Search for $K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$ with KTeV data

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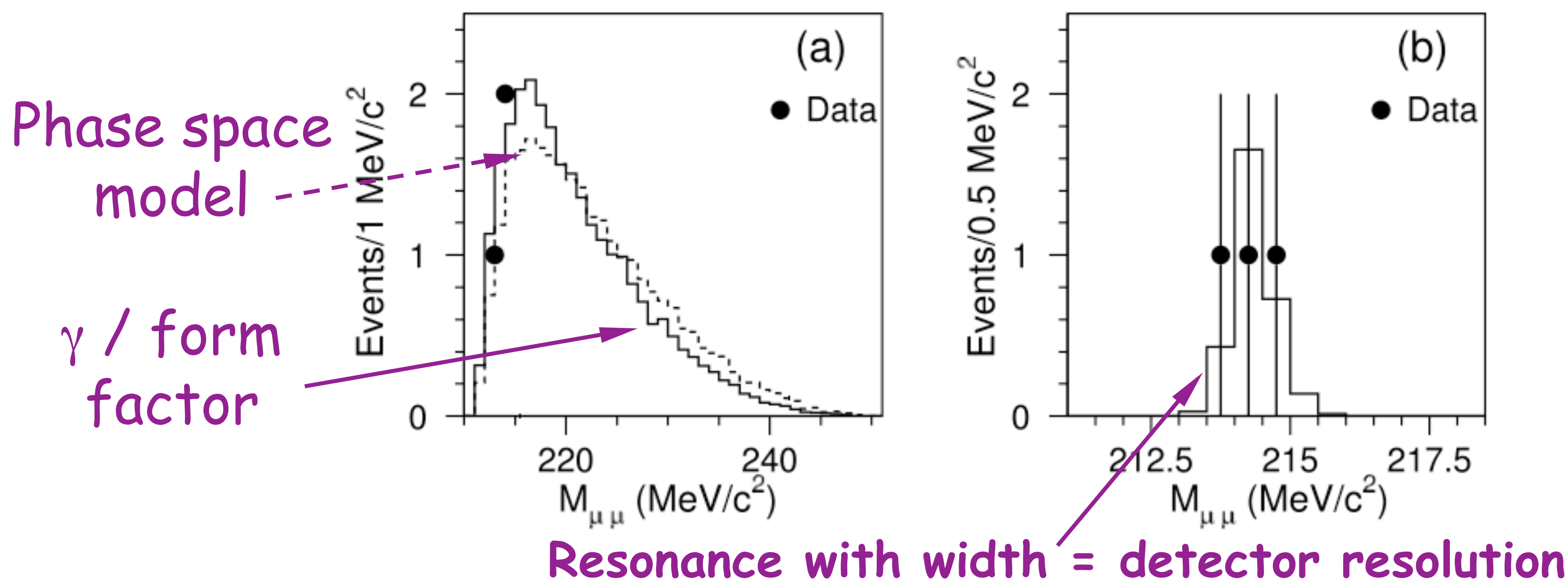
The HyperCP Result

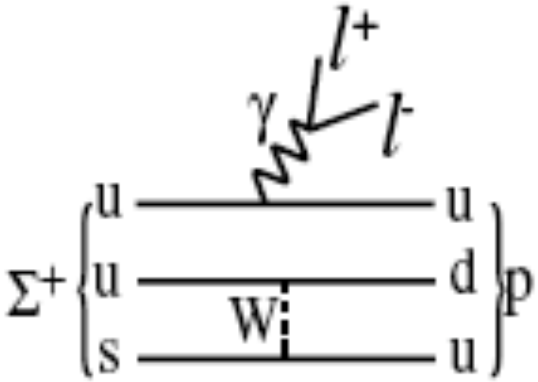
Park, et.al. (HyperCP), Phys.Rev.Lett. 94,021801 (2005)

- $Br(\Sigma^+ \rightarrow p\mu^+\mu^-) = (8.6^{+6.6}_{-5.4}{}_{STAT} \pm 5.5_{SYST}) \times 10^{-8}$ (3 events)
- Expectation is ~ 0.1×10^{-8}
- All 3 events at the same mass: 214.3 ±0.5 MeV
- C.L. for this in S.M. is 0.8%

