K – Triangle

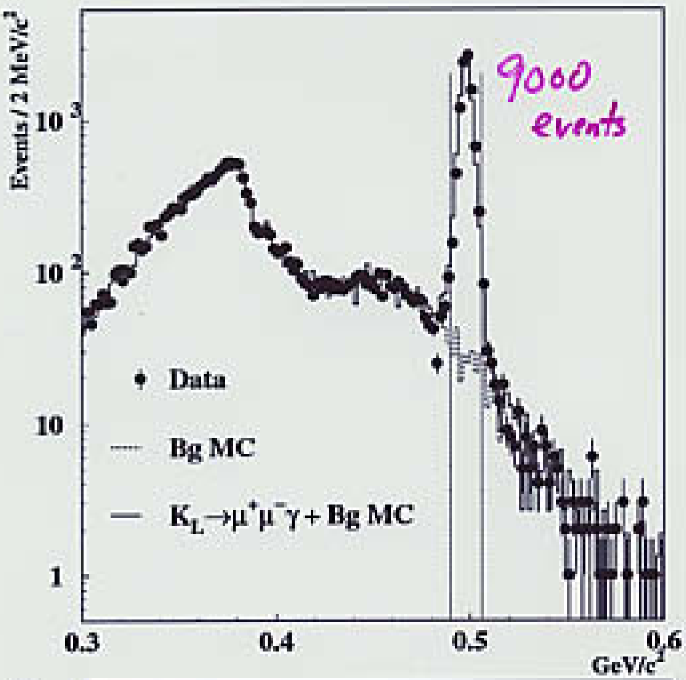
The important and unique-ness of $K_L \to \pi^0 \nu \bar{\nu}$ (pure direct ~~CP~~).

Some other equally important Symmetry Violation Decays

A detector @ JHF that will be able to achieve all these measurements

⇒ A Program for K_L Physics at JHF

$K_L \to \mu^+\mu^-\gamma$ (1 evt until 1995)



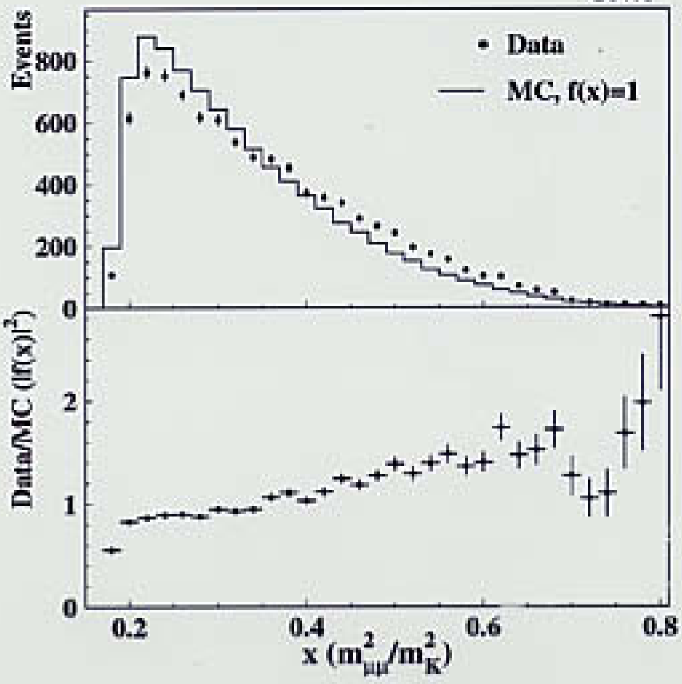
$B(K \to \mu\mu) = (7.18 \pm 0.17) \times 10^{-9}$

$= |\mathrm{Im} A|^2 + |\mathrm{Re} A_{expl}|$

↑ unitarity bound (known, 7.07×10^{-9})

