Search for the Decay $K_L \to \pi^0\pi^0\gamma$ in KTeV

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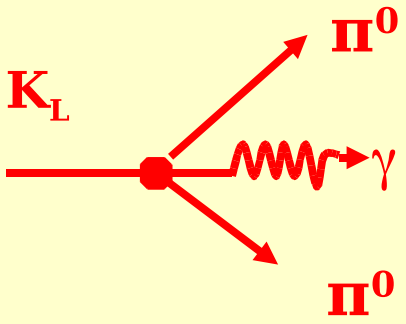
Introduction to the Decay

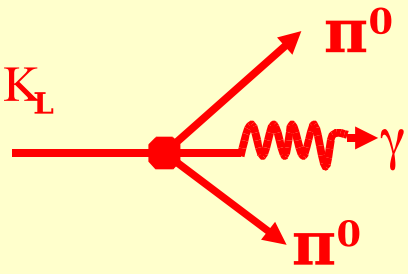
--Presence of two π^0's requires a D-wave decay

--Main contributions are second-order.

Leading Order Diagrams:



E2 Electric Quadrupole Direct Emission (CP conserving)



M2 Magnetic Quadrupole Direct Emission (CP violating)

Theoretical Significance

--Vanishes to order p^4 in Chiral Perturbation Theory; is a probe of the sixth order of ChPT

--Estimated Branching Ratio

--Based on $\pi^+\pi^-\gamma$ branching ratio: $1*10^{-8}$*

--From chiral perturbation theory: $7*10^{-11}$**

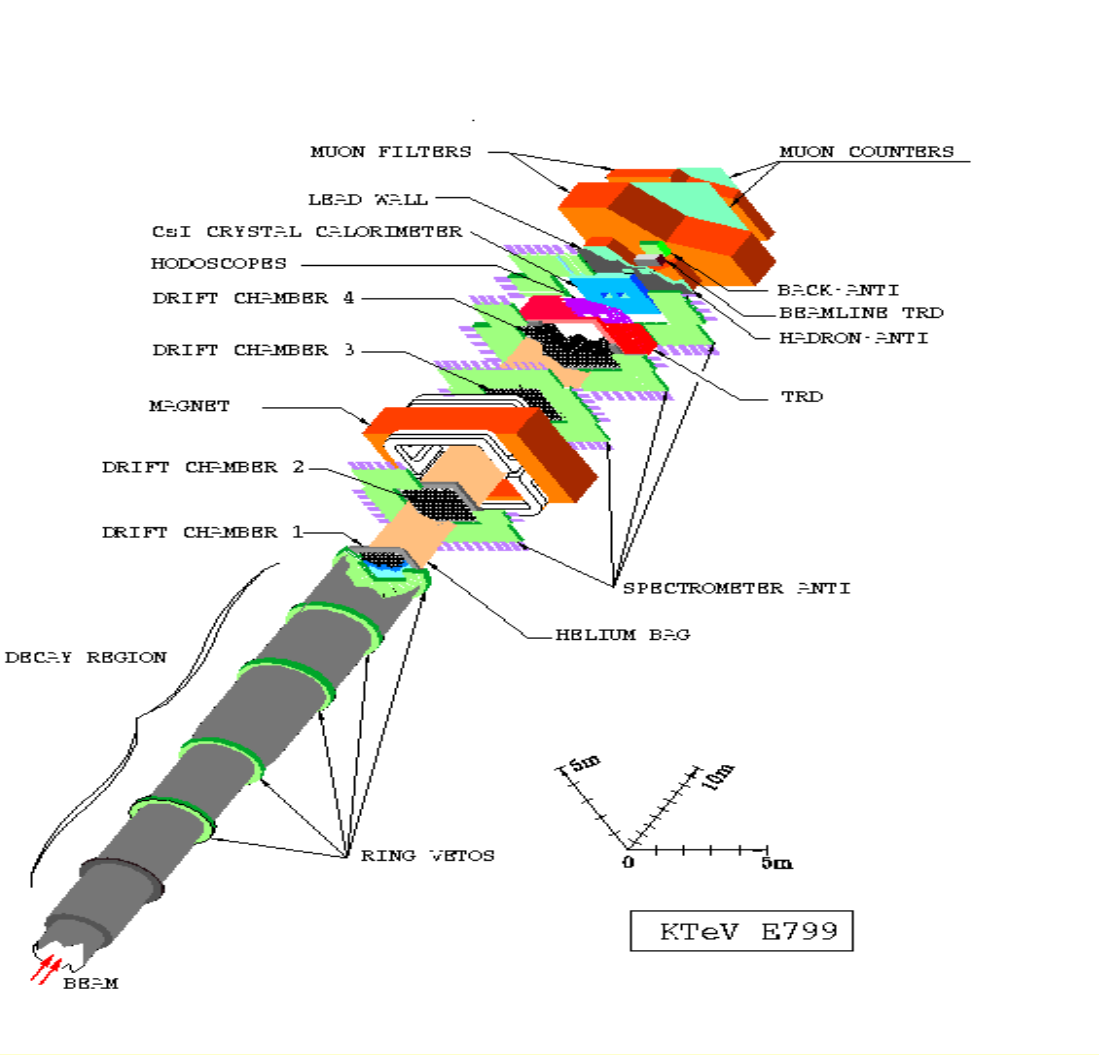
--Problem: signal is has large background