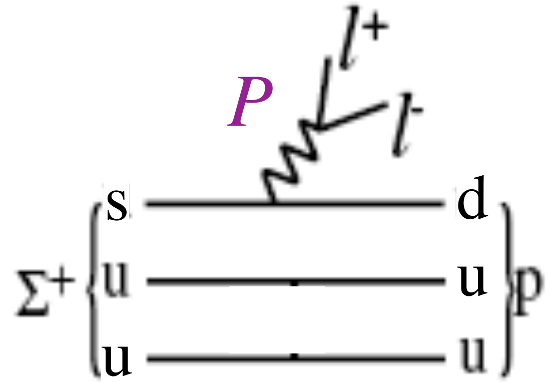


The HyperCP Result

Maybe it isn't just



Maybe there is also



That would change the detection efficiency

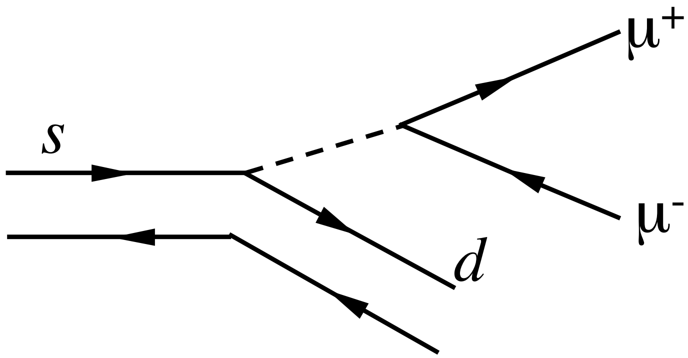
$$Br\left(\Sigma^+ \rightarrow pP^0, P^0 \rightarrow \mu^+\mu^-\right) = \left[3.1^{+2.4}_{-1.9} \pm 1.5\right] \times 10^{-8}$$

$\Rightarrow$ Partial width of

$$\Gamma\left(\Sigma^+ \rightarrow pP^0, P^0 \rightarrow \mu^+\mu^-\right) = 2.5 \times 10^{-19}\ MeV$$

Should appear at other *s*-*d* vertices

In Kaon Decays



The existing measurement of
$Br(K^+\to\pi^+\mu^+\mu^-) = 8.1\ \mathrm{x}10^{-8}$
corresponds to a $\Gamma = 4.3\ \mathrm{x}10^{-24}$ MeV
Almost 5 orders of magnitude
below the *Hyper CP* result

Maybe **$K\to\pi\mu^+\mu^-$ is parity suppressed(?) - look for $K_L\to\pi\pi\mu^+\mu^-$**

In fact, look for $\pi^0\pi^0$ not $\pi^+\pi^-$:

$$m(K_L) - 2[m(\pi^0) + m(\mu^\pm)] = 16.3\ \mathrm{MeV}$$
$$m(K_L) - 2[m(\pi^\pm) + m(\mu^\pm)] = 7.2\ \mathrm{MeV}$$

} Factor of 18 in phase space!

The CsI calorimeter of KTeV is very good at finding π^0s

Flurry Of Excitement

Gorbunov & Rubakov, Phys.Rev.D 73,035002 (2006)

It might be Sgoldstino!

He, Tandeen & Valencia, Phys.Rev.D 72,074003 (2005)

Revaluate the standard model branching ratio - the Br measurement is consistent with it

He, Tandeen & Valencia, Phys.Lett.B 631,100 (2005)

Can't be scalar or vector couplings

If pseudoscalar, $Br(K_L \to \pi^0\pi^0 X^0 \to \pi^0\pi^0\mu^+\mu^-) \sim 8.3 \times 10^{-9}$

If axial-vector, $Br(K_L \to \pi^0\pi^0 X^0 \to \pi^0\pi^0\mu^+\mu^-) \sim 1.0 \times 10^{-10}$

He, Tandeen & Valencia, Phys.Rev.Lett, 98,081812 (2007)

It could be the pseudoscalar a of the NMSSM

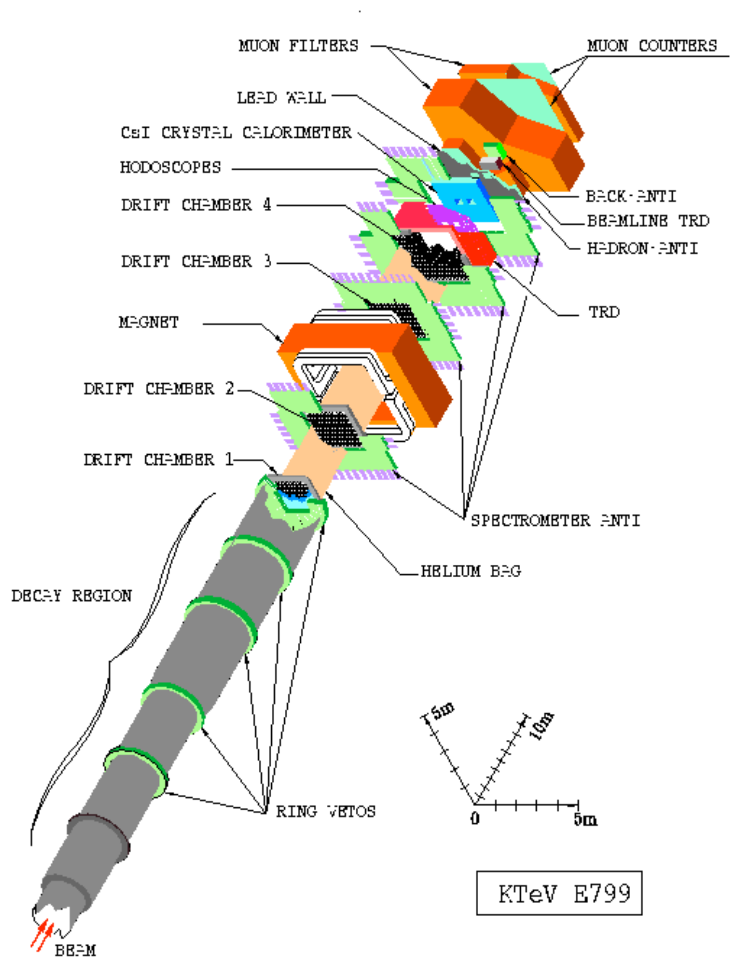
Leading to a searches by CLEO, BaBar, D0