$\mathrm{Re} A = A_{SD} + A_{LD}$

A_{SD} ↓ $\sim \rho$



$\Rightarrow$ $\rho > -0.2$

BR $\sim 3.7 \times 10^{-7}$

KTeV 9000 evts

JHF >5M events

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

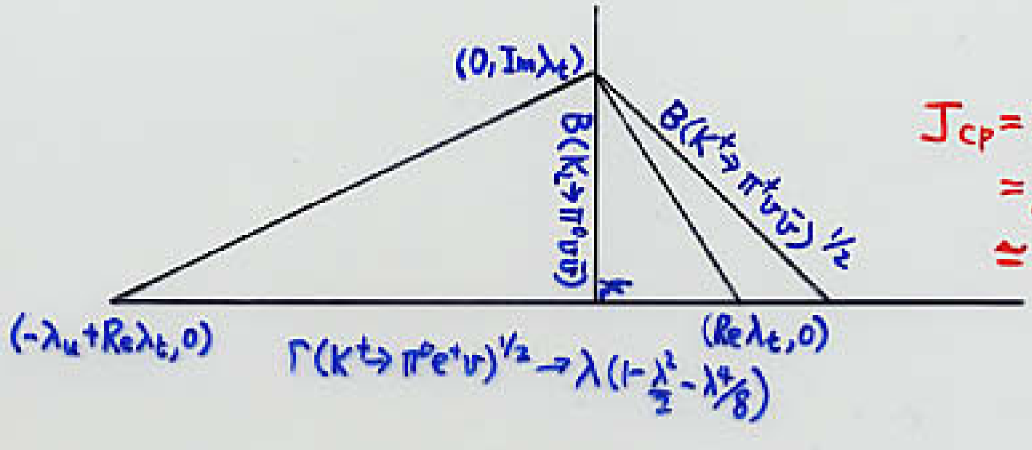
$$= \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

6 unitarity conditions ⇒ 6 triangles with same area $A = \frac{1}{2} J_{CP}$

"Kaon – triangle"

$$V_{us}^* V_{ud} + V_{cs}^* V_{cd} + V_{ts}^* V_{td} = 0$$

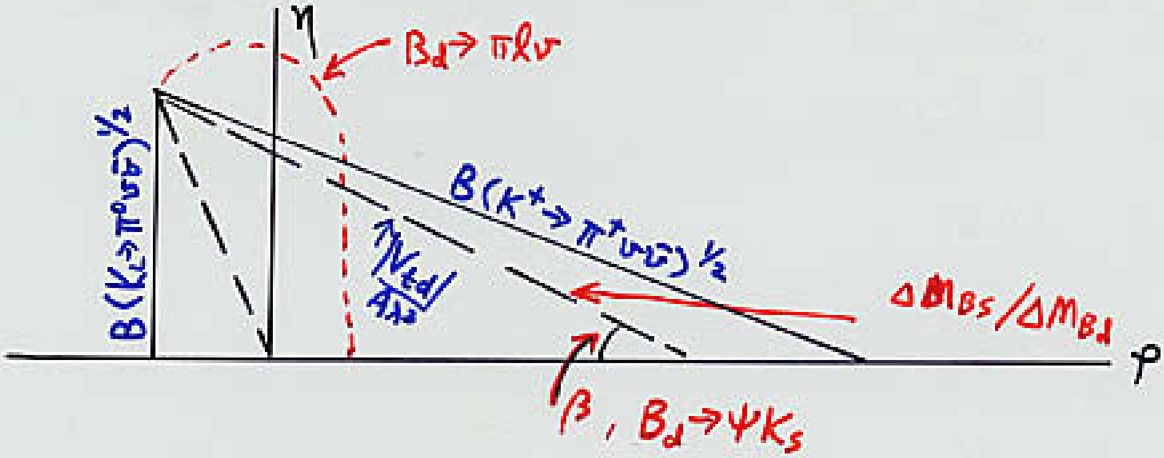
$$\lambda_u + \lambda_c + \lambda_t = 0$$



$$J_{CP} = 2a = b \cdot h$$
$$= \lambda_u \cdot \mathrm{Im}(\lambda_t)$$
$$\simeq \lambda \cdot \mathrm{Im}(\lambda_t)$$

"Other - triangle"

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$



1st pt:

$$J_{CP}\,(\text{K-triangle}) \stackrel{?}{=} J_{CP}\,(\text{B-triangle})$$

$$\sin\beta \stackrel{?}{=} \frac{B(K_L \to \pi^0 \nu\bar{\nu})^{1/2}}{B(K^+ \to \pi^+ \nu\bar{\nu})^{1/2}}$$

e.g. $$\frac{B_{\pi^0\nu\bar{\nu}} = 3\times10^{-11}}{B_{\pi^+\nu\bar{\nu}} = 8\times10^{-10}} = 0.38$$

$$\Downarrow$$

$$\sin 2\beta = 0.69 \quad ?$$

Unique-ness of $K_L \to \pi^0 \nu \bar{\nu}$ is the

CLEANEST STANDARD MODEL PREDICTION (~1%)

2nd pt: One can arguably state that this is also the best indirect search for beyond SM Physics

E391a @ KEK-PS (now status)

KOPIO @ BNL

How to measure $B(K_L \to \pi^0 \nu \bar{\nu})$? with $>10^2$ events ?

