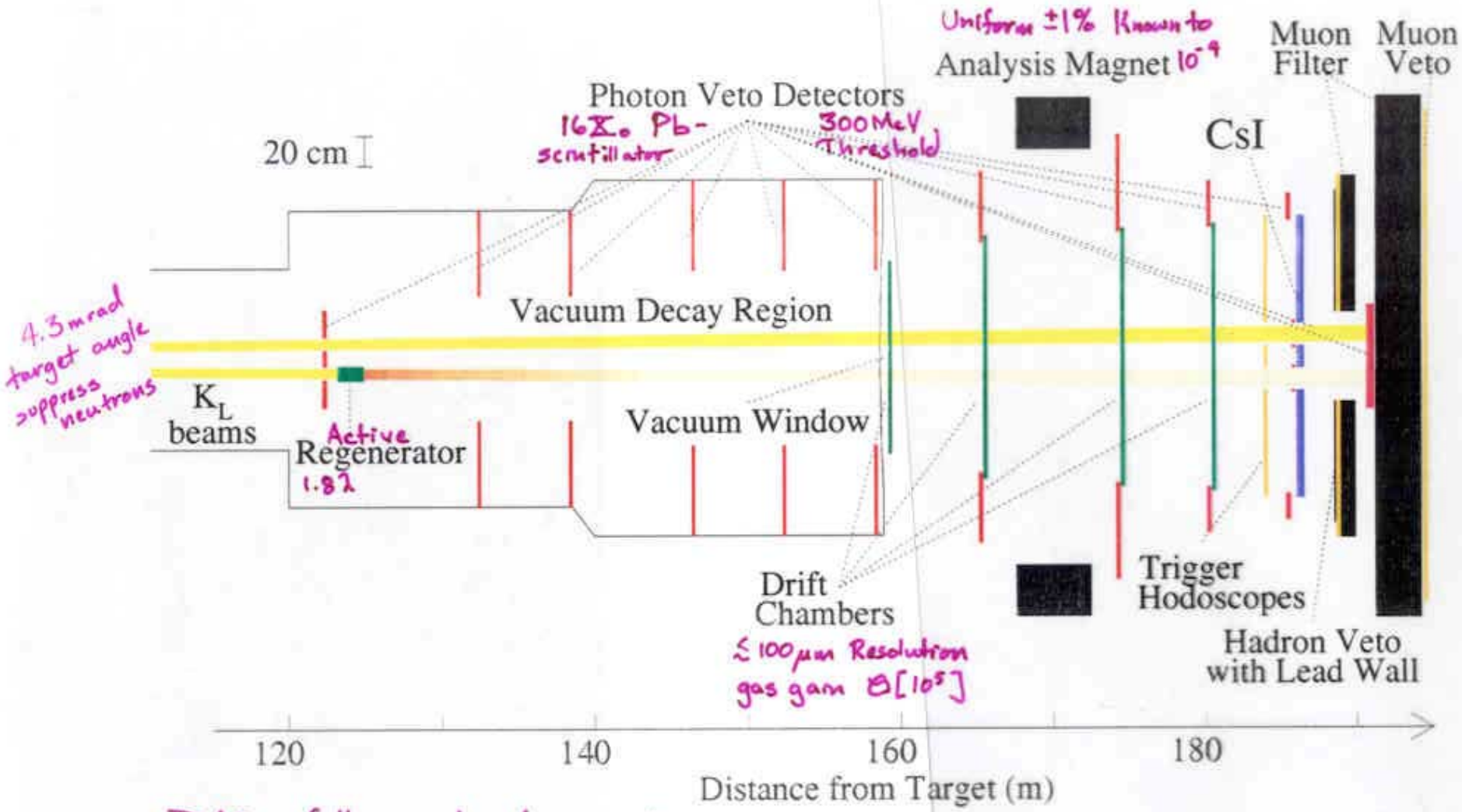
Recent Results from KTeV

- Charge asymmetry in K_{e3}
- K^0 charge radius
- $K_L \rightarrow \pi^0 \pi^0 e^+ e^-$
- Getting ρ_{CKM} with $K_L \rightarrow \mu^+\mu^-\gamma$
- $K_L \rightarrow \pi^0\mu^\pm e^\mp$
- Data not yet analyzed / taken

OMITTED: $K_L \rightarrow \pi^0 e^+ e^-$, $\pi^0\mu^+\mu^-$, $\pi^+\pi^-\gamma$ FINAL
$\Xi^0 \rightarrow \Lambda\gamma$, asym.

Leo Bellantoni
36th Moriond EW & UT
9 - 12 October 2000



DAQ: full reconstruction online
$\mathcal{O}[10^5]$ events 7kbytes each
per minute

CsI calorimeter:
$(1.9)^2$ m^2 pure CsI ; $27 X_0$ thick
π/e rejection ~ 400 to 1
±1mm position
±3/4 % Energy

Charge Asymmetry

$$K_L = (1+\varepsilon)\,K^0 + (1-\varepsilon)\,\overline{K}^0$$

$$\delta_L = \frac{N(e^+) - N(e^-)}{N(e^+) + N(e^-)} = 2\Re(\varepsilon - Y - X)$$

Where Y is CPT violation in $\Delta S = \Delta Q$ amplitude
X " $\Delta S = -\Delta Q$ "

PDG 2000 average, ($e^\pm$ and $\mu^\pm$)

$\delta_L = (3.27 \pm 0.12) \times 10^{-3}$

Best $e^\pm$ result

CERN-Heidelberg 1974

$\delta_L = (3.41 \pm 0.18) \times 10^{-3}$

using 34×10^6 events

This analysis based on 300×10^6 events

Charge Asymmetry

Very hard to build a detector with same detection efficiency for both charges at the required level.

