Search for the Rare Decay $K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$

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KTeV Institutions

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University of Arizona (Tucson, Arizona)

University of California at Los Angeles (Los Angeles, California)

Universidade Estadual de Campinas (Campinas, Brasil)

University of Colorado (Boulder, Colorado)

Elmhurst College (Elmhurst, Illinois)

Osaka University (Toyonaka, Osaka, Japan)

Rice University (Houston, Texas)

Universidade de Sao Paolo (Sao Paolo, Brasil)

University of Wisconsin (Madison, Wisconsin)
**The KTeV Detector**

KTeV's coordinate system is:

1) right-handed

2) defined such that the target is at the origin.

**Previous KTeV Dimuon Results:**

1) \( \text{Br}(K_L \rightarrow \mu^+ \mu^-) = (3.62 \pm 0.04_{\text{stat}} \pm 0.08_{\text{syst}}) \times 10^{-7} \) (9327 events) (PRL 87, 071801 (2001))

2) \( \text{Br}(K_L \rightarrow e^+e^-\mu^+\mu^-) = (2.69 \pm 0.24_{\text{stat}} \pm 0.12_{\text{syst}}) \times 10^{-9} \) (132 events) (PRL 90, 141801 (2003))

3) \( \text{Br}(K_L \rightarrow \pi^0\mu^+\mu^-) < 3.8 \times 10^{-10} \) (2 events obs.; 0.87 \pm 0.15 bkgd. events) (PRL 84, 5279-5282 (2000))
Motivation for the Study of $K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$

- There's no published calculation within the Standard Model for $\text{Br}(K_L \rightarrow \pi^0\pi^0\mu^+\mu^-)$, but Heiliger and Sehgal have a paper on $K_L \rightarrow \pi^0\pi^0e^+e^-$. (Phys. Lett. B307, 182-186 (1993))

- HyperCP reported evidence of the 'hypothetical' neutral boson $X^0$ in a claimed observation of $\Sigma^+ \rightarrow p\mu^+\mu^-$. They determined the following branching ratios:

$$\text{Br}(\Sigma^+ \rightarrow p\mu^+\mu^-) = (8.6^{+6.6}_{-5.4}(\text{stat})\pm 5.5(\text{syst})) \times 10^{-8}, \quad \text{(PRL 94, 021801 (2005))}$$

$$\text{Br}(\Sigma^+ \rightarrow pX^0 \rightarrow p\mu^+\mu^-) = (3.1^{+2.4}_{-1.9}(\text{stat})\pm 1.5(\text{syst})) \times 10^{-8}$$

- HyperCP determined the mass of the $X^0$ to be: $(214.3 \pm 0.5)\text{MeV}$

- Outside the Standard Model, this decay is possible via the same hypothetical $X^0$ neutral boson, which will be described in the coming slides.

- there is no current experimental upper limit on $K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ or $K_L \rightarrow \pi^0\pi^0X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-$. 

3 events observed!
Theoretical Estimates for $K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$

- the decay $K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ is feasible within the Standard Model although its' phase space is limited to a paltry 16.35 MeV.

- Valencia et al. and Deshpande et al. calculate $\text{Br}(K_L \rightarrow \pi^0\pi^0X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-)$ assuming that $X^0$ couples to $\bar{d}s$ (and $\mu^+\mu^-$). They also assume that the $X^0$'s are short lived, do not interact strongly and possess a mass of 214.3 MeV.

- Deshpande et al. estimates contraints on scalar and pseudoscalar $X^0$'s.

- finding that pseudoscalar couplings have the largest contribution, they find:

$$\text{Br}(K_L \rightarrow \pi^0\pi^0X^0_p \rightarrow \pi^0\pi^0\mu^+\mu^-) = 8.0 \times 10^{-9}$$  (Phys. Lett. B 632 (2006) 212-214)

- Valencia et al. take things a step further and consider scalar, pseudoscalar, vector and axial vector particle possibilities for the $X^0$ state.
- the decay $K^+ \rightarrow \pi^+\mu^+\mu^-$ places serious constraints on scalar and vector particle possibilities. The branching ratio for $K^+ \rightarrow \pi^+\mu^+\mu^-$ has been measured to be:

$$\text{Br}(K^+ \rightarrow \pi^+\mu^+\mu^-) = (8.1 \pm 1.4) \times 10^{-8}$$

(PRL 88, 111801 (2002))