--Dominated by K_L->$3\pi^0$ with missing photon (21% BR)

--Current upper limit: $5.6*10^{-6}$ (from NA31)

*Sehgal et al., Phys Lett. B 307 p182-86.
**Ecker et. al. CERN-TH.6920/93

The KTeV Experiment



--Ran at Fermilab, 1997-99

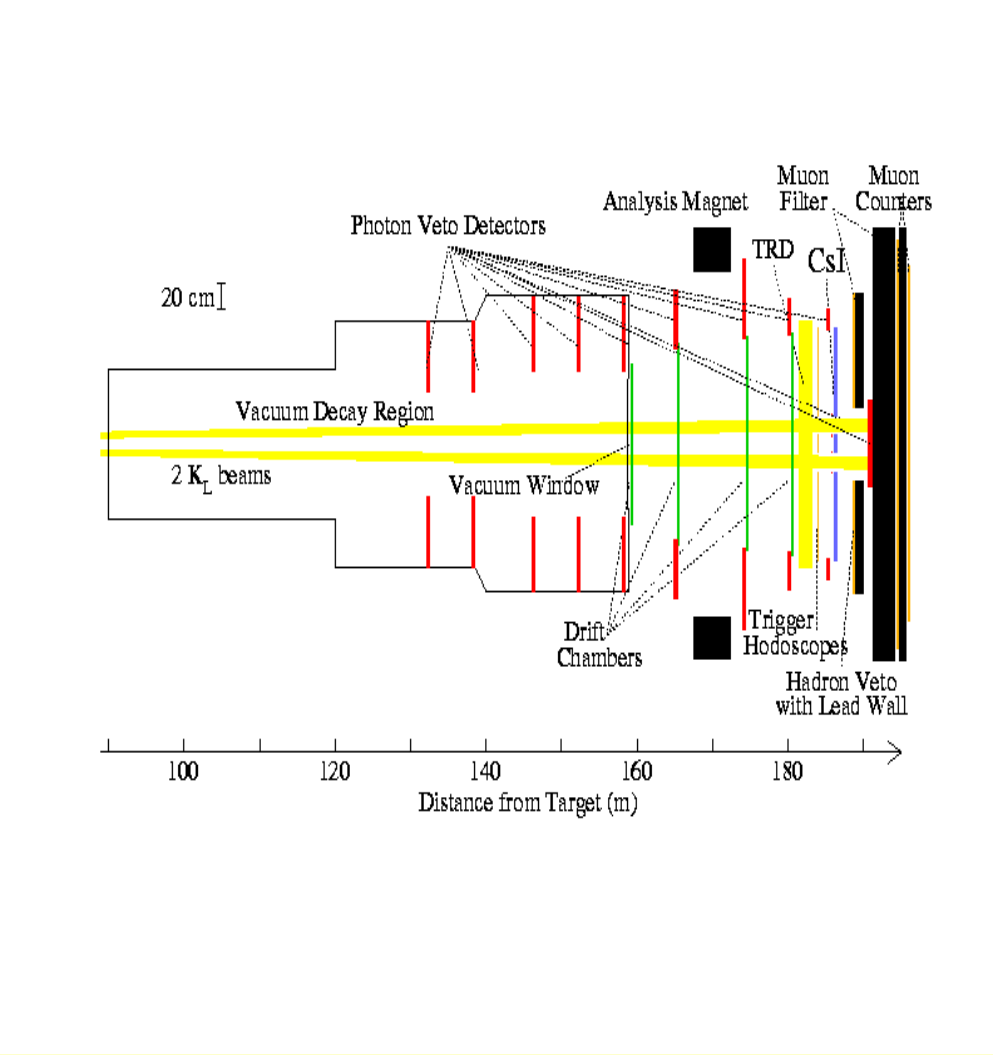
--Two experiments:

E799—studied rare K_L decays

E832—studied parameters due to K_L-K_S interference

This analysis is based on E799 data.