Instead, define subsamples with cancelling geometric acceptance

e^+ with spectrometer magnet positive *vs.*
e^- from east beam, negative polarity:

$$R = \frac{N(e^+;+mag)}{N(e^-;-mag)} = \frac{Br(\to e^+)\, \cancel{Flux(K_L;+mag)}\, \cancel{Accept(e^+;+mag)}}{Br(\to e^-)\, \cancel{Flux(K_L;-mag)}\, \cancel{Accept(e^-;-mag)}}$$

...similarly for N(e^+;-mag) / N(e^-;+mag) and 2 beams

Find 4 values of R, multiply them, take 4th root

$$\delta_L = (R-1) / (R+1)$$

... but you better be sure those ratios really cancel!

Charge Asymmetry

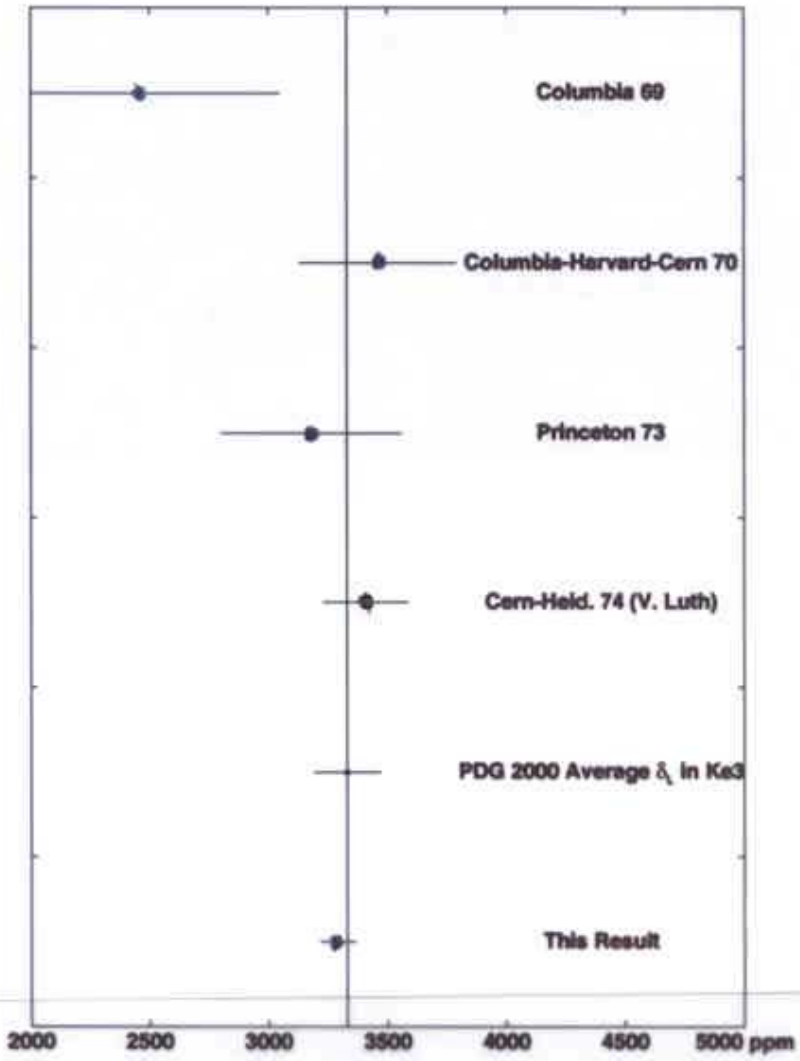
Summary of corrections for systematic effects

D	$\pi^+ \pi^-$ different in CsI	-156±10	x10^{-6}
D	$\pi^+ \pi^-$ loss in trigger scintillator	54±10	"
S	$\pi^+ \pi^-$ loss in spectrometer	3± 3	"
D	$\pi^+ \pi^-$ punchthrough	34±40	"
D	$e^+ e^-$ different in CsI	-19±18	"
S	δ-ray production difference	-8± 4	"
S	e^+ annihilation in spectrometer	11± 1	"
D	Backgrounds ($K_{\pi 3}$, $K_{\mu 3}$, Λ)	1± 1	"
S/D	Target/absorber interference	-2± 1	"
D	Collimator, regenerator scatter K_L	-1± 1	"
D	Spectrometer reversal mismatch	-3± 2	"
	Total	-97±46	x10^{-6}