2004 PDG Average

- combining the upper result with constraints on scalar and vector couplings, Valencia et al. calculates theoretical upper limits on $\text{Br}(\Sigma^+ \rightarrow pX^0_{S} \rightarrow p\mu^+\mu^-)$:

$$\text{Br}(\Sigma^+ \rightarrow pX^0_{S} \rightarrow p\mu^+\mu^-) < 6 \times 10^{-11}, \quad \text{Br}(\Sigma^+ \rightarrow pX^0_{V} \rightarrow p\mu^+\mu^-) < 3 \times 10^{-11}$$

- the above upper limits effectively eliminate both scalar and vector particles as explanations of the HyperCP result.

- Valencia et al. have ruled out the possibility of scalar or vector $X^0$'s. Using existing constraints on pseudoscalar and axial vector $X^0$'s, they predict:

$$\text{Br}(K_L \rightarrow \pi^0\pi^0X^0_p \rightarrow \pi^0\pi^0\mu^+\mu^-) = (8.3^{+7.5}_{-6.6}) \times 10^{-9}$$


$$\text{Br}(K_L \rightarrow \pi^0\pi^0X^0_A \rightarrow \pi^0\pi^0\mu^+\mu^-) = (1.0^{+0.9}_{-0.8}) \times 10^{-10}$$
Other Searches and Theories for $K_L \to \pi^0\pi^0X^0$

- using an sgoldstino model, the branching ratio for $K_L \to \pi^0\pi^0X^0$ (where $X^0 \to \gamma\gamma$) was predicted to be:

$$\text{Br}(K_L \to \pi^0\pi^0X^0 \to \pi^0\pi^0\gamma\gamma) < 1.2 \times 10^{-4}$$

(Phys. Rev. D73, 035002 (2006))

- E391a (KEK) will report on their search for $K_L \to \pi^0\pi^0X^0$ (where $X^0 \to \gamma\gamma$) in the next talk.

- a recent theoretical study suggests that the hypothetical $X^0$ neutral boson could be the lightest (pseudoscalar) Higgs boson in the *next-to-minimal supersymmetric standard model* (NMSSM). (PRL 98, 081802 (2007))
Status of $K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$ Analysis

- This analysis has addressed/will address various issues, such as the following:

  ~ this is a blind analysis with two signal boxes: one signal box for $K_L$ and one signal box for $X^0$.

  ~ the boxes for 1997 AND 1999 have been opened!

  ~ completed identification and estimation of signal mode background.

  ~ normalization mode ($K_L \rightarrow \pi^0 \pi^0 \pi^0_D$) acceptance has been obtained. Negligible background. Systematic studies have been finished.
\( K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^- \) Event Reconstruction