The KTeV Experiment



<u>Production Target</u>:
Protons incident on BeO crystal produce two parallel K_L beams

<u>Decay Region</u>:
60m long vacuum region

<u>Drift Chambers</u>
Four drift chambers w/ analysis magnet between 2 and 3

<u>CsI Calorimeter</u>
--Only neutral particle detector; energy deposited in EM showers
"beam holes" allow beam to pass through

Analysis Method

--Start with “crunch”: select data events with desired topology

--Topology: 4 photons + electron/positron pair

$K_L \rightarrow \pi^0\pi^0\gamma$, with $\pi^0 \rightarrow \gamma\gamma$ and $\pi^0 \rightarrow ee\gamma$

--Require ee pair due to sensitive charged trigger

--Most data events after the crunch are background $3\pi^0_D$ events with a missing photon

--Purpose of analysis: design a series of cuts that eliminate background $3\pi^0_D$ events while retaining signal events

--Test cut efficiencies with Monte Carlo (signal $K_L \rightarrow \pi^0\pi^0_D\gamma$ and background $K_L \rightarrow 3\pi^0_D$) and then apply cuts to data.

The Signal Box

--At this stage, 80% of Monte Carlo signal mode events fall in the "signal box" region:

--$|M_{ee\gamma\gamma\gamma\gamma} - M_k| < 0.003$ GeV/c^2

--$p_t^2 < 0.00015$ GeV^2

where

$M_{ee\gamma\gamma\gamma\gamma}$ = total mass of the event

p_t^2 = transverse momentum squared

= total momentum perpendicular to beam direction

≈ 0 for well-reconstructed event

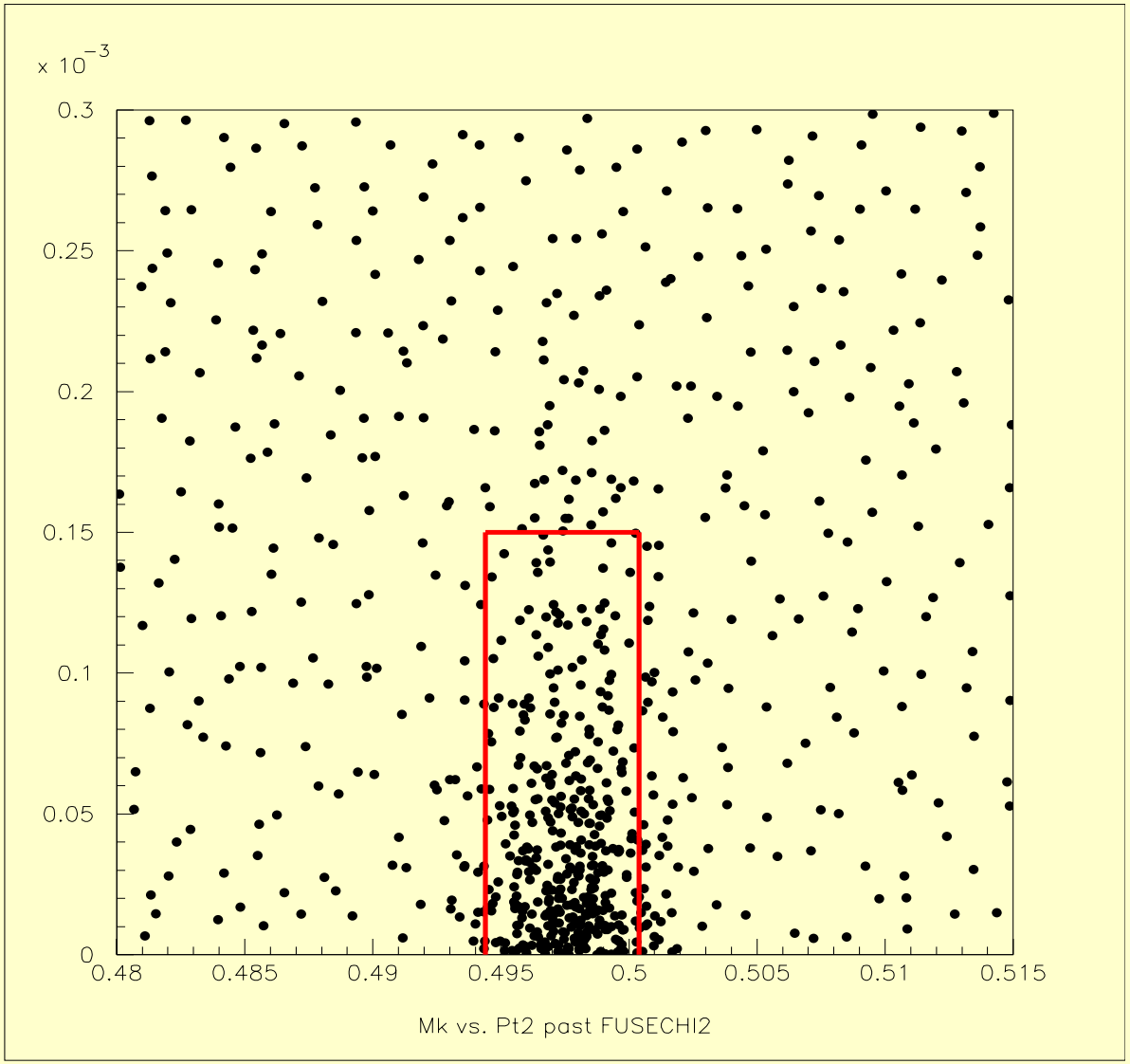
--Calculate upper limit based on # of events in the box after cuts

