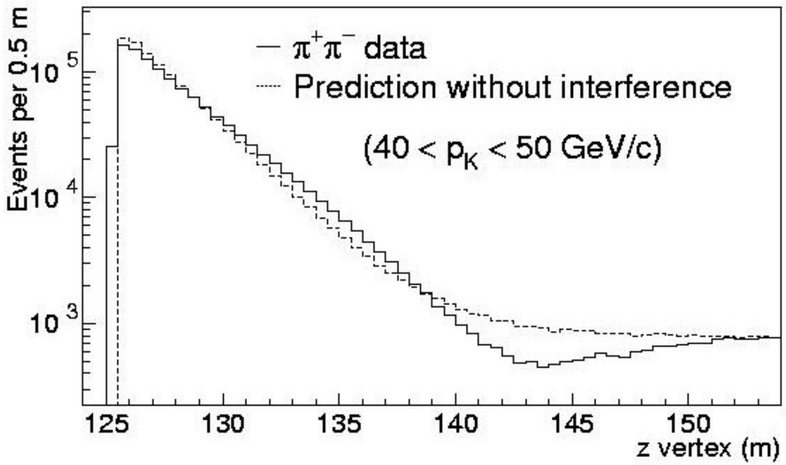
K_S/K_L by event position

MC acceptance correction

Maximize statistics

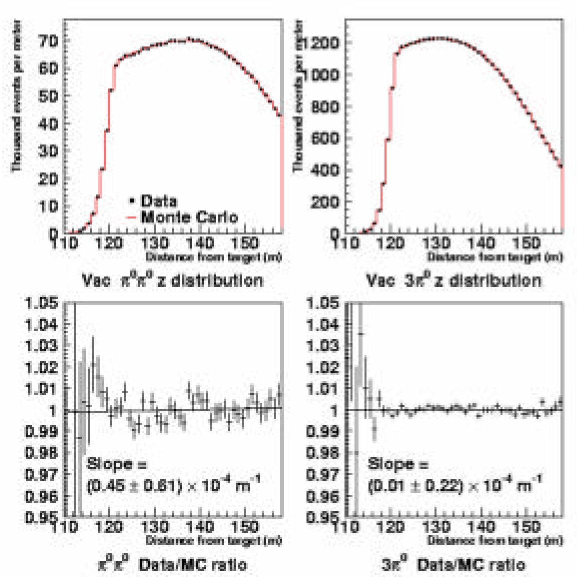


KTeV at Fermilab 1992-2002

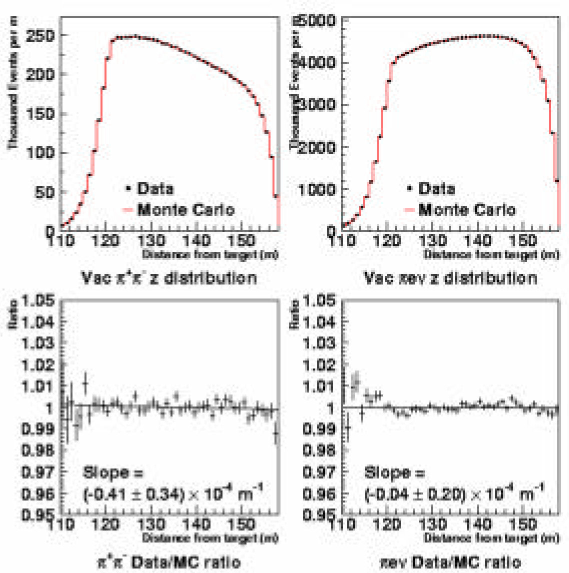


The Regenerator

$p^+ p^-$ Data/MC ratios

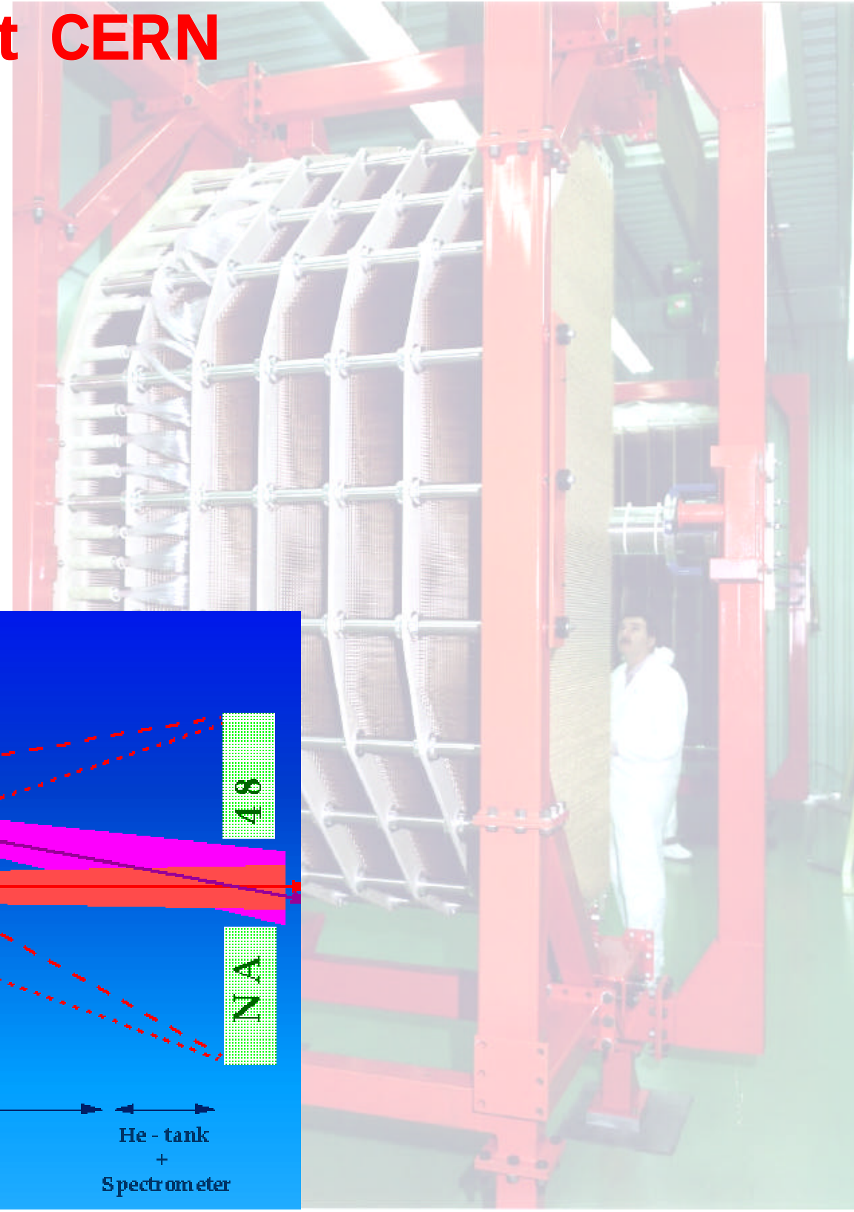


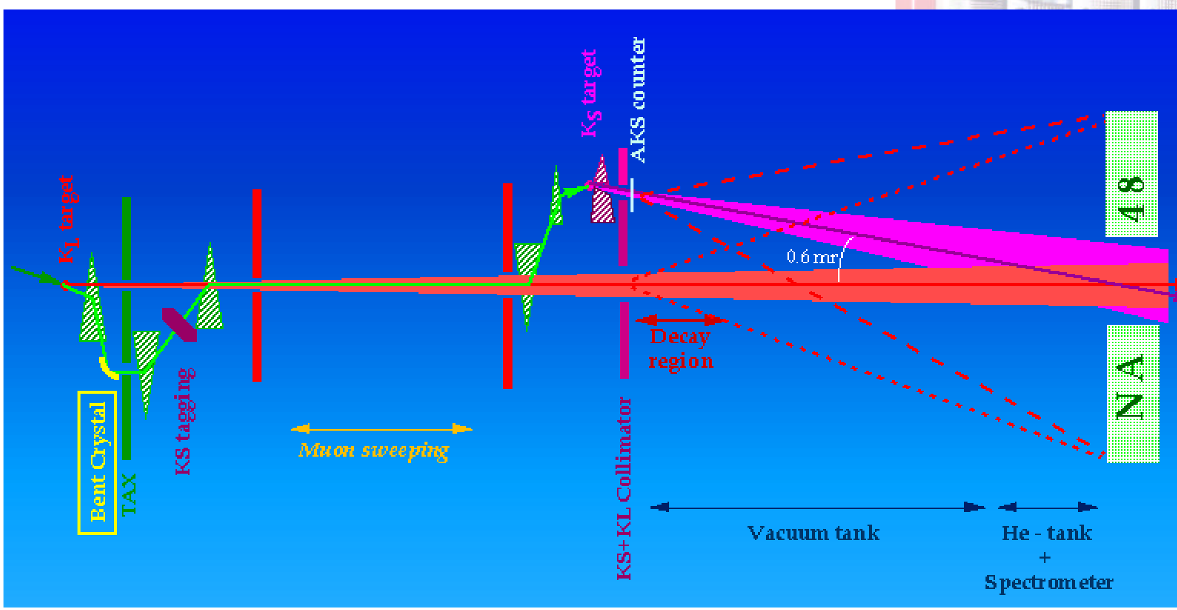