E391A/[redacted]/JHF	BNL KOPIO
$E_K \sim 10$ GeV@JHF $E_K \sim 1$ GeV@KEK	$E_K \sim 1$ GeV
$\sim 3 \times 10^{-10}$ by 2003	
$\sim 3 \times 10^{-14}$ @ JHF (1000 evts/yr)	$\sim 5 \times 10^{-13}$ by 2010 (60 evts/3 years)
* High Energy ⇒ Better bkg suppression	
* High K-Flux	
High Acceptance ⇒ simple technique	kinematics, γ direction Kaon time of flight
Step-by step approach	
pencil beam	flat ribbon beam

JHF:

50 GeV Synchrotron

Intensity : 3.2×10^{14} ppp → 8.2×10^{14} ppp

Rep rate : 0.3 Hz

Power : .8 MW → 5 MW

K_L rate @ 1×10^{14} pps } 120MHz
@ 10° prod angle }

⇒ ~1000 events/yr

* Not proposed yet, but will be
* E391a's results in coming 2 yrs will validate many principles and techniques

Conclusion so far : There seems no fundemental difficulties.
MUST DO

Symmetry Violation:

P "individually" violation

T "individually" violated

How come C violation has not been seen "individually" violated, rather it always goes with CP as a pair violation?

I claim all observed "CP" violation are individually T violation, so search for explicit C violation is of most interesting and importance.

$$K_L \to \gamma\gamma\gamma \text{ or}$$

$$\pi^0 \to \gamma\gamma\gamma \quad (\text{via } K_L \to \pi^+\pi^-\pi^0 \text{ or } 3\pi^0)$$

Lepton Flavor Violation:

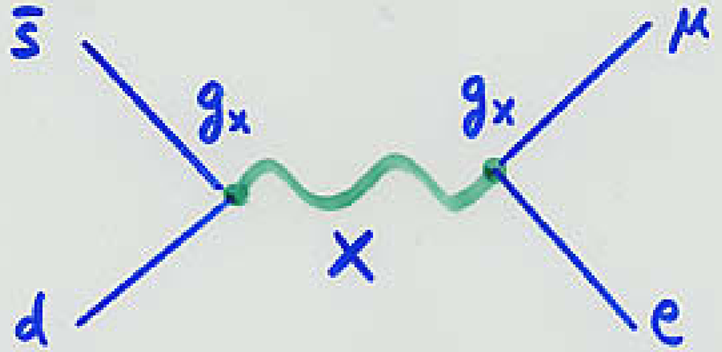
$$K_L \to \pi^0 \mu^\pm e^\mp$$

*** $K_L \to \mu^+\mu^+e^-e^-$

*** $K_L \to \pi^+\pi^+\mu^-e^-$

} L_{Total} OK, L_{flav} Violated

SEARCH FOR LEPTON FLAVOR VIOLATION

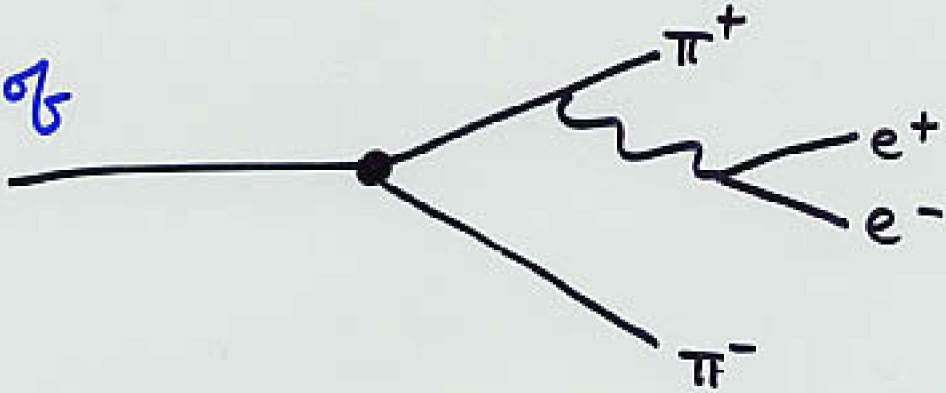


$$\text{Rate} \sim \left(\frac{g_x}{g}\right)^4 \left(\frac{M_W}{M_X}\right)^4$$

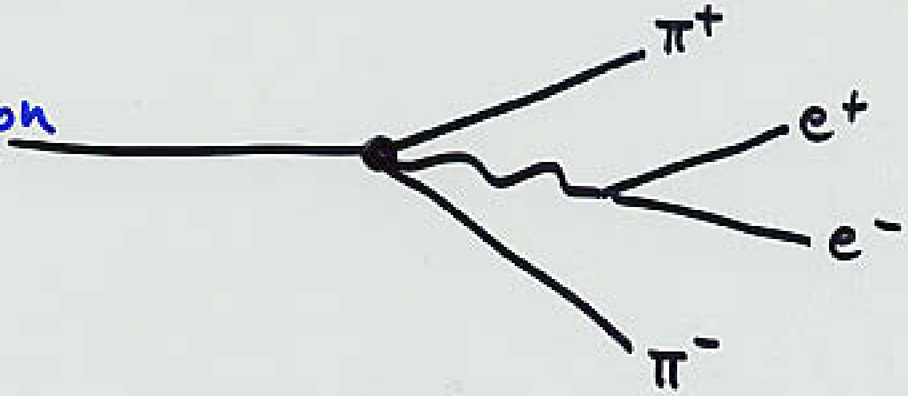
MODE	NOW (90% CL)	M_X (TeV)	1998–1999
$K^+ \to \pi^+ \mu^+ e^-$	$< 2.1 \times 10^{-10}$ BNL	37	$< 4 \times 10^{-11}$
$K_L \to \mu^\pm e^\mp$	$< 3.3 \times 10^{-11}$ BNL	91	$\sim 10^{-12}$
$K_L \to \pi^0 \mu^\pm e^\mp$	$< 3.5 \times 10^{-9}$ FNAL	27	$< 4 \times 10^{-11}$
$\pi^0 \to \mu^\pm e^\mp$	$< 8.6 \times 10^{-9}$ FNAL		$< 10^{-10}$

$K_L \to \pi^+\pi^- e^+e^-$

Inner-Brem of radiative ϵ
E2



Direct emission
M1



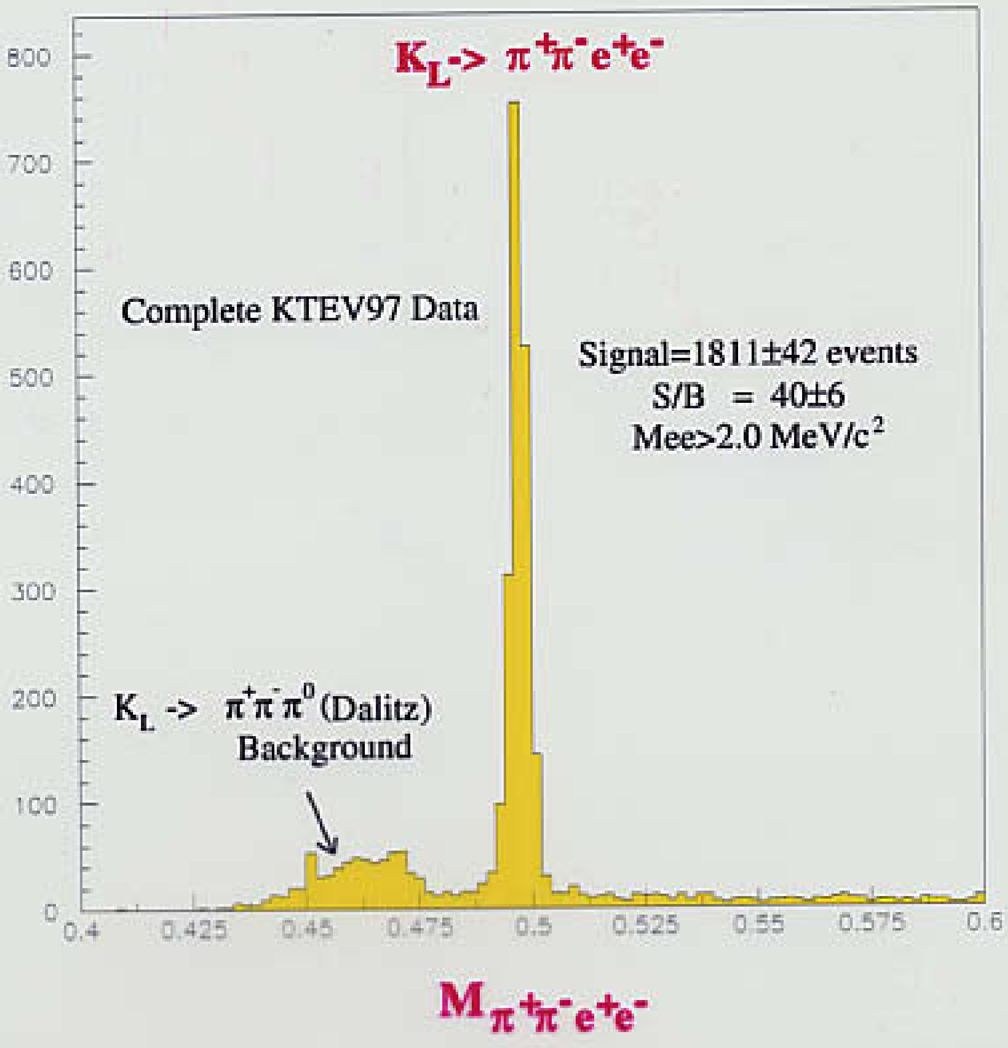
* If E1, ϵ' effect

Interference of IB & DE brings out the ϵ asymmetry in angular distribution (γ^* polarization) of e^+e^- relative to $\pi^+\pi^-$.