-Crunch Requirements-

<table>
<thead>
<tr>
<th>Crunch Requirement ( K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^- )</th>
<th>1997 Data</th>
<th>1997 MC</th>
<th>1999 Data</th>
<th>1999 MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation Level (MC)</td>
<td>-----</td>
<td>0.092</td>
<td>-----</td>
<td>0.091</td>
</tr>
<tr>
<td>Require 2 tracks</td>
<td>0.666</td>
<td>0.970</td>
<td>0.466</td>
<td>0.971</td>
</tr>
<tr>
<td>( C_{\text{track1}} = -C_{\text{track2}} )</td>
<td>0.999</td>
<td>0.999</td>
<td>0.999</td>
<td>0.999</td>
</tr>
<tr>
<td>( E_{e_l}(\text{track}) \leq 2.0 \text{ GeV} )</td>
<td>0.391</td>
<td>0.913</td>
<td>0.436</td>
<td>0.904</td>
</tr>
<tr>
<td>( E_{e_l}(\text{track}) / p_{\text{track}} \leq 0.9 )</td>
<td>0.999</td>
<td>0.999</td>
<td>0.999</td>
<td>0.999</td>
</tr>
<tr>
<td>NHCLUS \geq 4</td>
<td>0.056</td>
<td>0.636</td>
<td>0.050</td>
<td>0.686</td>
</tr>
<tr>
<td># hits in ( \mu ) planes \geq 1</td>
<td>0.980</td>
<td>0.999</td>
<td>0.989</td>
<td>0.999</td>
</tr>
<tr>
<td># \gamma \text{clus (not assoc. w/tracks)} = 4</td>
<td>0.444</td>
<td>0.964</td>
<td>0.471</td>
<td>0.970</td>
</tr>
<tr>
<td>(</td>
<td>M_{\text{rec,pi0}} - M_{\text{pi0}}</td>
<td>\leq 15 \text{ MeV} )</td>
<td>0.437</td>
<td>0.967</td>
</tr>
<tr>
<td>( 90.0 \text{ m} \leq Z_{\text{VTX}} \leq 160.0 \text{ m} )</td>
<td>0.265</td>
<td>0.985</td>
<td>0.310</td>
<td>0.984</td>
</tr>
<tr>
<td>Bad Spill</td>
<td>0.813</td>
<td>0.803</td>
<td>0.940</td>
<td>0.966</td>
</tr>
<tr>
<td>( p_T^2 \leq 0.06 \text{ GeV}^2/c^2 )</td>
<td>0.569</td>
<td>0.999</td>
<td>0.700</td>
<td>0.999</td>
</tr>
<tr>
<td>Total Acceptance</td>
<td>0.00034</td>
<td>0.0380</td>
<td>0.00043</td>
<td>0.0492</td>
</tr>
</tbody>
</table>

* = listed in chronological order, имв = initial # data events was \(~291 \text{ M (1997)}\) and \(~153 \text{ M (1999)}\),

= initial # MC events for 1997 and 1999 was \(~2.0 \text{ M (# generated MC events was ~20 M)}\).
### $K_L \to \pi^0 \pi^0 \mu^+ \mu^-$ Analysis Results

#### Analysis Requirements

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$480 \text{ MeV} \leq M_{\mu\mu\pi\pi} \leq 520 \text{ MeV}$</td>
<td>0.962</td>
<td>0.966</td>
<td>0.961</td>
<td>0.965</td>
</tr>
<tr>
<td>$p_T^2 \leq 0.001 \text{ GeV}^2/c^2$</td>
<td>0.982</td>
<td>0.980</td>
<td>0.984</td>
<td>0.983</td>
</tr>
<tr>
<td>$E_{\text{cl}}(\text{track}) \leq 1.0 \text{ GeV}$</td>
<td>0.974</td>
<td>0.974</td>
<td>0.966</td>
<td>0.965</td>
</tr>
<tr>
<td>$P_{\text{track}} \leq 7.0 \text{ GeV}$</td>
<td>0.999</td>
<td>0.999</td>
<td>0.994</td>
<td>0.995</td>
</tr>
<tr>
<td>$</td>
<td>M_{\text{rec,pi0}} - M_{\pi0}</td>
<td>\leq 9 \text{ MeV}$</td>
<td>0.997</td>
<td>0.997</td>
</tr>
<tr>
<td>$M_{\mu\mu} \leq 232 \text{ MeV}$</td>
<td>0.999</td>
<td>0.999</td>
<td>0.999</td>
<td>0.999</td>
</tr>
<tr>
<td>$495 \text{ MeV} \leq M_{\mu\mu\pi\pi} \leq 501 \text{ MeV}$ &amp; $p_T^2 \leq 0.00013 \text{ GeV}^2/c^2$</td>
<td>0.901</td>
<td>0.891</td>
<td>0.906</td>
<td>0.902</td>
</tr>
<tr>
<td>$213.8 \text{ MeV} \leq M_{\mu\mu} \leq 214.8 \text{ MeV}$ &amp; $p_T^2 \leq 0.00007 \text{ GeV}^2/c^2$</td>
<td>------</td>
<td>0.954</td>
<td>------</td>
<td>0.954</td>
</tr>
<tr>
<td>Total Acceptance (all inclusive)</td>
<td>0.0314</td>
<td>0.0280</td>
<td>0.0403</td>
<td>0.0374</td>
</tr>
</tbody>
</table>

* = requirements listed in chronological order
### Summary of Backgrounds

No background survive analysis cuts!!!
Opening of the 1997 $K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$ Signal Box!