$p^0 p^0$ Data/MC ratios



NA48 at CERN

Simultaneous near/far targets
Converging beams (<p>=100 GeV/c)
Liquid Kr calorimeter
Tagging by time-of-flight
Lifetime weighting to minimize acceptance correction





The weighting method used by NA48 at CERN

At the same z $\Rightarrow$ Acceptance $K_S = K_L$

But very different decay lenghts: $\tau_{K_L} \approx 600 \times \tau_{K_S}$

$\Rightarrow$ Different total acceptance for K_S and K_L

$\Rightarrow$ large correction on R

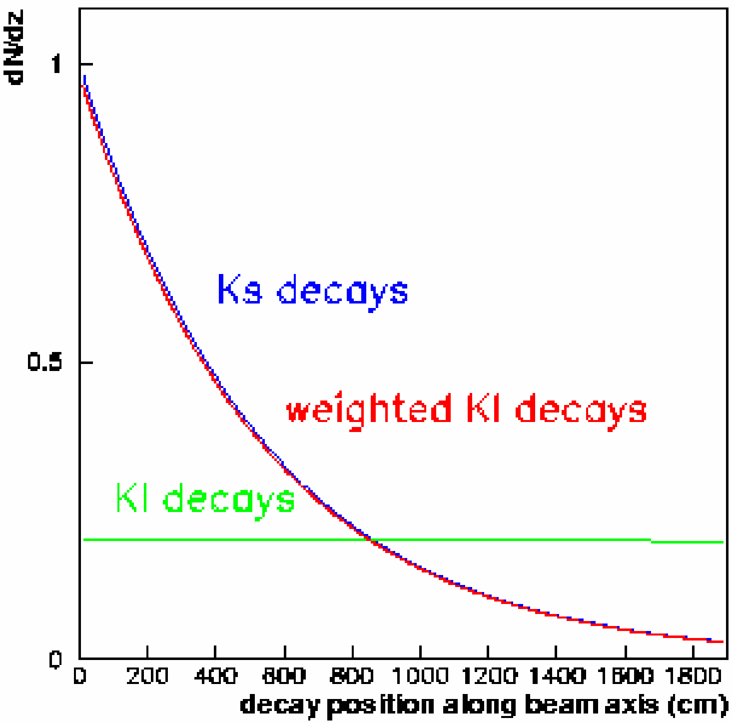
Solution: Weight K_L events with:

$$w = \frac{\pi\pi \text{ decay rate in } K_S}{\pi\pi \text{ decay rate in } K_L} \approx e^{-z/(\beta\gamma c)(1/\tau_{K_S} - 1/\tau_{K_L})}$$