$$Br(K_L \to \pi^+\pi^- e^+e^-) = [3.32 \pm 0.14\ (stat) \pm 0.28\ (syst)] \times 10^{-7}$$

$$a_1/a_2 = -0.705^{+0.01}_{-0.02} \quad (M1)$$

$$|g_{M1}| = 1.35 \pm 0.13\ (stat) \pm 0.04\ (syst)$$

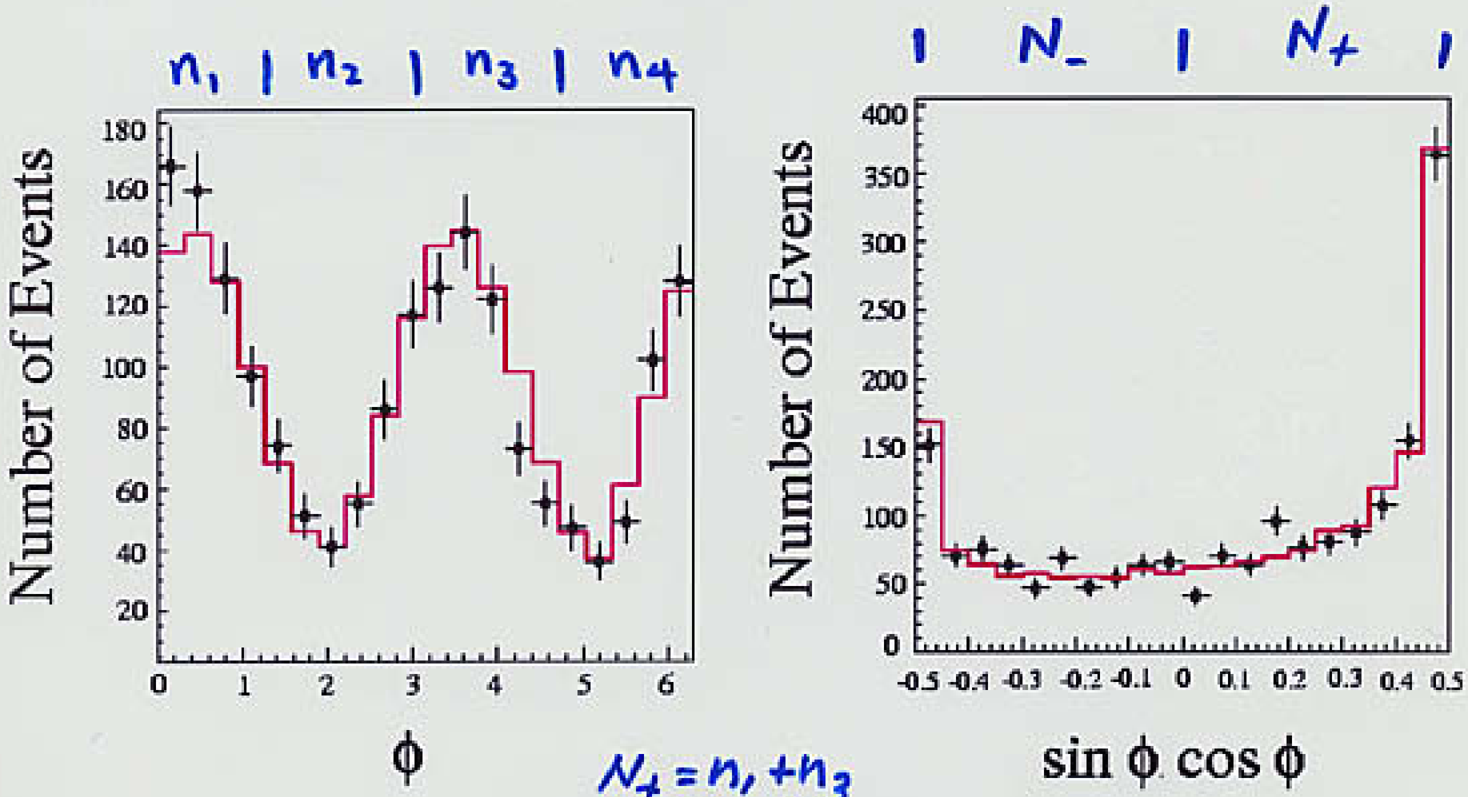


$K_L \to \pi^+\pi^-e^+e^-$

$\vec{n}_e = (\vec{p}_{e^+} \times \vec{p}_{e^-})$, $\vec{n}_\pi = (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-})$

$\hat{z} = (\vec{p}_{\pi^+} + \vec{p}_{\pi^-})$

T-odd ! triple products : $(\vec{n}_e \times \vec{n}_\pi) \cdot \hat{z} \sim \sin\phi\cos\phi$