--Analysis is "blind"--don't look at events in the box for data; after determining cuts, open the box and count the number of events

--Background level in box must be reduced to see signal

The Signal Box

This is the signal box for $K_L \rightarrow \pi^0\pi^0\gamma$ Monte Carlo events.



The Normalization Mode

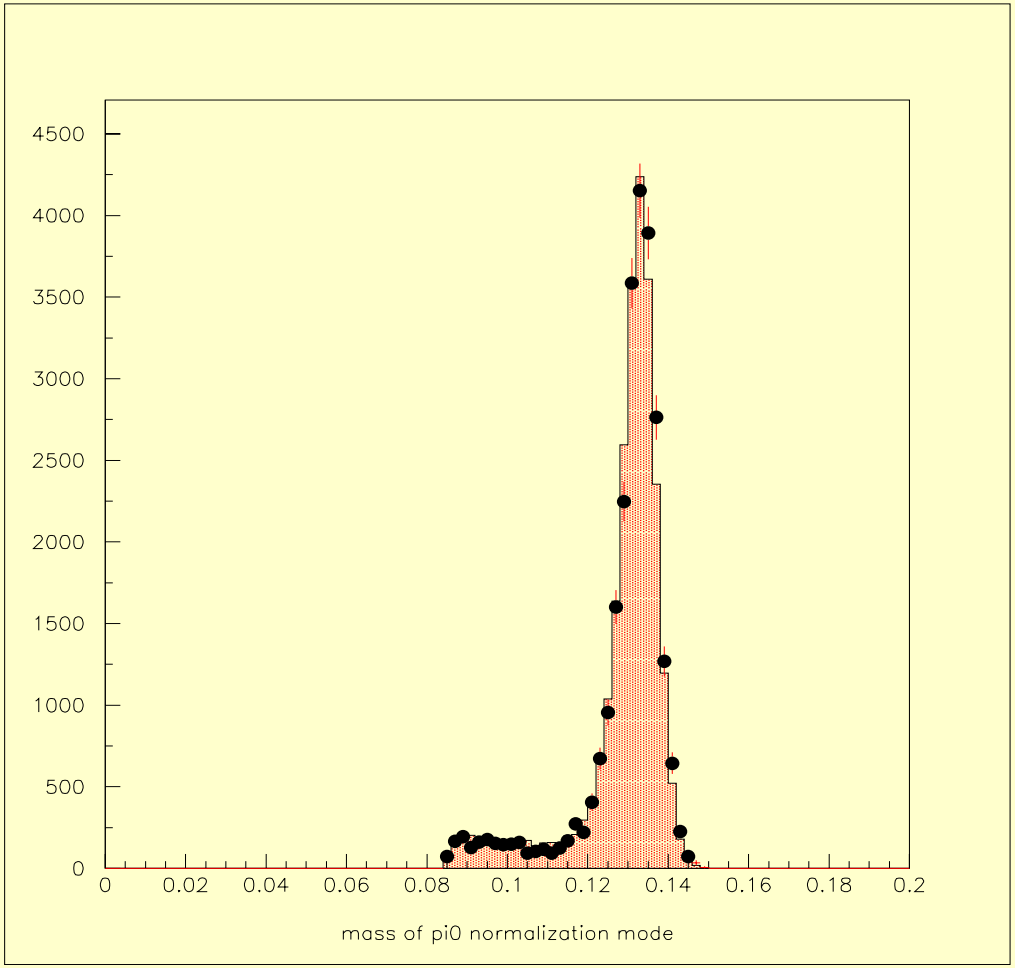
--Used to find total K_L flux

--Check of data/Monte Carlo agreement in mode w/ same topology as signal

--For this analysis:
K_L->$3\pi^0_D$ (with one photon down calorimeter beam hole)

--Beamhole photon calculated assuming perfect K^0 mass and zero p_t^2; combined with external photon to form π^0

The plot shows the mass of this π^0. Dots are data, histogram is $3\pi^0_D$ MC.
The "shoulder" on the plot is due to events where the "found" photons are mispaired.