Preliminary result on 1997 data

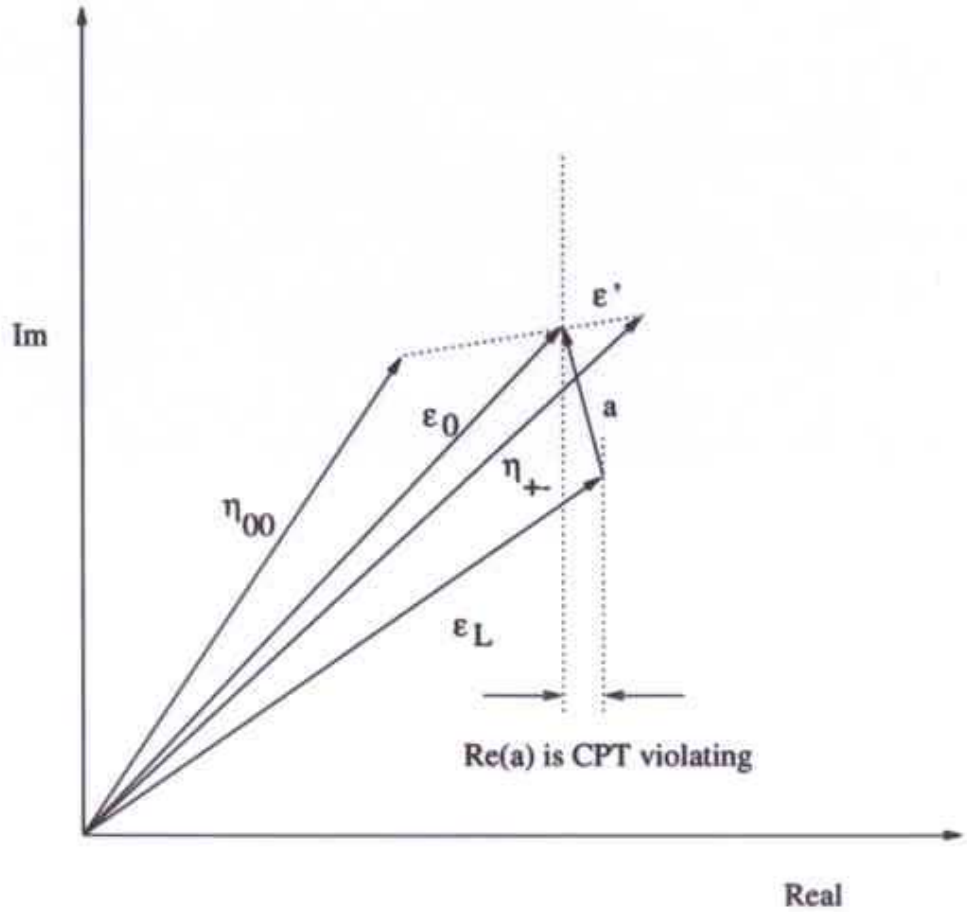
$$\delta_L = (3.320 \pm 0.058_{STAT} \pm 0.046_{SYS}) \times 10^{-3}$$

Charge Asymmetry



New World Average $(3.305 \pm 0.063) \times 10^{-3}$

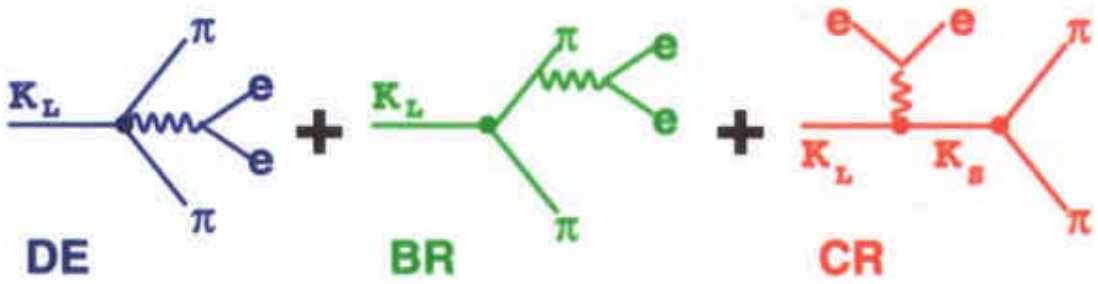
Charge Asymmetry



$$\Re(a) = \tfrac{2}{3}\Re(\eta_{+-}) + \tfrac{1}{3}\Re(\eta_{00}) - \Re(\varepsilon_L)$$

= -2 ± 35 ppm (assuming $\Delta S = +\Delta Q$)

K^0 Charge Radius



Each amplitude is multiplied by a coupling constant, and then summed to get total $\mathcal{A}$

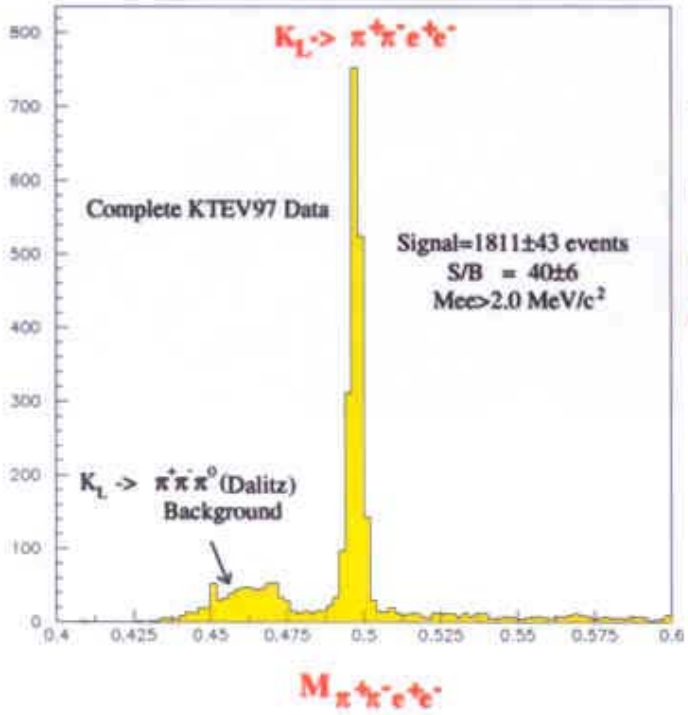
Different contributions populate phase space differently