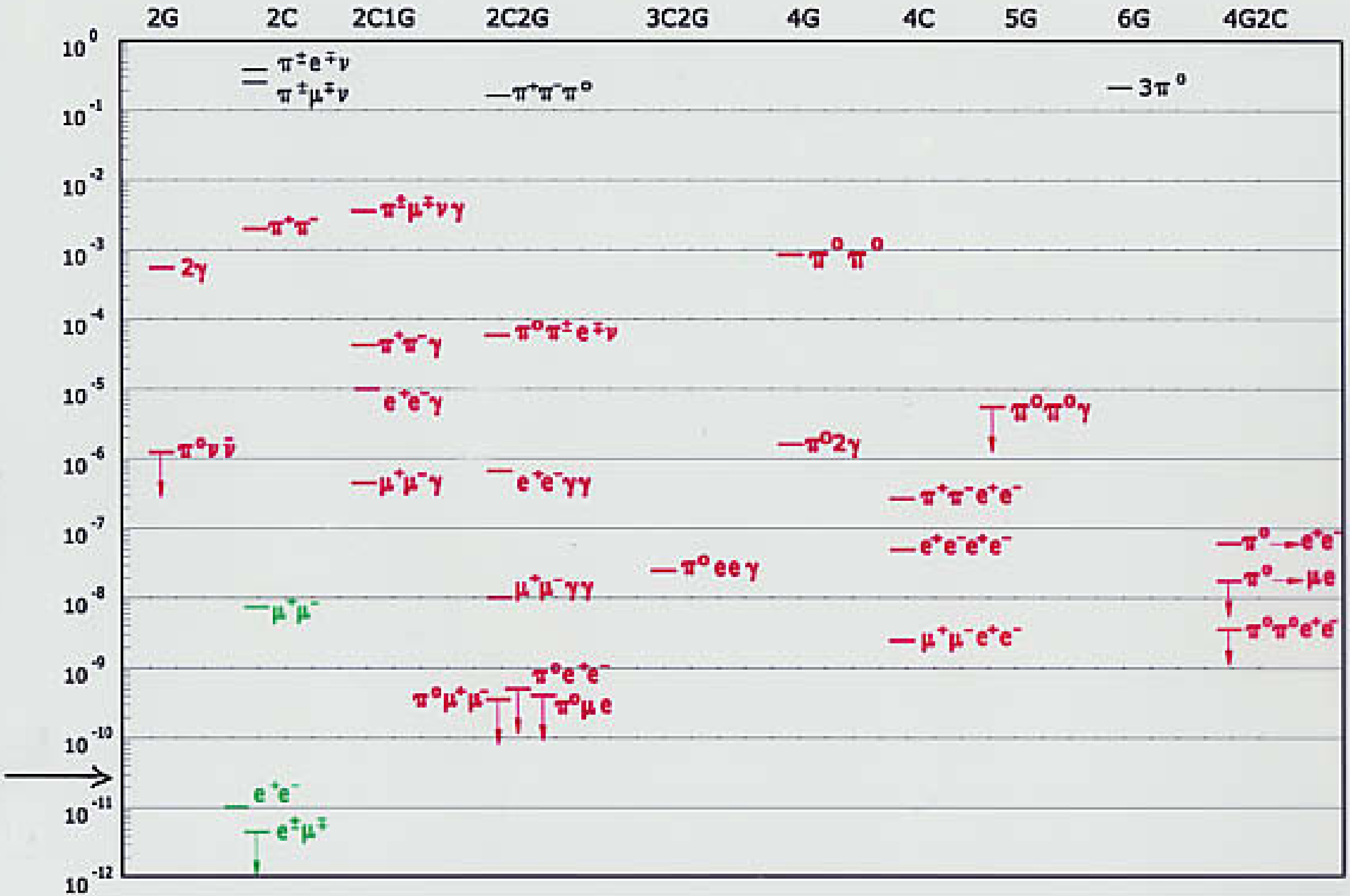
$N_+ = n_1 + n_3$
$N_- = n_2 + n_4$

$$\frac{N_+ - N_-}{N_+ + N_-} = \text{Asym} = (13.6 \pm 2.5 \pm 1.2)\%$$

stat   syst

1st observation of T violation with dynamical variable instead of quantum # counting!