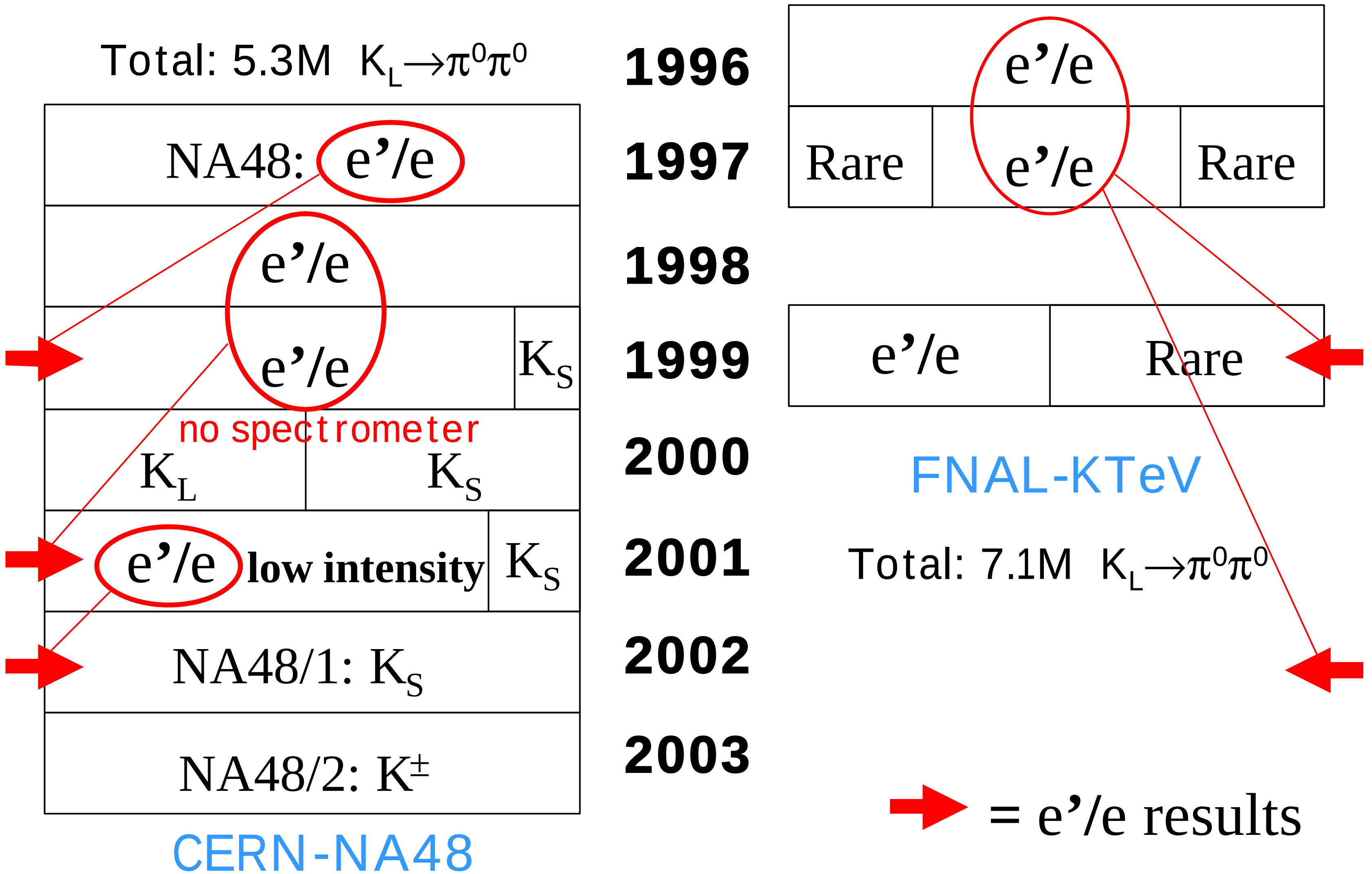
Same decay vertex distribution for K_S and weighted K_L

