
# Rare Kaon Decays

The Good, The Bad, The Ugly

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George Redlinger
Brookhaven National Laboratory

- Introduction
- Results from the past $\sim 2$ years (after PDG02) where "rare" means $< \mathcal{O}(10^{-7})$
- Outlook

# Big Picture

Wilczek (hep-ph/0401126):

> "Our current, working description of fundamental physics is based on three conceptual systems... it is not inappropriate to call them the Good, the Bad, and the Ugly"

- The Good: the gauge sector
  - Deep principles of symmetry and locality
  - Spectacular experimental success: e.g. precision electroweak/QCD tests
  - Powerful concepts for extension: quark-lepton unification, supersymmetry.
- The Bad: gravity
  - General relativity: powerful theory based on small set of concepts, valid up to Planck scale
  - Vacuum energy problem: $\sim 100$ orders of magnitude discrepancy
- The Ugly: the flavor sector
  - Many parameters! No deep principle which constrains Higgs Yukawa couplings
  - "Whether measured by the large number of independent parameters or by the small number of powerful ideas it contains, our theoretical description of this sector does not attain the same level as we've reached in the other sectors."

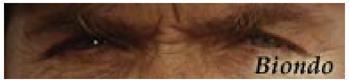
# Role of Rare Kaon Decays

Experiment is a big driving force in the flavor sector. Kaon decays have had a glorious history of elucidating this physics, and continue to serve as sensitive probes.

This talk covers progress in rare kaon decay experiments in the last $\sim 2$ years:

- The Good
  - Study of signatures explicitly beyond the Std Model. Most well-known are lepton flavor violating decays, but also includes other exotic decays like $K^+ \to \pi^+ X^0$.
  - Studies of quark-mixing parameters (including CP violating phase) with small theoretical uncertainty. Sensitivity to BSM physics.
- The Bad
  - Studies of low energy behavior of strong interactions. Not “bad” in itself, but not directly connected to studying the flavor sector. In some cases “bad” modes give rise to serious backgrounds to other modes.
- The Ugly
  - Decay modes that potentially probe quark-mixing, CP violation and BSM physics but which do not lend themselves to clean extraction of the fundamental parameters.

(All limits in this talk are at 90% CL)



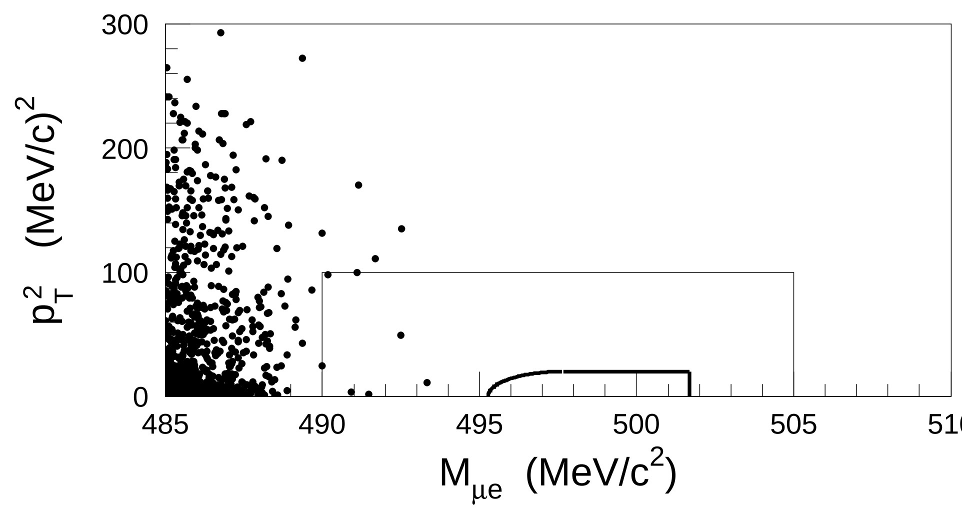

# Lepton Flavor Violation

State of the art set by BNL E871, E865

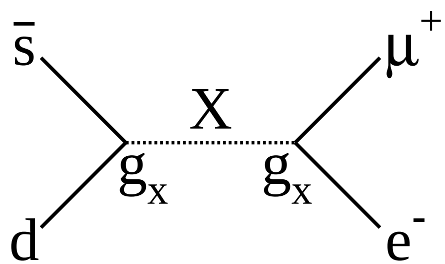
$K_L \rightarrow \mu^{\pm}e^{\mp}$ (parity odd couplings):