The coupling constant for the CR term is

$$g_{CR} = -\frac{1}{3}\langle R^2 \rangle m_K^2 e^{i\delta_o} = -\frac{1}{3}\left\langle \sum q_i \left(\vec{r}_i - \vec{R}\right)^2 \right\rangle m_K^2 e^{i\delta_o}$$

Charge Radius

K^0 Charge Radius



The 1997 KTeV data contains 1811 ±43 events over a 45 ±11 event background

⇒ ***A very clean sample***

We fit the data's phase space distribution as embodied in dΓ • (acceptance) with g_{CR} as the free parameter…

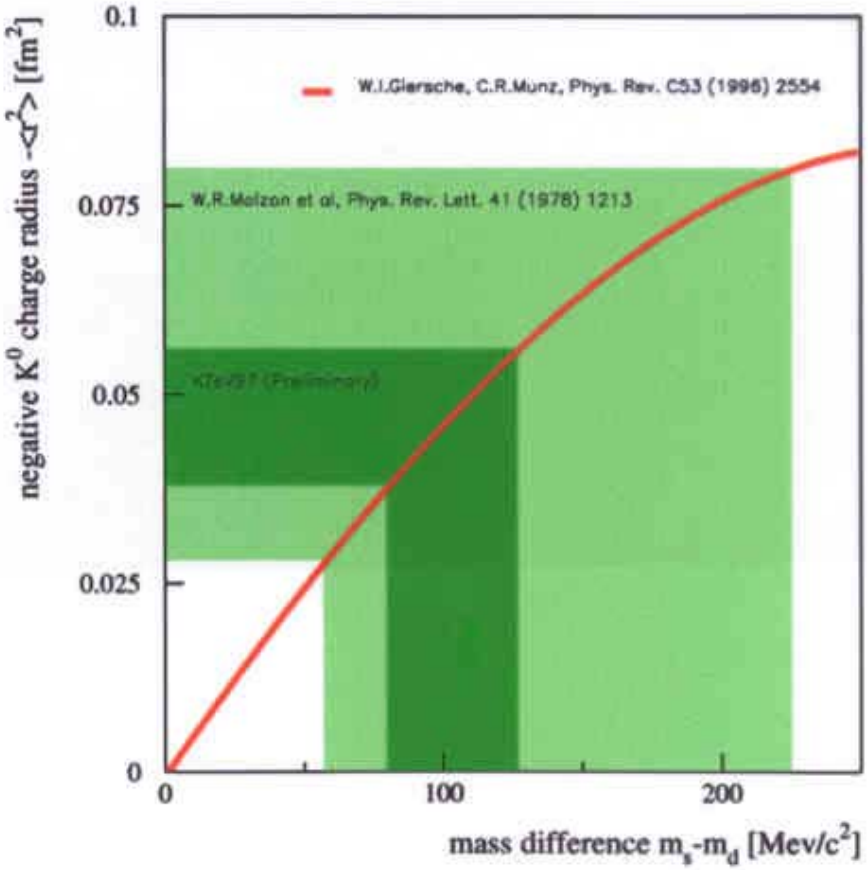
KTeV preliminary 1997 data:

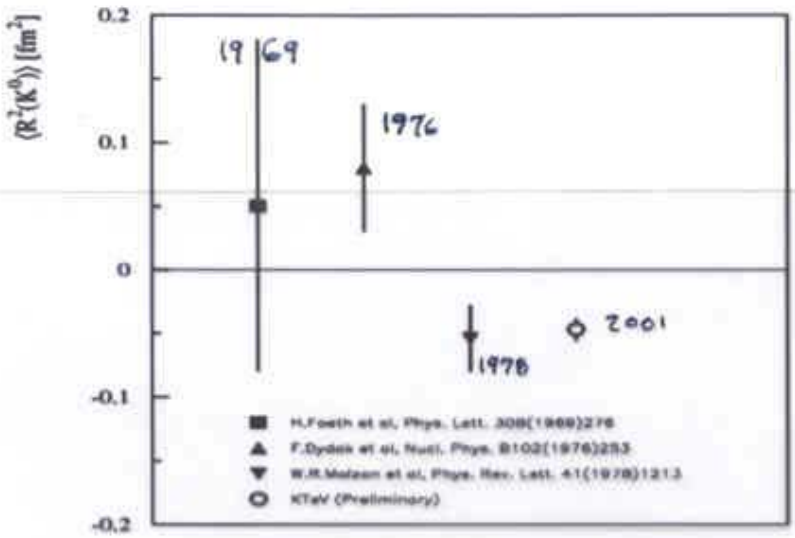
$$|g_{CR}| = 0.100 \pm 0.018_{STAT} \pm 0.013_{SYS}$$