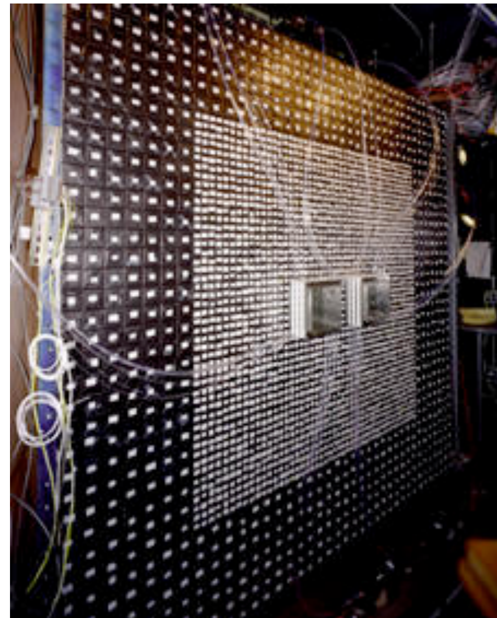
Deshpande, Eilam & Jiang, Phys.Lett.B 632,212 (2006)

If a pseudoscalar, $Br(K_L \to \pi^0\pi^0 X^0 \to \pi^0\pi^0\mu^+\mu^-) = 8.02 \times 10^{-9}$

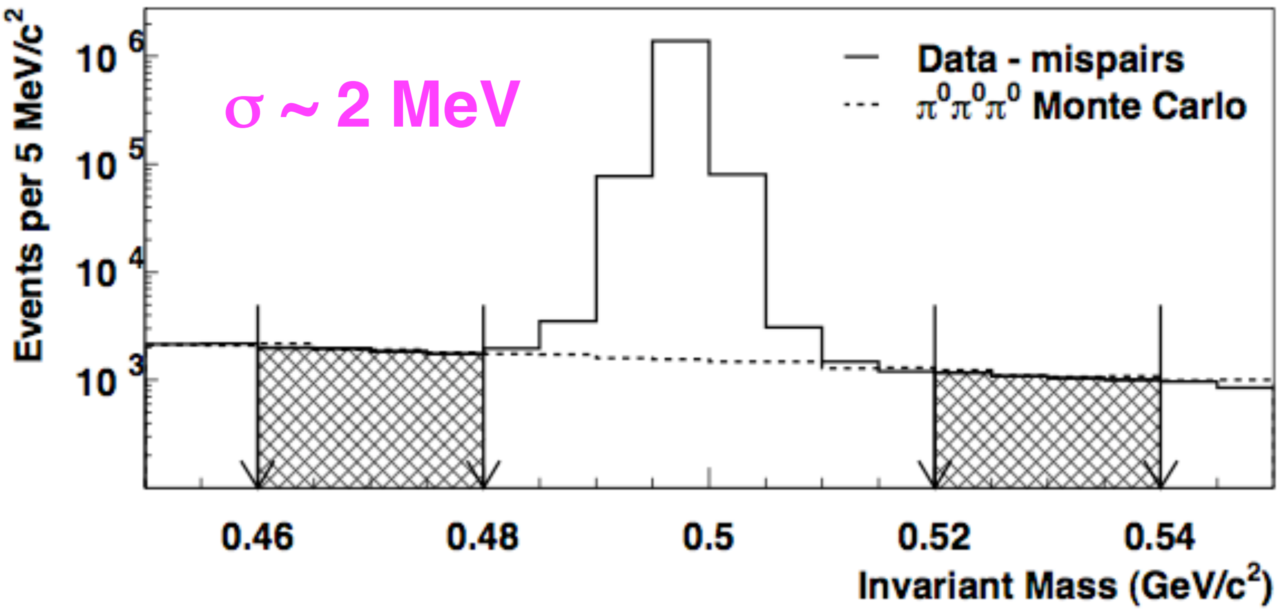
E391a set a 90% C.L. limit on $Br(K_L \to \pi^0\pi^0 X^0;\ X^0 \to \gamma\gamma) < 2.4 \times 10^{-7}$