- Pioneered 'blind analysis' technique in rare decay searches
- Expected bkg: 0.1 event. Main source: $K_L \rightarrow \pi^{\pm}e^{\mp}\nu$ with upstream $\pi$ decay + e scatter in vacuum window or first tracking chamber.
- BR($K_L \rightarrow \mu^{\pm}e^{\mp}$) $< 4.7 \times 10^{-12}$ (PRL81,1988)

$K_L \rightarrow \mu^{\pm}e^{\mp}$. BNL E871 (1995+1996)




Dimensional analysis:

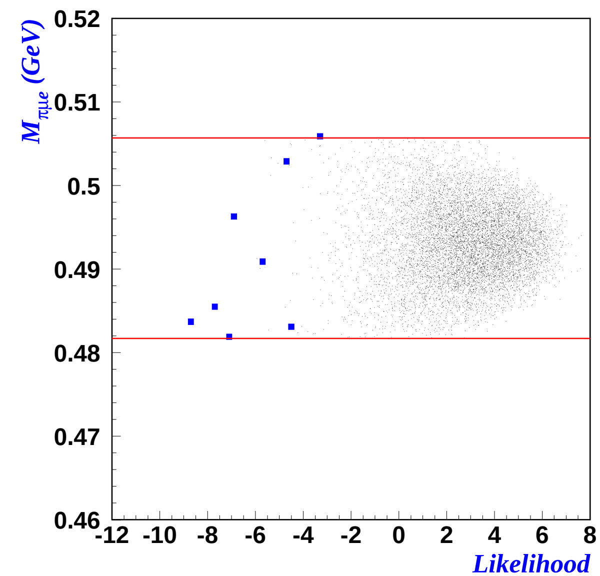



B($K_L \rightarrow \mu^{\pm}e^{\mp}$) $\sim (\frac{220TeV}{M_X})^4 \times 10^{-12}$
(for EWK coupling strength)

# Lepton Flavor Violation. Recent results

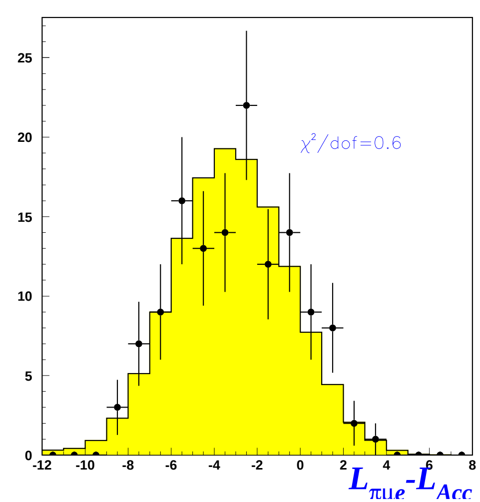
BNL E865 has completed analysis of 1995-1998 data on $K^+ \to \pi^+ \mu^+ e^-$(parity even couplings).

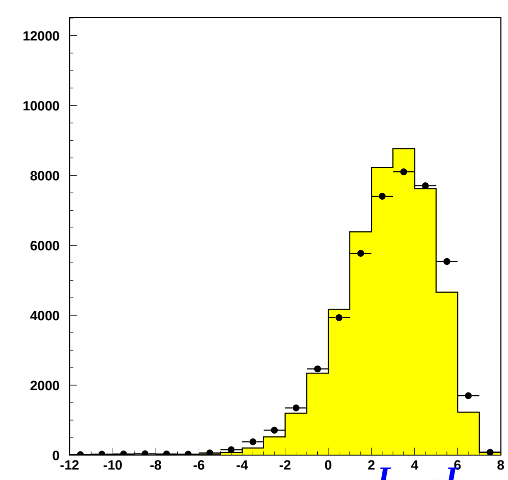
BNL E865. $K^+ \to \pi^+ \mu^+ e^-$ (98 data)