$$\langle R^2 \rangle = -0.047 \pm 0.008_{STAT} \pm 0.006_{SYS}\ fm^2$$

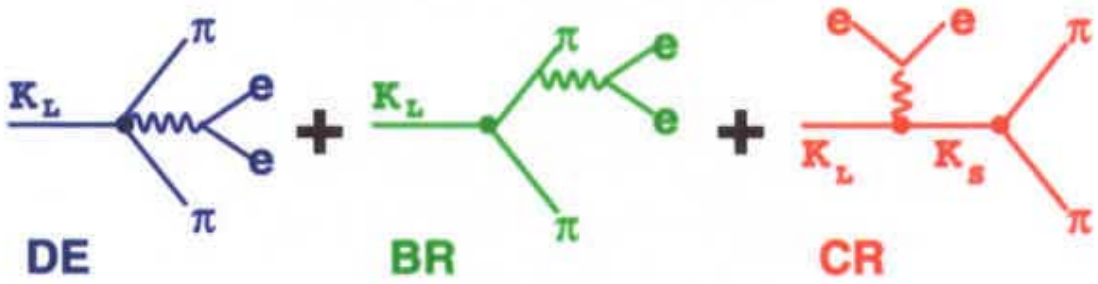
K^0 Charge Radius

Using Bethe-Salpeter equation to infer $m_s - m_d$





$K_L \to \pi^0\pi^0 e^+e^-$



For neutral pions, there is no bremsstrahlung and Bose statistics & gauge invariance suppresses direct emission – charge radius effects dominate

Existing *Br* predictions in χPT:

$> 0.8 \times 10^{-10}$ [R.Funck & J.Kambor, Nucl. Phys. B396, (1993) 53]

$< 2.0 \times 10^{-10}$ [P.Hellinger & L.M.Sehgal, Phys. Lett. B307, (1993) 182]