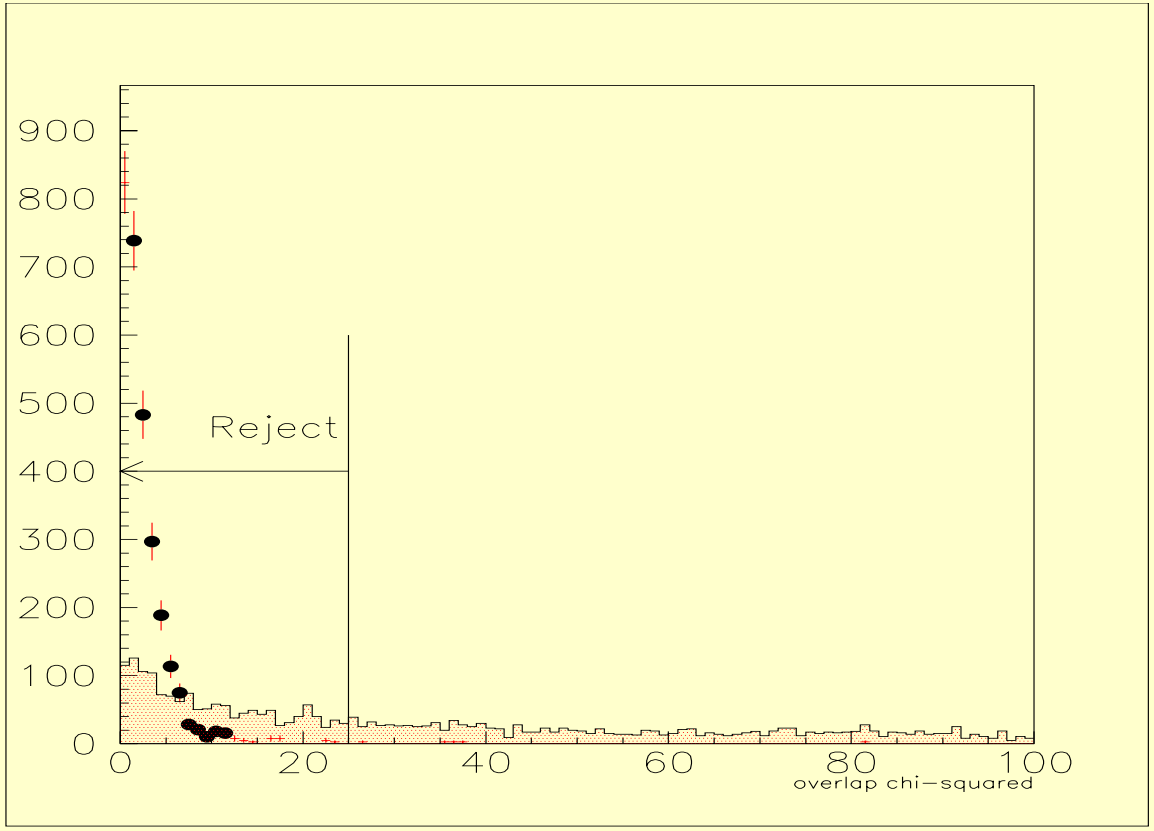
Signal Mode Analysis

--Cuts were applied to reduce background MC events in the box while retaining signal mode events

--Example: Overlapping Clusters Cut

Forms a χ^2 for each CsI calorimeter hit--measures probability that hit consists of two “overlapping” photons.

Cut if any hit has $\chi^2 < 25.0$.



Dots = background, red = signal

Results: Single Event Sensitivity

--Total Signal Acceptance: 0.13%

--There are 1.66±0.59 $3\pi^0$ MC background events left in the box

--From the normalization mode

$N_K = 2.40*10^{11}$ (KTeV 1997 K_L flux)

--The Single Event Sensitivity is defined as the signal branching ratio that will produce 1 event in the box.

$$1 = N_K * SES * \text{Signal Acceptance}$$

SES = $(1.47\pm0.06)*10^{-7}$ for $K_L \to \pi^0\pi^0\gamma$

Results: Systematic Errors

--The error on the background level is statistical.