The KTeV Detector





The KTeV Detector



E.T.Worcester Thesis

Pure CsI calorimeter: Energy resolution < 1% for > 10GeV γ
Position resolution ~ 1mm for $e^{\pm}$

Muon system: Total thickness 5.1m of steel ~ 31 λ_I
Efficiency > 98% for > 10 GeV $\mu^{\pm}$
$\pi^{\pm}$ punchthrough probability ~ (1.69 + 0.17P [GeV]) / 1000

The KTeV Detector

KTeV actually was 2 experiments:

- E832 - precision measurement of $\Re(\varepsilon'/\varepsilon)$
- E799 - kaon rare decay program

Data taken 1996-1997, 1999-2000

E799 configuration collected 733 x10^9 K_L decays

Previous KTeV Dimuon Results:

$Br(K_L \rightarrow \mu^+\mu^-\gamma) = (3.62 \pm 0.04_{STAT} \pm 0.08_{SYST}) \times 10^{-7}$ 9327 events

PRL 87, 071801 (2001)

$Br(K_L \rightarrow e^+e^-\mu^+\mu^-) = (2.69 \pm 0.24_{STAT} \pm 0.12_{SYST}) \times 10^{-9}$ 132 events

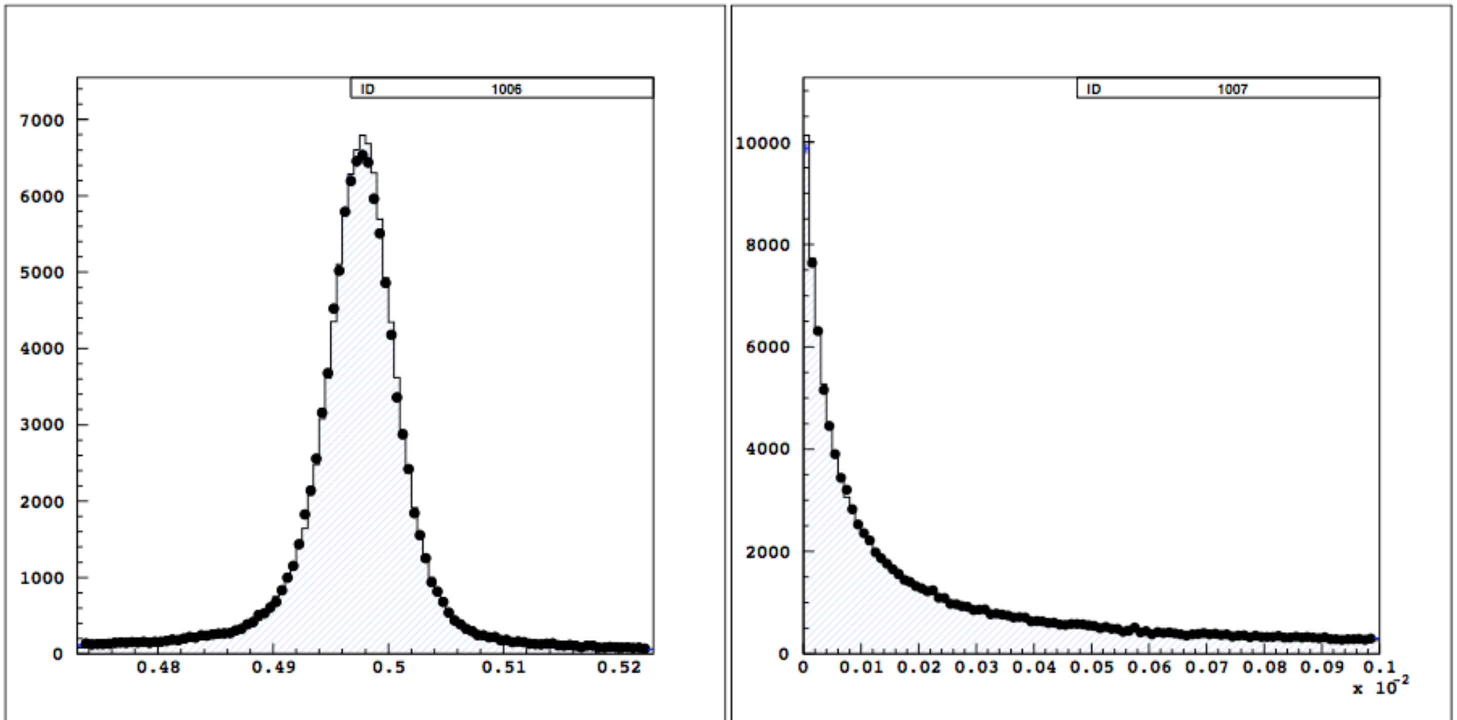
PRL 90, 141801 (2003)