1997 $K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$ MC
~ Box Dimensions ~
495 MeV $\leq M_{\gamma\gamma\mu\mu} \leq$ 501 MeV
$p_T^2 \leq 130$ MeV$^2$

Signal Box Opened and is EMPTY!

$EMPTY = No$ Signal Events AND No Bkgd Events!

1997 KTeV Data
~ Box Dimensions ~
495 MeV $\leq M_{\gamma\gamma\mu\mu} \leq$ 501 MeV
$p_T^2 \leq 130$ MeV$^2$
Opening of the $1997 X^0 \rightarrow \mu^+ \mu^-$ Signal Box!

$1997 K_L \rightarrow \pi^0 \pi^0 X^0 \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$ MC

~ Box Dimensions ~

$213.8 \text{ MeV} \leq M_{\mu\mu} \leq 214.8 \text{ MeV}$

$p_T^2 \leq 700 \text{ MeV}^2$

$1997 \text{ KTeV Data}$

~ Box Dimensions ~

$213.8 \text{ MeV} \leq M_{\mu\mu} \leq 214.8 \text{ MeV}$

$p_T^2 \leq 700 \text{ MeV}^2$

Signal Box Opened and is EMPTY!
### Normalization Mode ($K_L \rightarrow \pi^0\pi^0\pi^0_D$) Results

<table>
<thead>
<tr>
<th>Requirement*</th>
<th>1997 Data</th>
<th>1997 MC</th>
<th>1999 Data</th>
<th>1999 MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger Level</td>
<td>0.027</td>
<td>0.034</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Require 2 tracks</td>
<td>0.889</td>
<td>0.985</td>
<td>0.965</td>
<td>0.985</td>
</tr>
<tr>
<td>$C_{\text{track1}} = -C_{\text{track2}}$</td>
<td>0.999</td>
<td>0.999</td>
<td>0.999</td>
<td>0.999</td>
</tr>
<tr>
<td>$0.95 \leq E_{\text{cl}}(\text{track}) / p_{\text{track}} \leq 1.05$</td>
<td>0.679</td>
<td>0.886</td>
<td>0.848</td>
<td>0.851</td>
</tr>
<tr>
<td>NHCLUS $\geq 5$</td>
<td>0.916</td>
<td>0.967</td>
<td>1.000</td>
<td>0.972</td>
</tr>
<tr>
<td>$# \gamma$ clus (not assoc. w/tracks) $= 5$</td>
<td>0.374</td>
<td>0.447</td>
<td>0.999</td>
<td>0.463</td>
</tr>
<tr>
<td>$</td>
<td>M_{\text{rec,pi0}} - M_{\pi0}</td>
<td>\leq 15 \text{ MeV}$</td>
<td>0.066</td>
<td>0.067</td>
</tr>
<tr>
<td>$90.0 \text{ m} \leq Z_{\text{VTX}} \leq 160.0 \text{ m}$</td>
<td>0.977</td>
<td>0.985</td>
<td>0.970</td>
<td>0.982</td>
</tr>
<tr>
<td>Bad Spill</td>
<td>0.792</td>
<td>0.789</td>
<td>0.934</td>
<td>0.944</td>
</tr>
<tr>
<td>$p_T^2 \leq 0.06 \text{ GeV}^2/c^2$</td>
<td>0.928</td>
<td>0.934</td>
<td>0.928</td>
<td>0.937</td>
</tr>
<tr>
<td>$473 \text{ MeV} \leq M_{\text{eeeffff}} \leq 523 \text{ MeV}$</td>
<td>0.471</td>
<td>0.477</td>
<td>0.494</td>
<td>0.504</td>
</tr>
<tr>
<td>$</td>
<td>M_{\text{rec,pi0}} - M_{\pi0}</td>
<td>\leq 14 \text{ MeV}$</td>
<td>0.992</td>
<td>0.992</td>
</tr>
<tr>
<td>$94.0 \text{ m} \leq Z_{\text{VTX}} \leq 158.0 \text{ m}$</td>
<td>0.987</td>
<td>0.990</td>
<td>0.986</td>
<td>0.990</td>
</tr>
<tr>
<td>Total Acceptance</td>
<td>131526 events</td>
<td>0.006%</td>
<td>363531 events</td>
<td>0.013%</td>
</tr>
</tbody>
</table>