K_L Decays PDG '2000 + KTeV results

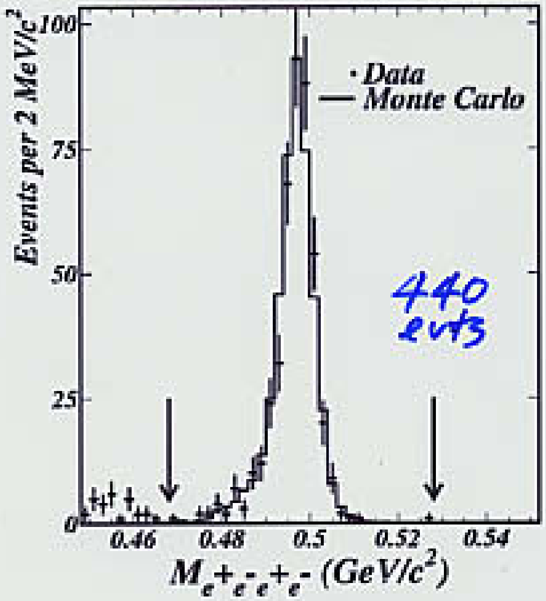


Can only be done with JHF with

$\times 10^{3}$ better ⇐ $E_K > 5$ GeV, detector with tracking ability,

to achieve multibody high acceptances.

Double Dalitz :

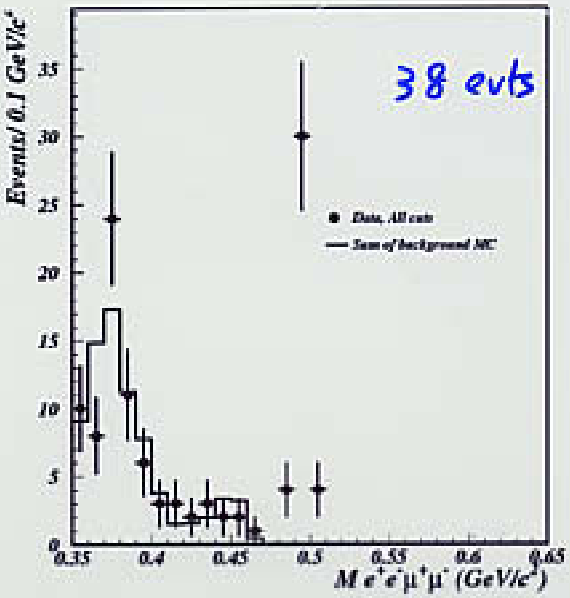


$K_L \to e^+e^-e^+e^-$

Double Dalitz

$BR \sim 3.7 \times 10^{-8}$

JHF ~100K



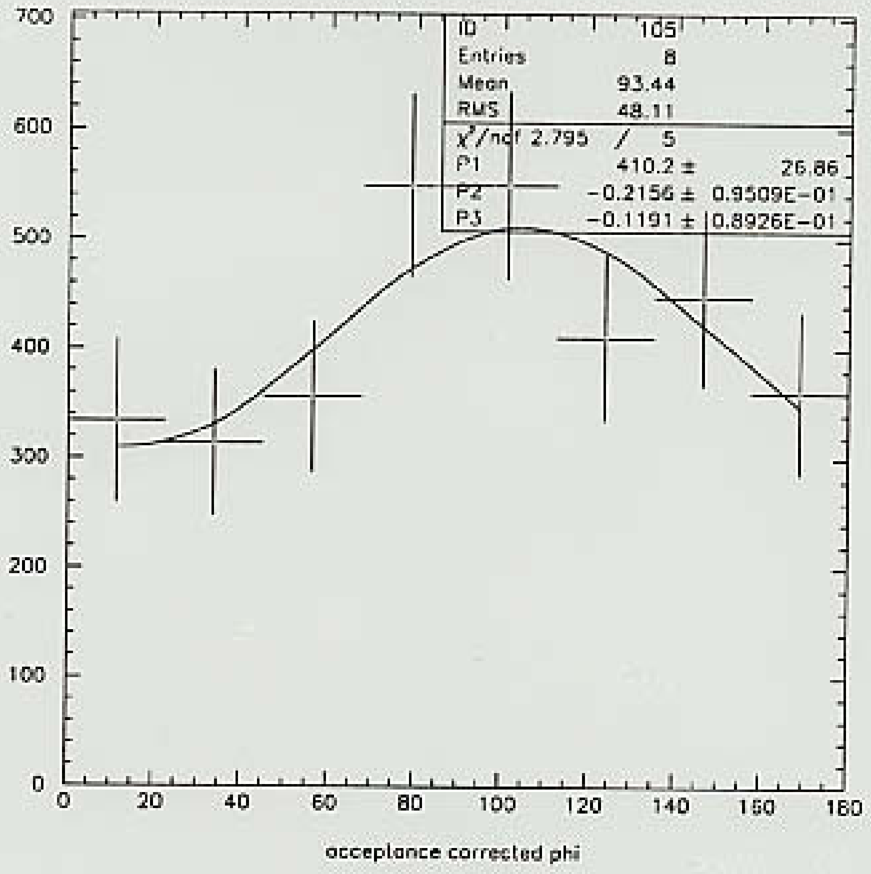
$K_L \to \mu^+\mu^-e^+e^-$

mixed double

$BR \sim 2.5 \times 10^{-9}$

JHF ~ 20K

$K_L \to e^+e^-e^+e^-$



$$\frac{d\Gamma}{d\phi} \sim 1 + \beta \cos 2\phi + \gamma \sin 2\phi \;; \quad \beta = -0.212 \pm 0.091 \pm 0.02$$