- Dominant background: multiple $K^+$ decays
- Estimate from time sidebands, projecting into signal region from high $p_K$ region: $8.2 \pm 1.9$ events
- Likelihood analysis in the signal region to get the BR

| Data | BR limit |
|---|---|
| 1998 | $< 2.2 \times 10^{-11}$ |
| 95+96+E777 | $< 2.8 \times 10^{-11}$ |
| Combined | $< 1.2 \times 10^{-11}$ |

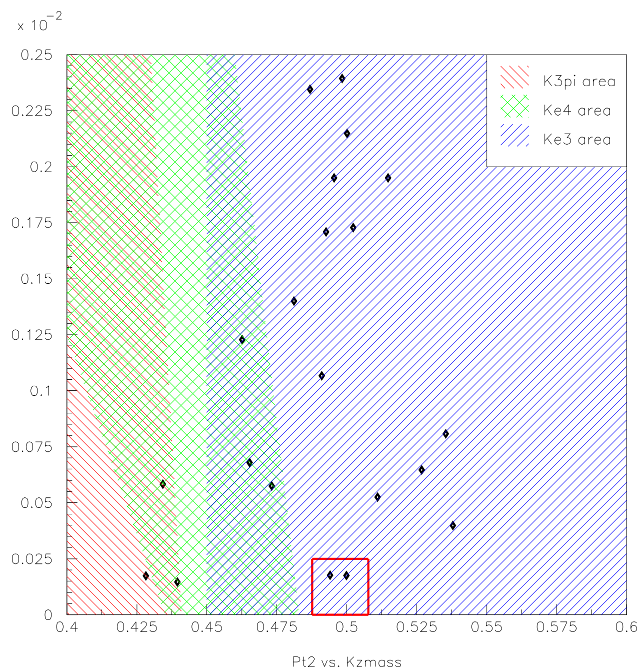


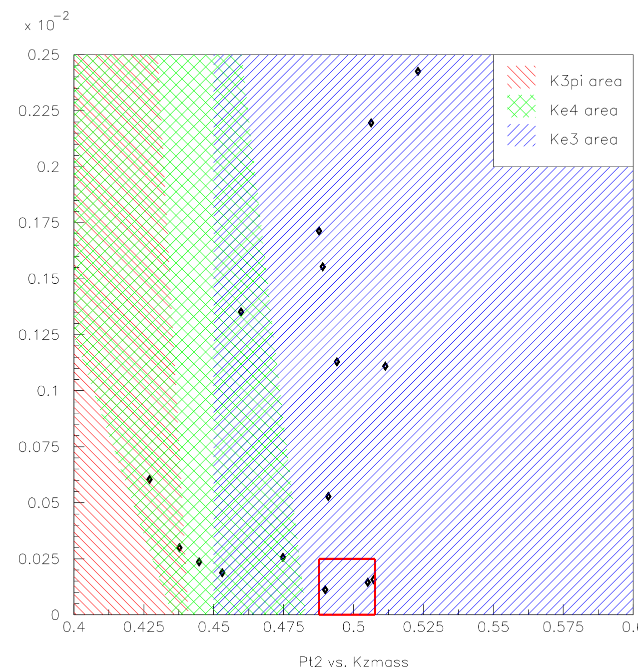
# Lepton Flavor Violation. Recent results

- KTeV $K_L \to \pi^0 \mu^\pm e^\mp$ analysis is not complete, but results from both 1997 and 1999 datasets have been shown (e.g. BNL May 04).
- For a given $M_X$, $K_L$ BR is higher by factor of $\frac{\tau_L}{\tau^+} \simeq 4$ compared to $K^+$.