* = requirements listed in chronological order,

\( \updownarrow = \text{initial # data events was \sim 47.2 M (\# generated MC events was \sim 1.41 G)} \),

\( \downarrow = \text{initial # data events was \sim 50.4 M (\# generated MC events was \sim 1.84 G)} \).
1997 $K_L \to \pi^0\pi^0\pi^0_D$ Inv. Mass and $P_T^2$ After All Cuts

1997 $\pi^0\pi^0\pi^0_D$ Inv. Mass

- • = Data
- □ = MC

1997 $\pi^0\pi^0\pi^0_D$ $P_T^2$
1997 $K_L \rightarrow \pi^0\pi^0\pi^0_D$ 1st $\pi^0$ Mass and Zvtx After All Cuts

1997 $\pi^0\pi^0\pi^0_D$ 1st $\pi^0$ Mass

$\bullet$ = Data

$\square$ = MC

1997 $\pi^0\pi^0\pi^0_D$ Zvtx
Acceptance Results

1997 Acceptance \((K_L \rightarrow \pi^0\pi^0\mu^+\mu^-)\) = \(3.14 \pm 0.004\ \text{stat.}\) \%

1997 Acceptance \((K_L \rightarrow \pi^0\pi^0X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-)\) = \(2.80 \pm 0.004\ \text{stat.}\) \%

1997 Acceptance \((K_L \rightarrow \pi^0\pi^0\pi^0)\) = \(5.94 \pm 0.02\ \text{stat.}\) \times 10^{-5}

1999 Acceptance \((K_L \rightarrow \pi^0\pi^0\mu^+\mu^-)\) = \(4.03 \pm 0.005\ \text{stat.}\) \%

1999 Acceptance \((K_L \rightarrow \pi^0\pi^0X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-)\) = \(3.74 \pm 0.004\ \text{stat.}\) \%

1999 Acceptance \((K_L \rightarrow \pi^0\pi^0\pi_D)\) = \(1.29 \pm 0.003\ \text{stat.}\) \times 10^{-4}
\[ N_{\text{Data}}^{\text{Norm}} = F_K \times BR(K_L \rightarrow \pi^0 \pi^0 \pi_D^0) \times A_{\text{Norm}}, \text{ where } A_{\text{Norm}} = \frac{N_{\text{acc}}}{N_{\text{gen}}}. \]

\[ N_{\text{Data}}^{\text{Norm}} = \text{number of data events after all normalization mode cuts.} \]

\[ N_{\text{acc}} = \text{number of MC events after all normalization mode cuts.} \]

\[ N_{\text{gen}} = \text{number of MC events generated.} \]

\[ A_{\text{Norm}, 1997} = \frac{109532}{1842926908} = 5.94 \times 10^{-5} \quad A_{\text{Norm}, 1999} = \frac{183131}{1414181218} = 1.29 \times 10^{-4} \]

\[ BR(K_L \rightarrow \pi^0 \pi^0 \pi_D^0) = 3BR(K_L \rightarrow \pi^0 \pi^0 \pi_D^0) \times BR(\pi_D^0) \times BR(\pi^0 \rightarrow \gamma\gamma)^2 = (6.85 \pm 0.23) \times 10^{-3} \]

Putting everything together yields:

\[ N_{\text{Data}}^{\text{Norm}, 1997} = 131526 \text{ events} \quad N_{\text{Data}}^{\text{Norm}, 1999} = 363531 \text{ events} \]

\[ F_{K, 1997} = 3.23 \times 10^{11} \text{ events} \quad F_{K, 1999} = 4.10 \times 10^{11} \text{ events} \]
# Systematic Errors in Flux from $K_L \rightarrow \pi^0\pi^0\pi^0_D$