$Br(K_L \rightarrow \pi^0\mu^+\mu^-) < 3.8 \times 10^{-10}$ 2 events

PRL 84,5279 (2000)

733 x10^9 K_L decays

We measure the number of $K_L \to \pi^0\pi^0\pi^0$; $\pi^0 \to \gamma e^+e^-$
A mode of similar signature and the *Br*s are known



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

1997 $\pi^0\pi^0\pi^0_D$ P_T^2

● = Data

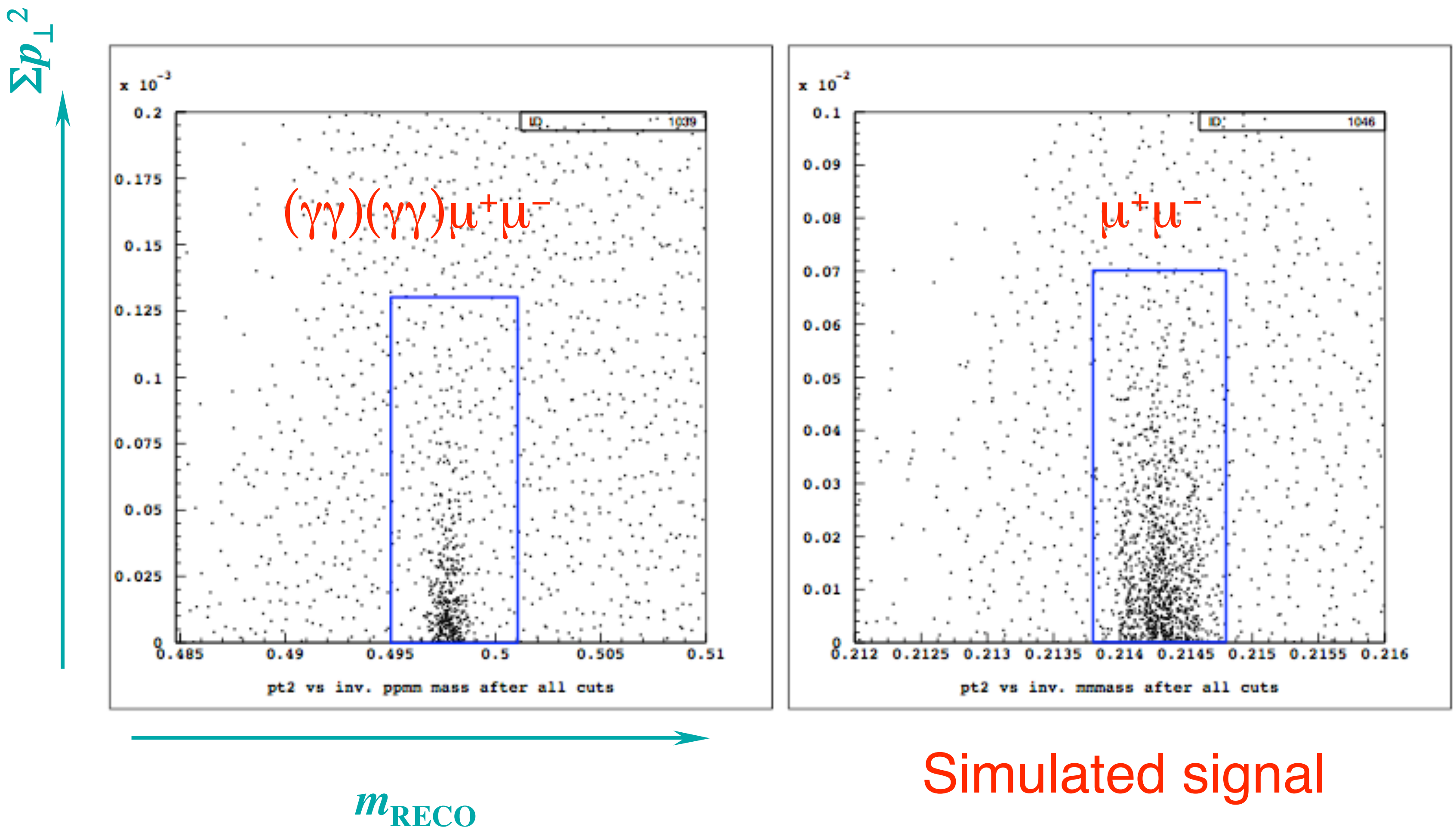
□ = MC

Signal Characteristics

$\pi^0 \rightarrow \gamma\gamma$	4 CsI clusters without matching tracks
μ + matter $\rightarrow$ ions	2 opposite-sign tracks with hits in μ system and > 7 GeV
μ + CsI $\rightarrow$ not much	CsI cluster matching track has $E < 1$ GeV
All decay products reconstructed	Sum of momenta $\perp$ to K line of flight $< \sqrt{0.001}$ GeV
$m(K_L) - 2m(\pi^0) > m(\mu\mu)$	$m(\mu\mu) < 232$ MeV
π^0 and μ pair originate at K_L decay point	$m(\pi^0)$ within 9 MeV