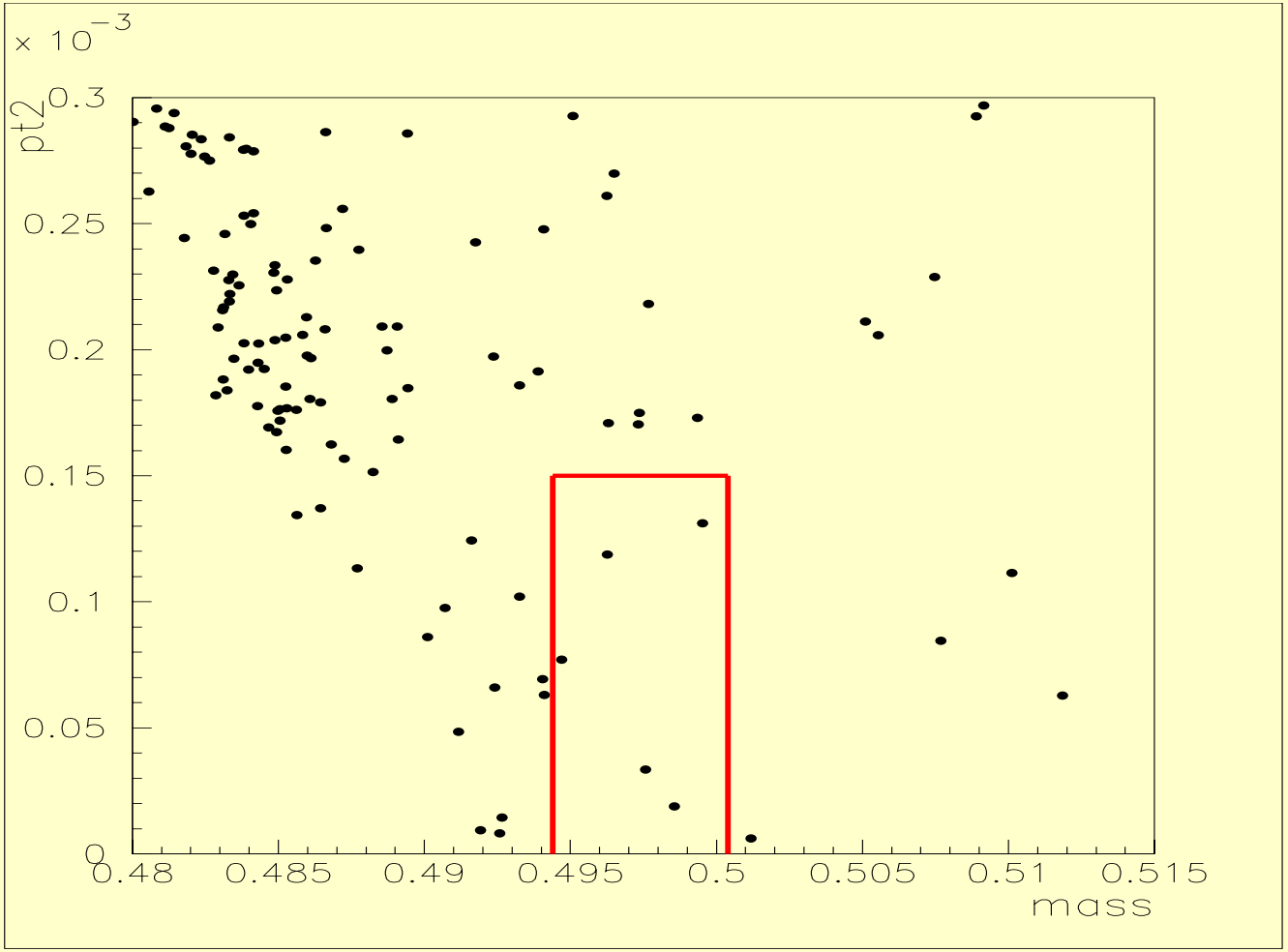
--The error on the SES has three components, one statistical and two systematic:

1. $3\pi^0$ Branching Ratio Error -- 1.24%
2. Data/$3\pi^0$ MC disagreement -- 3.40%
3. Statistical acceptance error-- 1.60%

Total Error on SES: 3.94 %

--Possible error source: other backgrounds
  --Generated several other backgrounds in Monte Carlo
  --No events in signal box or normalization mode
  --No systematic error due to other backgrounds