KTeV 1997




KTeV 1999

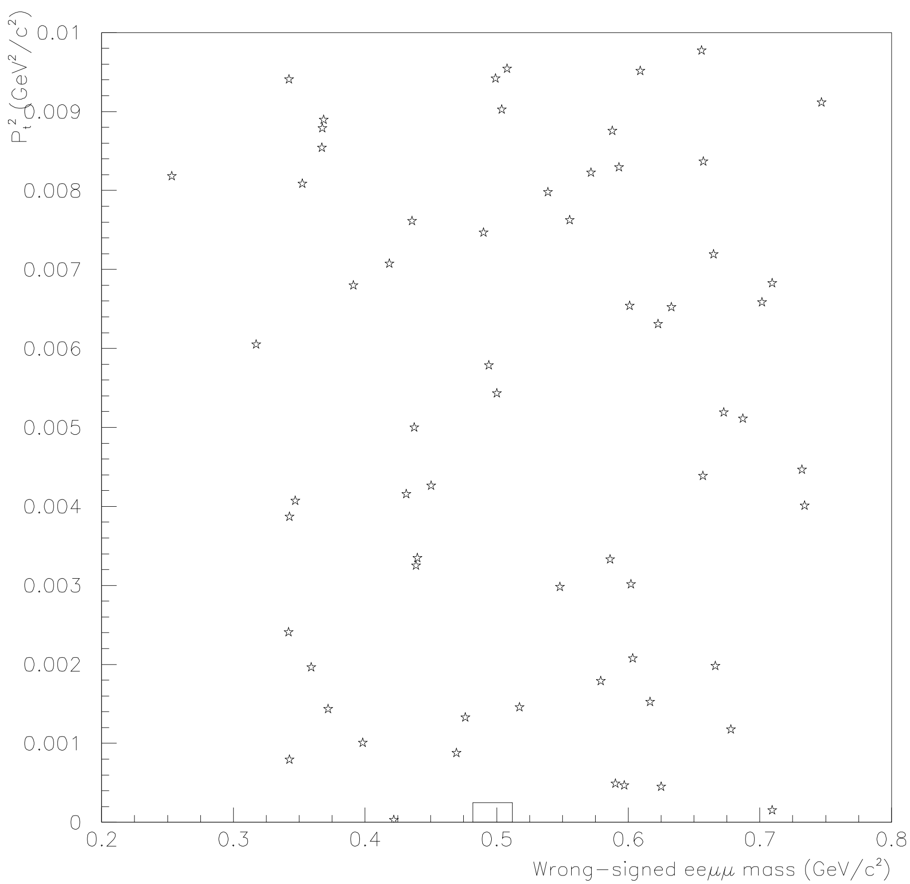



| Year | Est. Bkg | # evts seen |
|---|---|---|
| 1997 | $0.53 \pm 0.14$ | 2 |
| 1999 | $0.48 \pm 0.14$ | 3 |

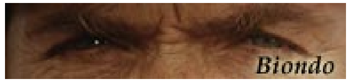
- Candidates do not look signal-like based on a likelihood variable
- Nevertheless, treating 5 events as signal, BR($K_L \to \pi^0 \mu^\pm e^\mp$) < $3.31 \times 10^{-10}$

# Lepton Flavor Violation. Recent results

KTeV $K_L \rightarrow e^{\pm}e^{\pm}\mu^{\mp}\mu^{\mp}$ (97+99 data). Byproduct of the $K_L \rightarrow e^{+}e^{-}\mu^{+}\mu^{-}$ analysis




- Lepton-number violating in addition to LFV
- Bkg from 2 $K_L$ semileptonic decays $= 0.08 \pm 0.01$
- BR($K_L \rightarrow e^{\pm}e^{\pm}\mu^{\mp}\mu^{\mp}$) $< 4.12 \times 10^{-11}$. Factor 3 improvement over PDG02.