Signal Boxes

Two boxes to open… one for the K_L and one for the X^0



Simulated signal

Signal Sensitivity

1997 Acceptance ($K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$) = $(3.14 \pm 0.004_{stat.})\%$
[flat phase space]

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

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

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

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

1999 Acceptance ($K_L \rightarrow \pi^0\pi^0\pi^0_D$) = $(1.29 \pm 0.003_{stat.}) \times 10^{-4}$

A single detected signal event corresponds to a *Br* of 4.1×10^{-11}

Backgrounds

An obvious background is $K_L \rightarrow \pi^{\mp}\pi^0\mu^{\pm}\nu$

→ decays to μ in flight
punches through steel

Br ~ 5.9 x10^{-5}

Intensity of beam means particles from a 2nd decay in beam can occur coincidentally with a K_L decay e.g. $K_L \rightarrow \pi^+\pi^-\gamma$ - so called accidentals

Frequently reconstruct to incorrectly high K_L masses (unless also a K_L decay product escaped detection)

We attempted a background estimate by method of MC simulation of all the backgrounds we could think of

Backgrounds

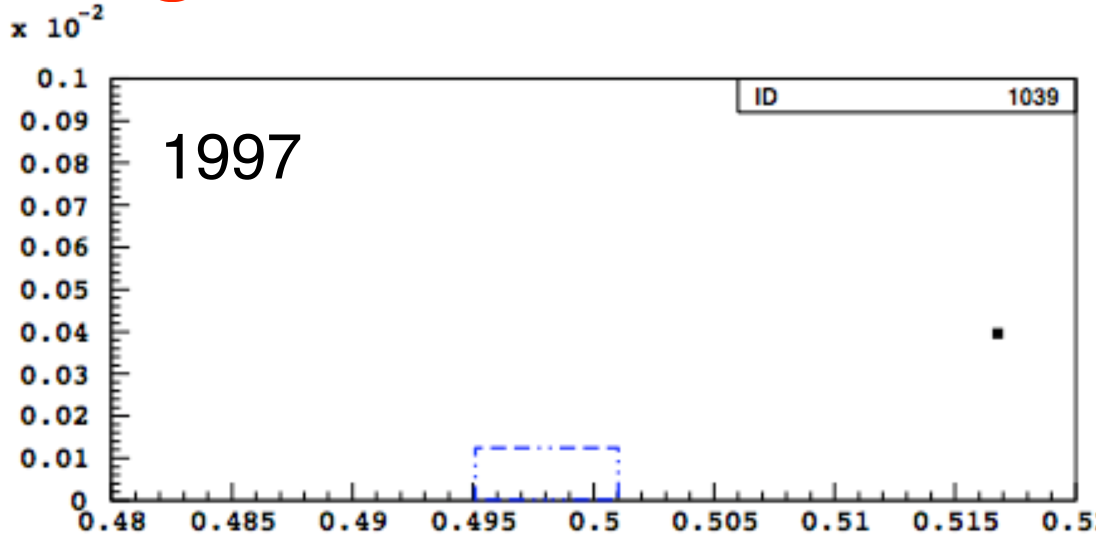
Decay Mode	# '97 MC events generated	# '99 MC events generated
$K^0_{\mu 3}$ (punch through)	~ 2.6 Billion (0.039 *f*)	1,752,020,868 (0.027 *f*)
$K^0_{\mu 3}$ (pion decay = $\pi^{+-} \to \mu^{+-} \nu_\mu$)	244,692,689 (0.0037 *f*)	421,656,663 (0.0064 *f*)
$K^0_{\mu 4}$ (punch through)	120,066,571 (8.38 *f*)	96,372,292 (6.72 *f*)
$K^0_{\mu 4}$ (pion decay) *	93,373,819 (6.51 *f*)	109,831,267 (7.66 *f*)
$K_L \to \pi^+\pi^-\pi^0$ (2x punch through)	1,848,796,492 (0.060 *f*)	1,062,004,339 (0.035 *f*)
$K_L \to \pi^+\pi^-\pi^0$ (2x pion decay)	85,552,978 (0.0028 *f*)	106,912,811 (0.0035 *f*)
$K_L \to \pi^+\pi^-\pi^0$ (punch & decay)	455,374,316 (0.015 *f*)	456,480,690 (0.015 *f*)
$K_L \to \pi^+\pi^-\gamma$ (2x punch through)	15,034,557 (1.41 *f*)	21,646,250 (2.03 *f*)
$K_L \to \pi^+\pi^-\gamma$ (2x pion decay)	20,304,857 (1.90 *f*)	16,311,114 (1.53 *f*)
$K_L \to \pi^+\pi^-\gamma$ (punch & decay)	14,249,908 (1.34 *f*)	14,495,323 (1.36 *f*)
$K_L \to \pi^+\pi^-$ (2x punch through)	683,676,428 (1.35 *f*)	671,923,195 (1.32 *f*)
$K_L \to \pi^+\pi^-$ (2x pion decay)	8,529,573 (0.017 *f*)	21,840,183 (0.044 *f*)
$K_L \to \pi^+\pi^-$ (punch & decay)	50,306,906 (0.100 *f*)	26,557,616 (0.053 *f*)
$K_L \to \mu^+\mu^-$	1,183,635 (670.0 *f*)	5,240,705 (2967 *f*)
$K_L \to \mu^+\mu^-\gamma$	9,582,978 (109.8 *f*)	119,650,358 (1372 *f*)
$K_L \to \mu^+\mu^-\gamma\gamma$	10,869,003 (4473 *f*)	48,801,465 (20084 *f*)
$K_L \to \pi^0\mu^+\mu^-$	11,042,193	13,008,645 [1]