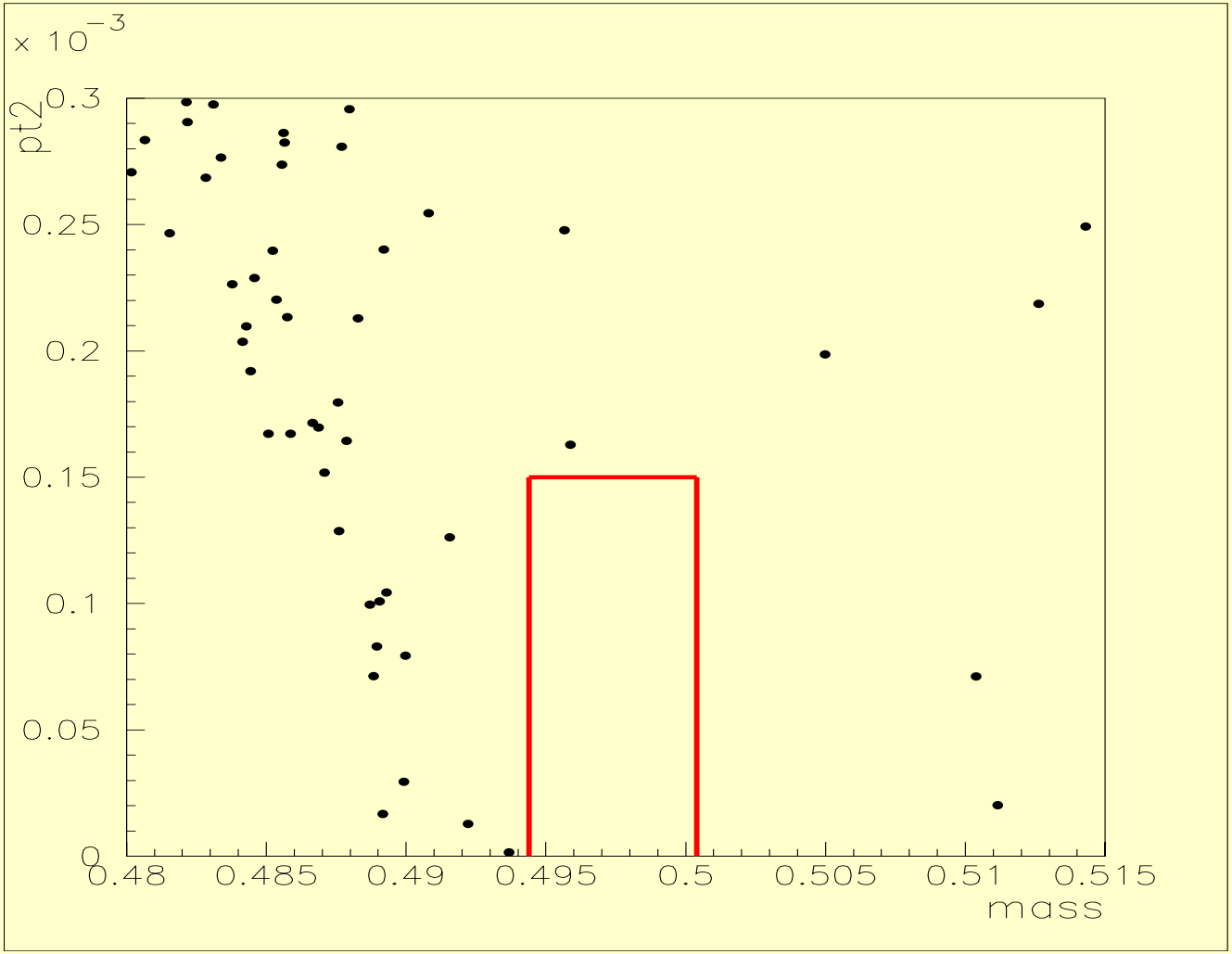
The Box: Expected Background



This plot shows the $3\pi^0_D$ MC, with the box, after all cuts. 4.88 times as many $3\pi^0_D$ events were generated in the Monte Carlo as are in the data.

Opening the Box

Upon opening the box for data...



Zero events were found

Deriving the Upper Limit

The 90% upper limit for BR($K_L \to \pi^0\pi^0\gamma$) is found using a method of confidence belts.