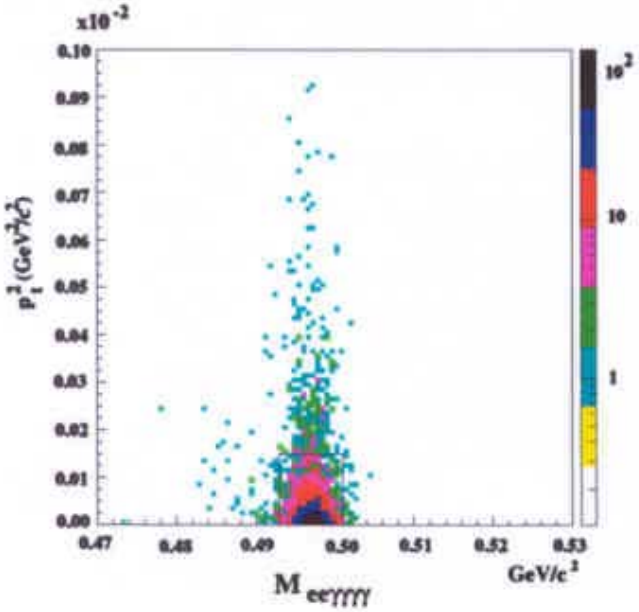
Experimental background is

$K_L \to \pi^0\pi^0\pi^0$

↳ $\gamma\gamma$

↳ e^+e^-, either internally or externally

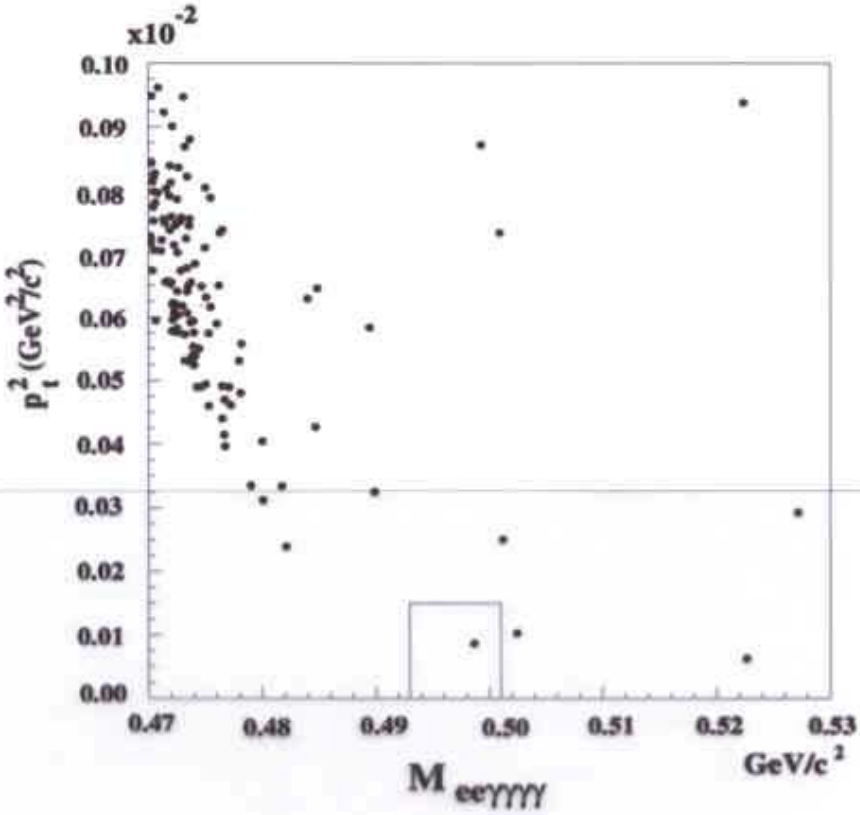
$K_L \rightarrow \pi^0\pi^0 e^+ e^-$



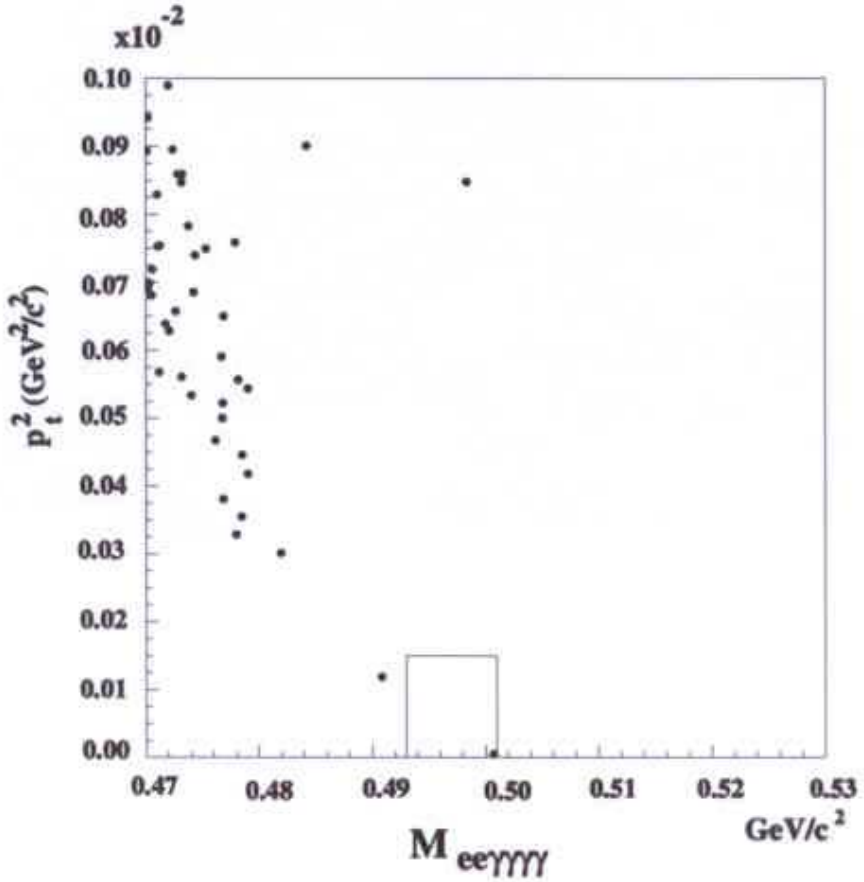
MC signal

MC background 3x equivalent data sample

$0.4^{+0.4}_{-0.3}$ *events*



$K_L \rightarrow \pi^0\pi^0 e^+ e^-$



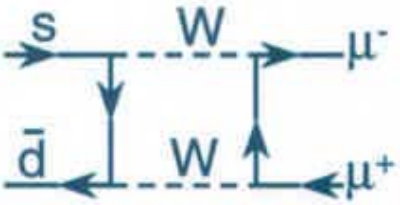
One event in the data…

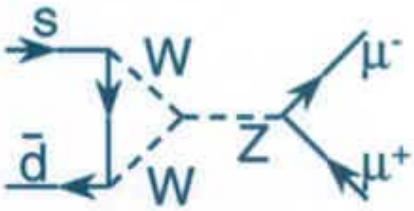
$Br(K_L \rightarrow \pi^0\pi^0 e^+ e^-) < 5.4 \times 10^{-9}$

KTeV preliminary result, 1997 data

First experimental result

Measuring ρ_{CKM} with Kaon Decays



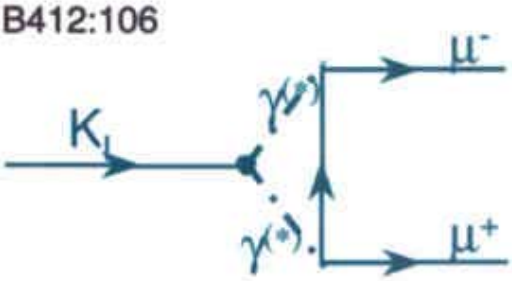


Short distance physics sensitive to ρ_{CKM}:

$$Br(K_L \to \mu^+\mu^-) = \frac{\alpha^2 Br(K^+ \to \mu^+\nu)}{\pi^2 \sin^4\theta_W}\left(\frac{\tau(K_L)}{\tau(K^+)}\right)\left\{\left(1-\lambda^2/2\right)Y_{NL} + A^2\lambda^5(1-\rho)Y_t\right\}$$

Buchalla & Buras, Nucl. Phys. B412:106

Unfortunately:



Amplitude from two real γs is imaginary and found from $Br(K_L \to \gamma\gamma)$ to be $(7.07 \pm 0.18) \times 10^{-9}$

$Br(K_L \to \mu^+\mu^-) = (7.18 \pm 0.17) \times 10^{-9}$

$\Rightarrow$ $< 3.7 \times 10^{-10}$ (90%CL) for short range + dispersive terms

Real part of the amplitude needs understanding of the $K_L\gamma^{(*)}\gamma^{(*)}$ form factor