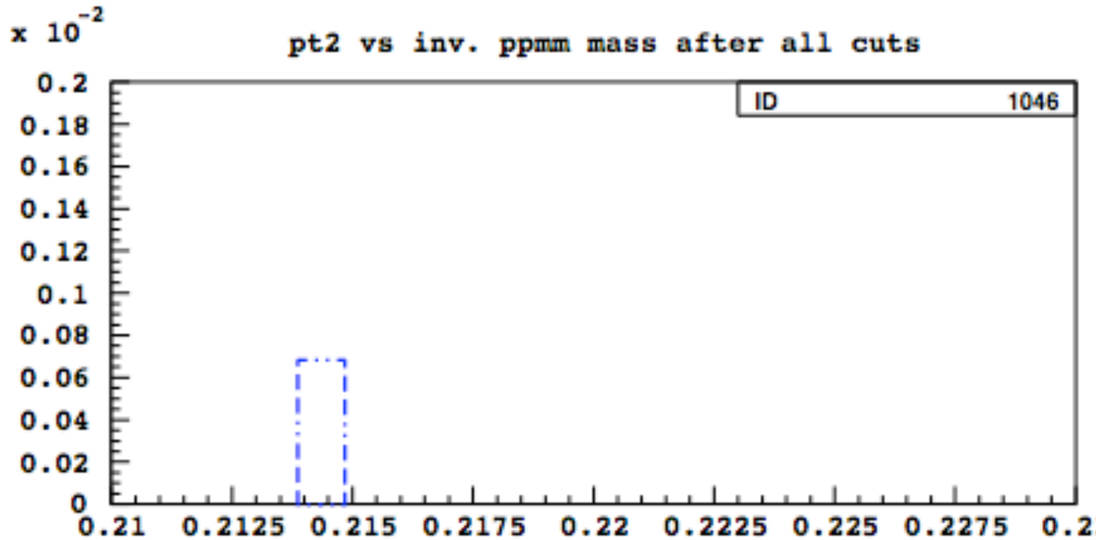
Not one of these events passed event selection