The belts are constructed by scanning over all values of BR($K_L \to \pi^0\pi^0\gamma$), calculating a Poisson distribution

$P(n_{exp}, n_{obs})$ where

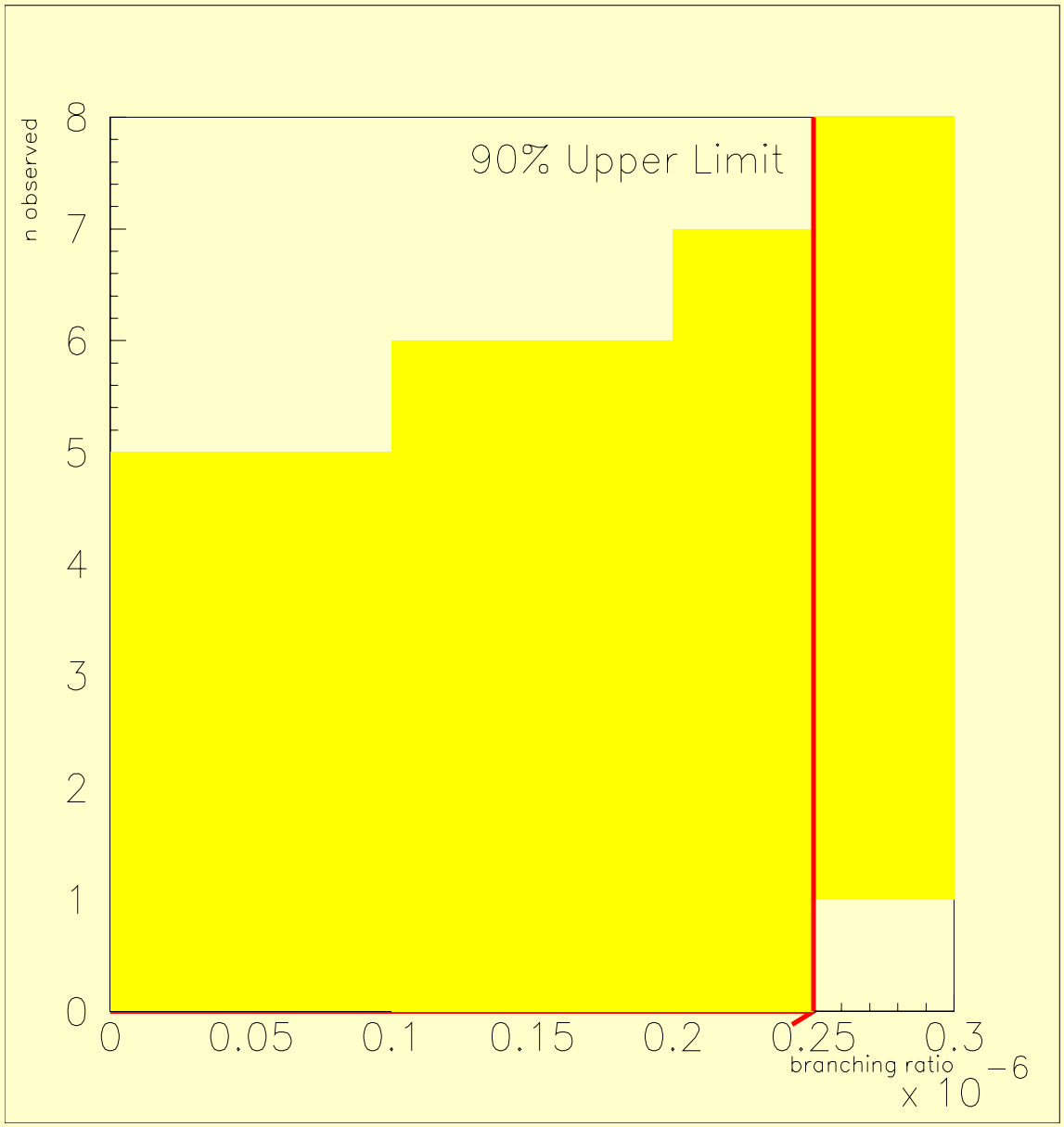
n_{obs} = # of data events in box

n_{exp} = # of events expected

$= n_{bg} + BR(K_L \to \pi^0\pi^0\gamma)/SES$

The belt for each value of the branching ratio contains 90% of the Poisson distribution in n_{obs}.

Confidence Belt Plot



This is the confidence belt plot described in the previous slide.

To find the upper limit, we find where our n_{obs} (=0) intersects the right edge of the confidence region.

Conclusion

Based on the 1997 KTeV data set...

$BR(K_L \to \pi^0\pi^0\gamma) < 2.52 \times 10^{-7}$ (at 90% CL)

--Factor of 22 improvement on NA31 result

--Work is continuing on 1999 data

Current Status

--Working on 1999 analysis; “box” is closed

--Generated 2.66 fluxes of '99 background; still generating

--More background in box, so need extra cuts

--Using PDFs to define signal region for '99

--Considering:

--Confidence belt method using PDFs

--How to combine 1997 and 1999 data