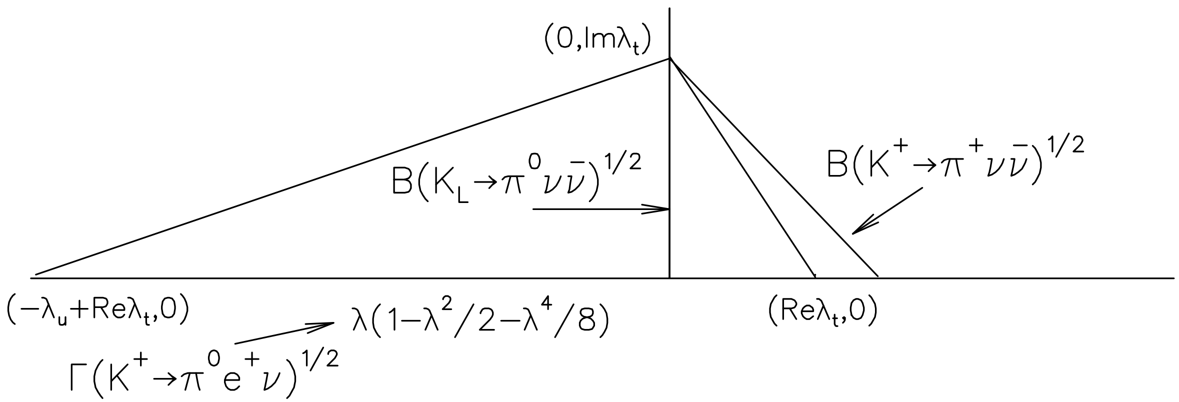



# Quark Mixing. $K \to \pi\nu\overline{\nu}$

The kaon unitarity triangle:

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

$$\text{or } \lambda_{\rm u} + \lambda_{\rm c} + \lambda_{\rm t} = 0$$




- $K \to \pi\nu\overline{\nu}$ and $K^+ \to \pi^0 e^+ \nu$ decays completely determine the UT.
- $K_L \to \pi^0\nu\overline{\nu}$ provides direct measurement of triangle area ($J_{CP}$, “the price of CP violation” in the quark sector). Theoretical uncertainty on BR $\sim 2\%$.
- $K^+ \to \pi^+\nu\overline{\nu}$ probes both real and imaginary parts of $\lambda_t$. BR uncertainty (theor) $\sim 7\%$.
- Comparison with UT determination from B sector will be a powerful tool to try to unravel the flavor dynamics

# $K^+ \to \pi^+\nu\overline{\nu}$. Recent developments

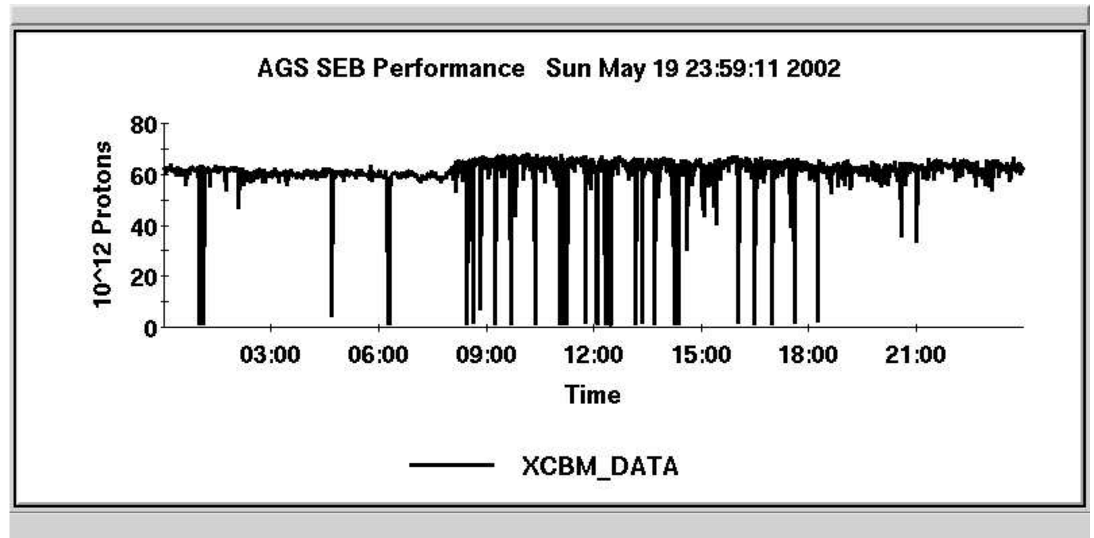
- BNL E787 (1995-98) observed 2 $K^+ \to \pi^+\nu\overline{\nu}$ candidates with a background of $0.15 \pm 0.05$ events
- Likelihood analysis based on additional signal/bkg discrimination yielded:
  - Probability of bkg alone giving rise to these 2 (or “cleaner”) events = 0.0014.
  - BR($K^+ \to \pi^+\nu\overline{\nu}$) = $1.57^{+1.75}_{-0.82} \times 10^{-10}$.
- E787 was primarily limited by proton flux from AGS on K production target.
- E949 is based on “modest” upgrades to the E787 program.
  - Use “entire” proton flux. $15 \times 10^{12}$ p/spill $\to 65 \times 10^{12}$
  - Longer AGS running during RHIC operation ($\geq 25$ weeks/yr)
  - Detector upgrades: photon veto, $\pi^+$ tracking and kinematic resolution, trigger/DAQ, $K^+$ tracking system
- Aimed at SES$\leq 10^{-11}$ or 5-10 SM events
- Detailed presentation of recent E949 results: T. Sekiguchi talk