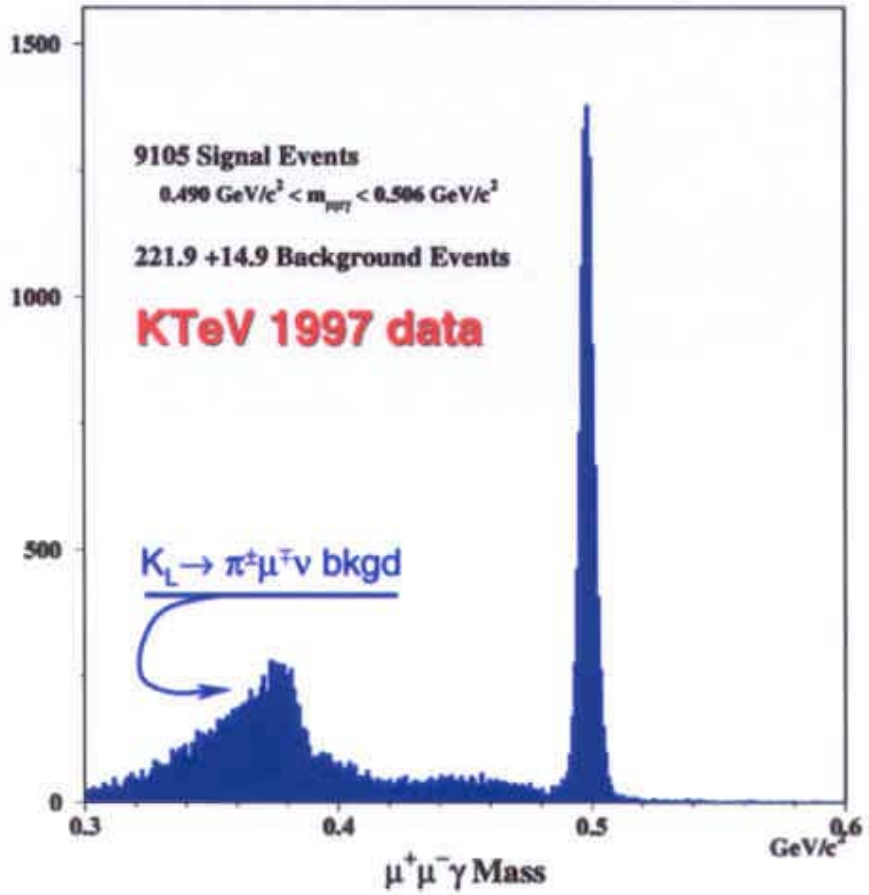
$K_L \rightarrow \mu^+\mu^-$

Q: What tools do we have to quantify the $K_L\gamma^{(*)}\gamma^{(*)}$ vertex?

- $K_L \rightarrow \mu^+\mu^- e^+e^-$ - low stats (38 events from KTeV, 21 from NA48)
- $K_L \rightarrow e^+e^- e^+e^-$ - better stats (441 events at KTeV, 132 at NA48) – but radiative corrections ~ 4x(stat uncertainty in α_{K^*})
- $K_L \rightarrow \mu^+\mu^- \gamma$ - 9105 events, but 1 γ on-shell
- $K_L \rightarrow e^+e^- \gamma$ - NA48 (1999) has 6864 events KTeV $\mathcal{O}[10^5]$ unpublished events - both radiative corr's and 1 γ on-shell

At this time, strongest constraints on ρ are from $\mu^+\mu^- \gamma$

$K_L \rightarrow \mu^+\mu^-\gamma$



$$BR(K_L \rightarrow \mu^+\mu^-\gamma) = (3.66 \pm 0.04_{stat} \pm 0.07_{sys}) \times 10^{-7}$$

Form Factors from Br and $m_{\mu\mu}$ fit obtained for 2 models:

Bergström, Massó and Singer [PL B131(1983)229; B249(1990)141]
D'Ambrosio, Isidori, and Portolés [PL B423(1998) 385]