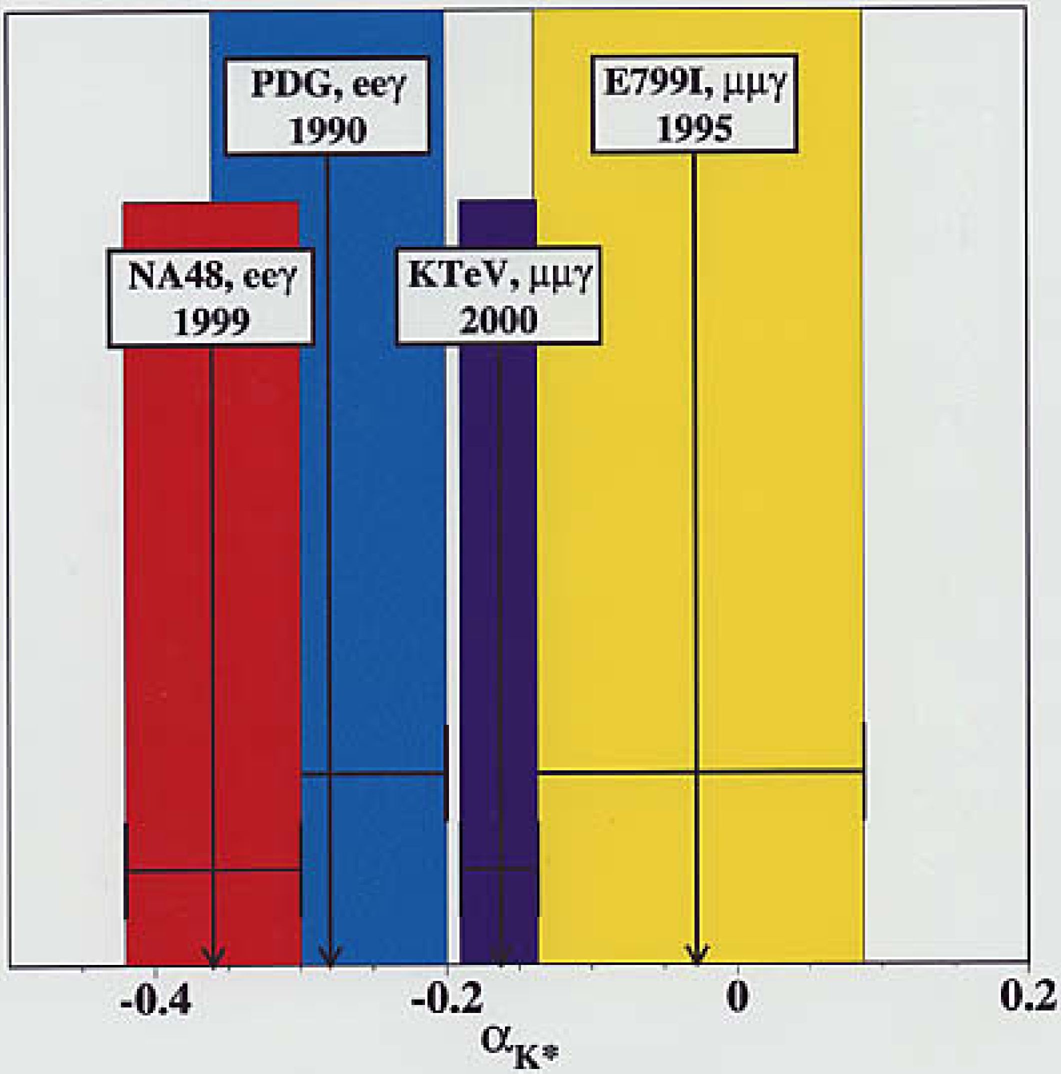
$\uparrow$ -0.2

$$\gamma = -0.119 \pm 0.085 \pm 0.02$$

~~CPV~~ in EM decay

α_{K^*} (BMS) $= 0.03 \pm 0.17 \pm 0.18$ (stat) (syst)

Comparison with Previous Experiments



- Twice the precision of other experiments
- Difference between $K_L \to \mu^+\mu^-\gamma$ and $K_L \to e^+e^-\gamma$ established at the 3σ level

A Neutral Kaon Physics Program at JHF is

- Great Physics
- Unique (maybe the only way)
- world class (∵ of JHF)
- High acceptance, high precision detector with multi-bodies final state capabilities will bring <u>ALL</u> physics sensitivities to beyond SM.

- Best training ground for young physicists;
- Time scale is "right" for physcists,