## Source of Systematic Error

<table>
<thead>
<tr>
<th>Source of Systematic Error</th>
<th>$\Delta F_{\text{Norm}, 1997}$</th>
<th>$\Delta F_{\text{Norm}, 1999}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(473 \pm 1)$ MeV $\leq M_{eeeffeeff} \leq (523 \pm 1)$ MeV</td>
<td>+0.04%</td>
<td>+0.05%</td>
</tr>
<tr>
<td>$</td>
<td>M_{\text{rec.pi0}} \times M_{\pi0}</td>
<td>\leq (14 \pm 1)$ MeV</td>
</tr>
<tr>
<td>$(94.0 \pm 1.0)$ m $\leq Z_{\text{VTX}} \leq (158.0 \pm 1.0)$ m</td>
<td>+0.16%</td>
<td>+0.20%</td>
</tr>
<tr>
<td>$P_T^2 \leq (1.0 \pm 0.1) \times 10^{-3}$ GeV$^2$</td>
<td>+0.11%</td>
<td>+0.06%</td>
</tr>
<tr>
<td>$(0.95 \pm 0.1) \leq E_{\text{cl.(track)}} / p_{\text{track}} \leq (1.05 \pm 0.1)$</td>
<td>+1.24%</td>
<td>+2.23%</td>
</tr>
<tr>
<td>$P_z$ Weighting</td>
<td>-------</td>
<td>1.87%</td>
</tr>
<tr>
<td>Cracks in $\mu$ Counting Planes</td>
<td>0.50%</td>
<td>0.50%</td>
</tr>
<tr>
<td>Energy Loss in $\mu$ Filters</td>
<td>0.40%</td>
<td>0.40%</td>
</tr>
<tr>
<td>$\text{Br}(K_L \rightarrow \pi^0\pi^0\pi^0)$</td>
<td>0.61%</td>
<td>0.61%</td>
</tr>
<tr>
<td>Total Systematic Error from Flux</td>
<td>+1.54%</td>
<td>+3.05%</td>
</tr>
<tr>
<td></td>
<td>- 2.57%</td>
<td>- 4.55%</td>
</tr>
</tbody>
</table>

$$F_{\text{Norm}} = \frac{N_{\text{Data}}}{A_{\text{Norm}}} = F_K \times BR(K_L \rightarrow \pi^0 \pi^0 \pi^0_D), \quad \Delta F_{\text{Norm}} = \frac{N_{\text{Data}}}{A_{\text{Norm}}} \pm \Delta N \quad F_{\text{Norm}} = \frac{A_{\text{Norm}} \pm \Delta A}{A_{\text{Norm}}}$$
- after all analysis cuts, there were **ZERO** signal events found in the Data and **ZERO** background events found in MC.

- in the case of **ZERO** signal events and **ZERO** background events, the upper limit of the branching ratio (at 90% CL) may be found by:

  \[
  Br = 2.30 \times (1 + 2.30 \sigma_r^2 / 2) \times SES_{total},
  \]

  where \( SES_{total} = (F_{K,1997} \times A_{1997} + F_{K,1999} \times A_{1999})^{-1} \)

- this result holds for either a Bayesian or a Classical viewpoint [2] and can also be found in the 2008 PDG [3].


Using $F_{K,1997} = 3.23 \times 10^{11}$, $F_{K,1999} = 4.10 \times 10^{11}$ and $\sigma_r^2$, one finds the following upper limits at 90% CL:

$$Br(K_L \rightarrow \pi^0\pi^0\mu^+\mu^-) < 8.63 \times 10^{-11}$$

$$Br(K_L \rightarrow \pi^0\pi^0X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-) < 9.44 \times 10^{-11}$$

Compare with:

$$Br(K_L \rightarrow \pi^0\pi^0X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-) = (8.3^{+7.5}_{-6.6}) \times 10^{-9}$$

$$Br(K_L \rightarrow \pi^0\pi^0X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-) = (1.0^{+0.9}_{-0.8}) \times 10^{-10}$$
Preliminary Conclusions and Future Plans

- the preliminary upper limit for $\text{Br}(K_L \rightarrow \pi^0 \pi^0 X^0 \rightarrow \pi^0 \pi^0 \mu^+ \mu^-)$ is roughly two orders of magnitude less than the theoretical prediction of the same decay with a pseudoscalar $X^0$.