Acceptance correction cancels

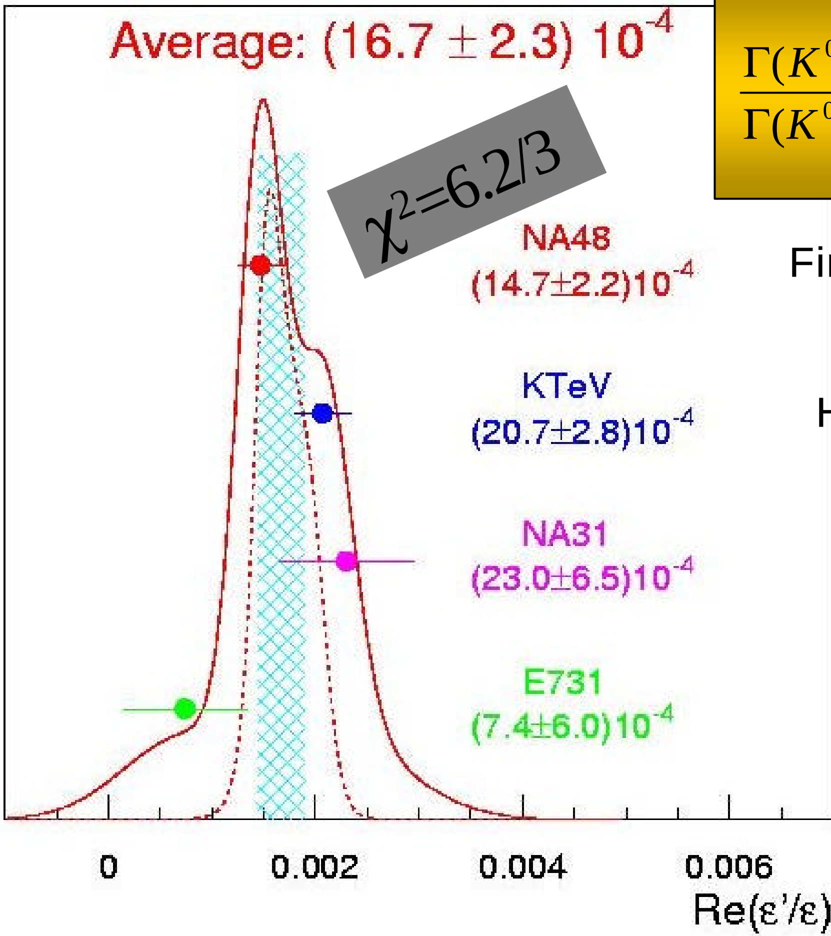
Price: Increase in statistical error ($\approx 35\%$)



Data Taking Periods



Experimental results on Re(e'/e)



$$\frac{\Gamma(K^0 \to p^+p^-) - \Gamma(\overline{K}^0 \to p^+p^-)}{\Gamma(K^0 \to p^+p^-) + \Gamma(\overline{K}^0 \to p^+p^-)} = (5.04 \pm 0.82) \times 10^{-6}$$

Final result (1997-2001)