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

BMS model: $\alpha_{K^*} = -0.157^{+0.025}_{-0.027}$

DIP model: $\alpha = -1.53 \pm 0.09$

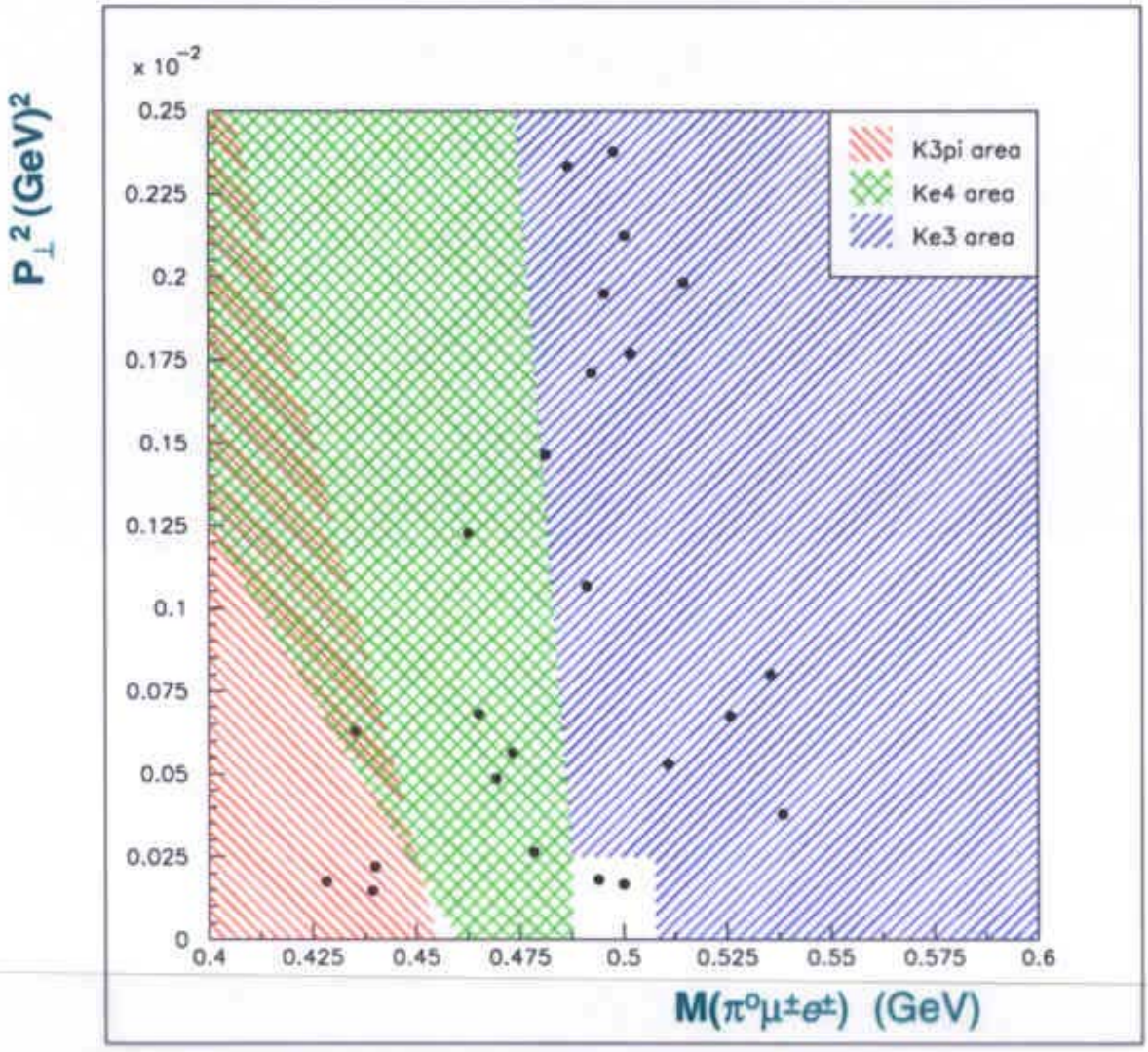
Using these form factors to compute the $\gamma^{(*)}\gamma^{(*)}$ contributions to $K_L \to \mu^+\mu^-$, we find that the short distance contribution corresponds to (at the 90% C.L.):

BMS model:	$\rho_{CKM} > -1.0$
DIP model:	$\rho_{CKM} > -0.2$

But a warning is called for ~ one can not find the form factor for $q^2(\gamma^{(*)}) > m_K$ from kaon decays.

Perhaps this region can be probed with $e^+e^- \to \gamma^{(*)}\gamma^{(*)}$ measurements at colliders?

$K_L \rightarrow \pi^0 \mu^{\pm} e^{\mp}$



2 events in data *vs* 0.61 $\pm$0.56 background
(We have set background to zero so far)

$Br(K_L \rightarrow \pi^0 \mu^{\pm} e^{\mp}) < 4.40 \times 10^{-10}$ (90% C.L.)
Preliminary 1997 data

The 1999 Run

Rare Decay running Sept 1999 to Jan 2000:

- $\pi^0 e^+ e^-$, $\pi^0 \mu^+ \mu^-$, $\pi^0 \mu^\pm e^\mp$ *datasets ≈ 2.5x larger*
- $\pi^+ \pi^- e^+ e^-$, $\mu^+ \mu^- e^+ e^-$, $e^+ e^- e^+ e^-$ *datasets ≈ 3.2x larger*

$K_L \rightarrow \mu^+ \mu^- e^+ e^-$, $e^+ e^- e^+ e^-$, $\pi^0 \mu^\pm e^\mp$ analyses will profit greatly from more data

$K_L \rightarrow \mu^+ \mu^- \gamma$, $e^+ e^- \gamma$, $\pi^+ \pi^- e^+ e^-$ become high-statistics analyses

$K_L \rightarrow \pi^0 e^+ e^-$, $\pi^0 \mu^+ \mu^-$ are reaching background limits already

Kaon Physics with MI

- **FNAL Main Injector**
  - Dedicated June 1st, 1999
  - 120- 150 GeV beam
- **KaMI collaboration**
  - Goal is <u>measurement</u> of $K_L \rightarrow \pi^0 \nu\bar{\nu}$
  - First test (beam spectrum) Jan 2000

CONSTRAIN $|\eta|$

- **CKM collaboration**
  - Goal is <u>measurement</u> of $K^+ \rightarrow \pi^+ \nu\bar{\nu}$
  - Superconducting RF separators to create 22 GeV K^+ beam
  - R & D underway

Constrain $\eta^2 + (\rho - \rho_0)^2$