Backgrounds

Not a lot of background in the data either

3 events that all look like accidentals

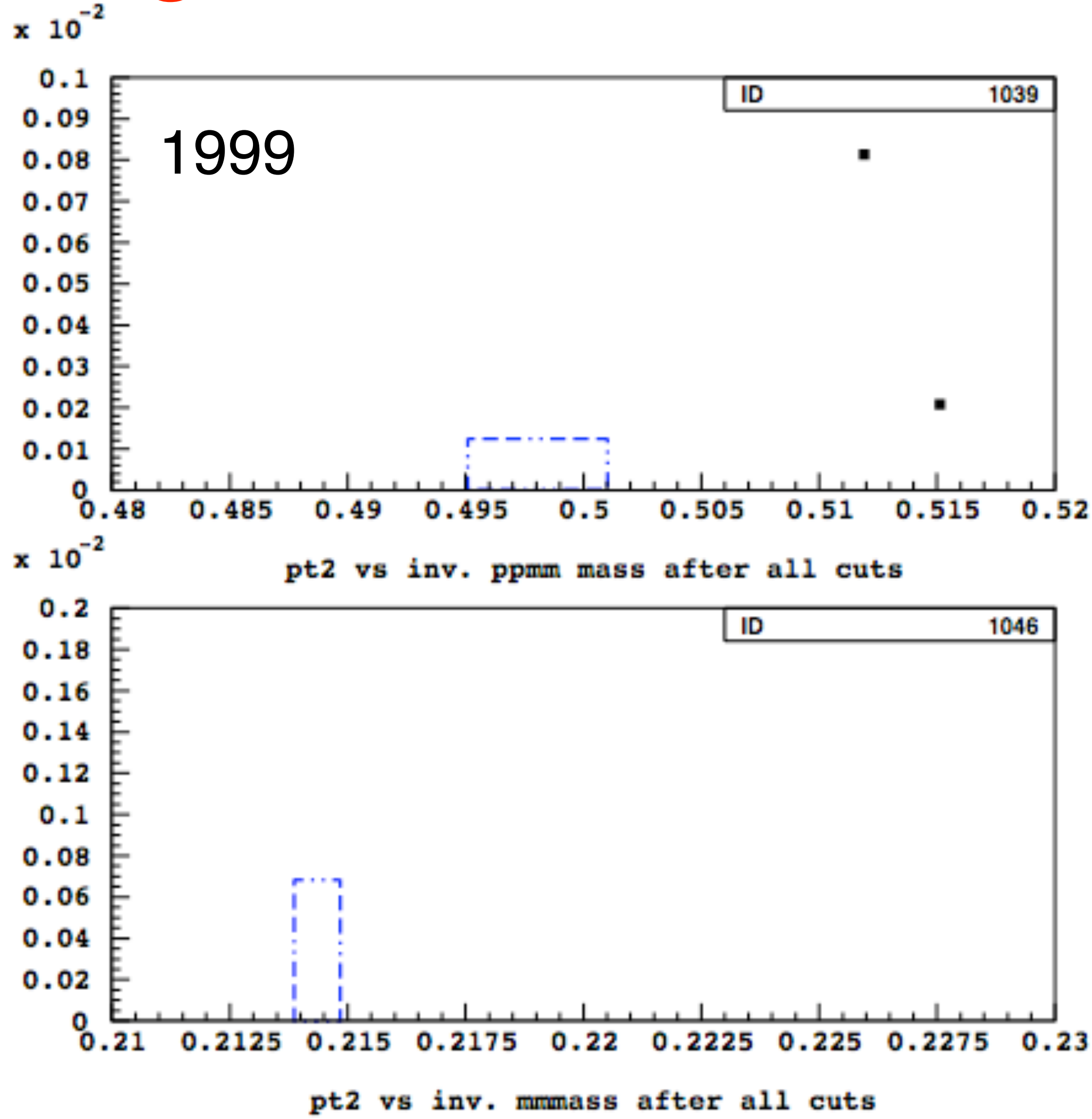




Backgrounds

Assume no background at all

not subtracting background is more conservative than doing the subtraction



Systematic Uncertainties

Source of Systematic Error	$\frac{\Delta F_{Norm,1997}}{F_{Norm,1997}}$	$\frac{\Delta F_{Norm,1999}}{F_{Norm,1999}}$
(473 ∓ 1) MeV $\leq M_{ee\gamma\gamma\gamma\gamma} \leq (523 \pm 1)$ MeV	+0.04% -0.05%	+0.05% -0.06%
$\lvert M_{rec,pi0} - M_{pi0} \rvert \leq (14 \pm 1)$ MeV	+0.02% -0.03%	+0.02% +0.01%
(94.0 ∓ 1.0) m $\leq Z_{VTX} \leq (158.0 \pm 1.0)$ m	+0.16% +0.02%	+0.20% -0.10%
$P_T^2 \leq (1.0 \pm 0.1) * 10^{-3}$ GeV^2	+0.11% +0.02%	+0.06% -0.08%
$(0.95 \mp 0.1) \leq E_{cl}$(track) / $p_{track} \leq (1.05 \pm 0.1)$	+1.24% -2.41%	+2.23% -4.05%
P_z Weighting	-------	1.87%
Cracks in μ Counting Planes	0.50%	0.50%
Energy Loss in μ Filters	0.40%	0.40%
$Br(K_L \rightarrow \pi^0\pi^0\pi^0)$	0.61%	0.61%
Total Systematic Error from Flux	+1.54% - 2.57%	+3.05% - 4.55%

Preliminary!

Result

There were no events in the signal boxes when opened

At 90% C.L. $Br < 2.30\left(1+\frac{2.30}{2}\left[\frac{\sigma_R(SES^{-1})}{SES^{-1}}\right]^2\right)\bullet SES$

Preliminary!!!

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

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

Conclusions

The 90% C.L. upper limit on $Br(K_L \to \pi^0\pi^0X^0 \to \pi^0\pi^0\mu^+\mu^-)$ is about 80 times the *Br* that would obtain if the *HyperCP* result were due to new pseudoscalar couplings

The 90% C.L. upper limit on $Br(K_L \to \pi^0\pi^0X^0 \to \pi^0\pi^0\mu^+\mu^-)$ is only a little below the *Br* that would obtain if the *HyperCP* result were due to new axial-vector couplings
This must still be regarded as possible

The possibility that the *HyperCP* result is due to new tensor couplings remains to be examined

The transition Dave Phillips → Dr. David Phillips has also been observed