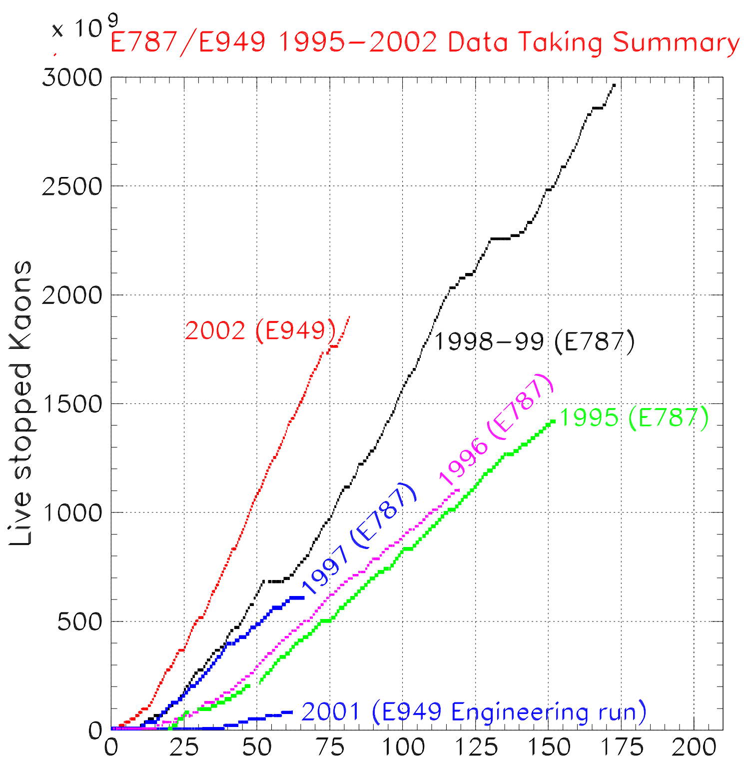
# BNL E949: Beam

Proton intensity:

- $76 \times 10^{12}$/spill (peak)
- $65 \times 10^{12}$/spill (typical)

E949 (2002) protons on target (typical day)