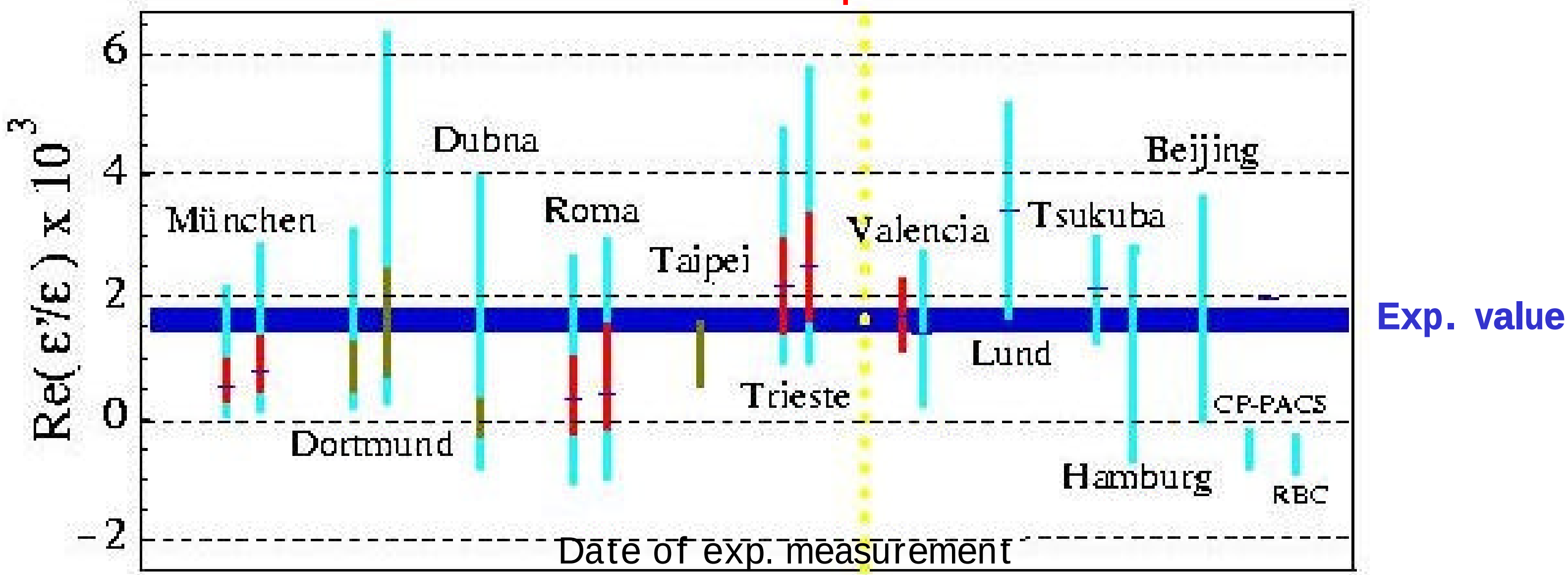
Half statistics (1997)

Direct CP violation observed with neutral K i.e. 2 numbers for C̸P

More results expected from KTeV and KLOE

Re(ε'/ε) and the SM

SM theoretical predictions

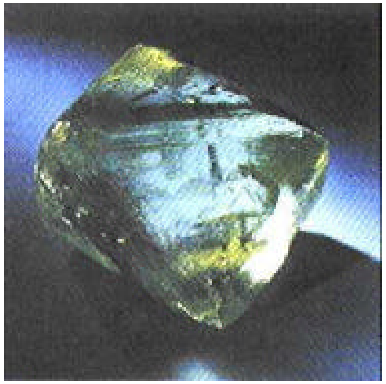


Despite huge efforts, ε'/ε not yet computed reliably
Measured value is roughly compatible with the SM
Expect improvements from lattice

Yields and background for $K_{L?}$ 2p^{o}

Year	Experiment	K_L? $2\pi^0$	Background	Data volume
1985	E617-FNAL Chicago-Saclay	3,152	~11.3%	10GB
1985	Yale-BNL	1,361	~17.6%	
1988	E731-Test-FNAL	6,950	~5.0%	
1988	NA31-CERN	109,000	~4.0%	
1990	E731A-FNAL	52,200	~5.0%	
1993	E731-FNAL Final	410,326	~5.0%	100 GB
1993	NA31-CERN Final	428,000	~2.7%	
2001	KTeV-FNAL	10,000,000	~0.48%	
2001	NA48-CERN	5,000,000	~0.16%	100 TB

The legacy of ~2 decades of experiments



Direct CP violation has received experimental evidence in K^0 system

$$\varepsilon'/\varepsilon = (16.7 \pm 2.3) \times 10^{-4}$$

The experimental results have higher precision than current calculations.