- based on these preliminary results, the pseudoscalar $X^0$ candidate has been ruled out as an explanation for the neutral boson $X^0$ observed by HyperCP. However, an axial vector $X^0$ candidate has not been ruled out.
~ Backup Slides ~
**Cut on** $P_T^2$ **vs. Inv. $K_L$ Mass**

(1997 $K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ Analysis - 1st Cut)

**1997 $K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ MC**

~ Box Dimensions ~

$495 \text{ MeV} \leq M_{\pi\pi\mu\mu} \leq 501 \text{ MeV}$

$p_T^2 \leq 130 \text{ MeV}^2$

**1997 $K^0_{\mu4}$ MC Background**

* $K^0_{\mu4}$ is the most dangerous bkgd, but is not really so dangerous.

According to MC, no $K^0_{\mu4}$ events in the signal box.
Cut on $P_T^2$ vs. Inv. $K_L$ Mass

(1999 $K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$ Analysis - 1st Cut)

1999 $K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$ MC

~ Box Dimensions ~

$495 \text{ MeV} \leq m_{\pi^0 \pi^0 \mu^+ \mu^-} \leq 501 \text{ MeV}$

$p_T^2 \leq 130 \text{ MeV}^2$

Signal box for MC is open, but for Data remains closed!

According to MC, no $K_L^{0 \mu 4}$ events in the signal box.
Opening of the 1999 $K_L$ Signal Box!

1999 $K_L \rightarrow \pi^0 \pi^0 \mu^+ \mu^-$ MC
~ Box Dimensions ~
495 MeV $\leq M_{\pi\pi\mu\mu} \leq$ 501 MeV
$p_T^2 \leq 130 \text{ MeV}^2$

$K_L$ Signal Box Opened and is EMPTY!

1999 KTeV Data
~ Box Dimensions ~
495 MeV $\leq M_{\pi\pi\mu\mu} \leq$ 501 MeV
$p_T^2 \leq 130 \text{ MeV}^2$
Opening of the 1999 $X^0$ Box!

1999 $K_L \rightarrow \pi^0\pi^0 X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-$ MC

~ Box Dimensions ~
213.8 MeV $\leq M_{\mu\mu} \leq 214.8$ MeV
$p_T^2 \leq 700$ MeV$^2$

$X^0$ Signal Box Opened and is EMPTY!

1999 KTeV Data

~ Box Dimensions ~
213.8 MeV $\leq M_{\mu\mu} \leq 214.8$ MeV
$p_T^2 \leq 700$ MeV$^2$
1997 Normalization Mode \( (K_L \rightarrow \pi^0\pi^0\pi^0_D) \)

1997 K\(_L\) → \(\pi^0\pi^0\pi^0_D\) MC

1997 KTeV Data

~ Initial K\(_L\) → \(\pi^0\pi^0\pi^0_D\) Analysis Cuts ~

\[ 473 \text{ MeV} \leq M_{\gamma\gamma\gamma\gamma} \leq 523 \text{ MeV} \]

\[ p_T^2 \leq 0.001 \text{ GeV}^2 \]
1999 Normalization Mode ($K_L \rightarrow \pi^0\pi^0\pi^0_D$)

1999 $K_L \rightarrow \pi^0\pi^0\pi^0_D$ MC

1999 KTeV Data

~ Initial $K_L \rightarrow \pi^0\pi^0\pi^0_D$ Analysis Cuts ~

$473 \text{ MeV} \leq M_{\pi\pi\pi} \leq 523 \text{ MeV}$

$p_T^2 \leq 0.001 \text{ GeV}^2$
1999 $K_L \rightarrow \pi^0\pi^0\pi^0_D$ Inv. Mass and $P_T^2$ After All Cuts

1999 $\pi^0\pi^0\pi^0_D$ Inv. Mass

$\bullet = \text{Data}$

$\square = \text{MC}$

1999 $\pi^0\pi^0\pi^0_D$ $P_T^2$
1999 $K_L \rightarrow \pi^0\pi^0\pi^0_D$ 1st $\pi^0$ Mass and Zvtx After All Cuts

1999 $\pi^0\pi^0\pi^0_D$ 1st $\pi^0$ Mass

1999 $\pi^0\pi^0\pi^0_D$ Zvtx

• = Data
□ = MC