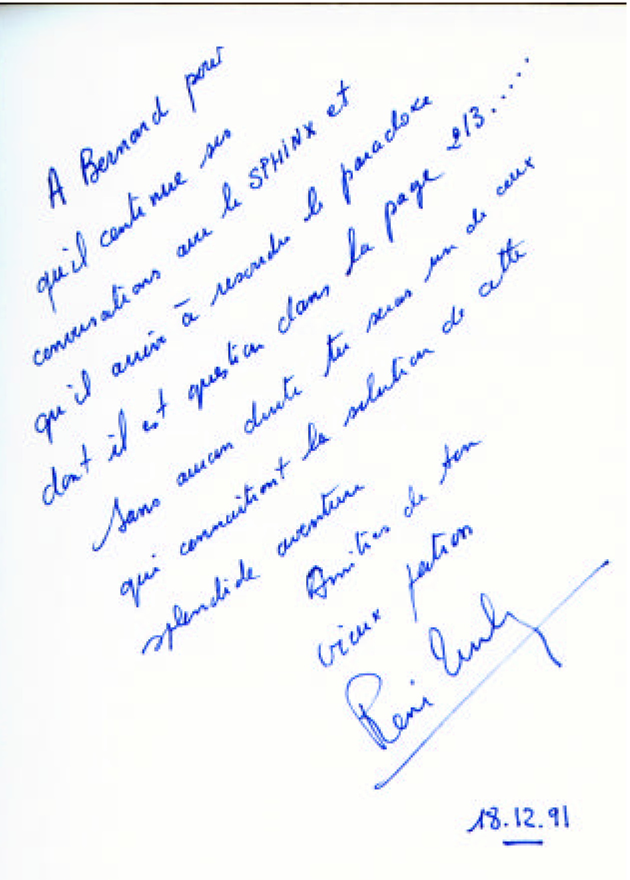
The fine cutting is left to theory ...

The holy grail measurements: $K_L \rightarrow \pi^0 \nu \bar{\nu}$, $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

BNL E926 (KOPIO), KEK E391 ? M. Sozzi's talk

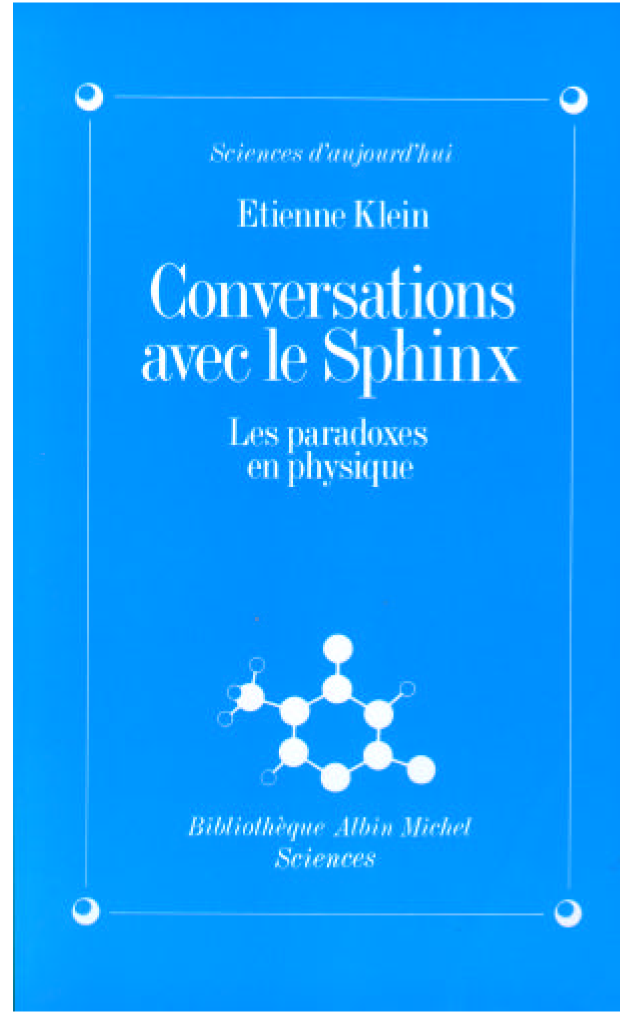
hopefully the harvest of the next decade

René Turlay: a gentleman dedicated to physics and to people


A Bernard pour
qu'il continue ses
conversations avec le SPHINX et
qu'il arrive à résoudre le paradoxe
dont il est question dans la page 213.....
Sans aucun doute tu seras un de ceux
qui connaîtront la solution de cette
splendide aventure
Amitiés de ton
vieux patron
René Turlay
18.12.91

... I trust that you will be one of those to know the solution to this splendid adventure.

With best regards from your old boss.



A true leader in physics

A grand master in understanding human beings