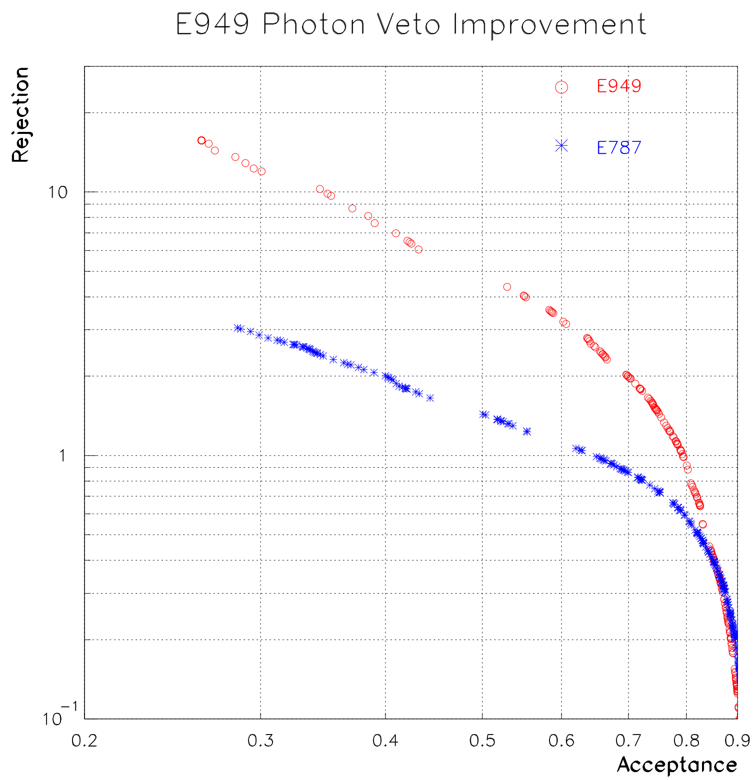


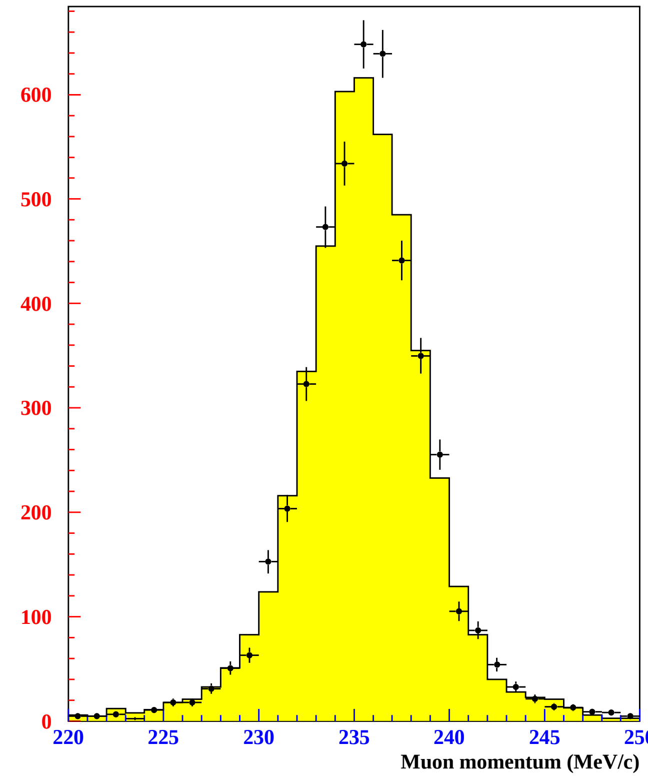

Not optimal in 2002:

- Short run (see plot at left)
- AGS main power supply problem. Lower proton momentum $\Rightarrow\sim 10\%$ loss in K flux. 20% worse duty factor compared to E787
- $K/\pi$ separator problems

# BNL E949: Detector upgrades



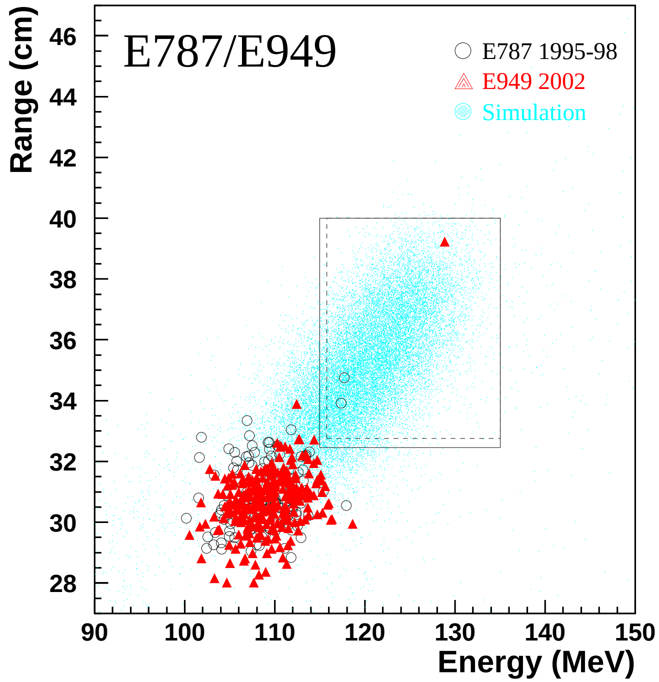

E949 momentum resolution




- Photon veto: $\times 2$ more rejection at nominal acceptance
- Comparable momentum resolution at $\times 2$ instantaneous rate

# $K^+ \to \pi^+ \nu\overline{\nu}$. Recent results

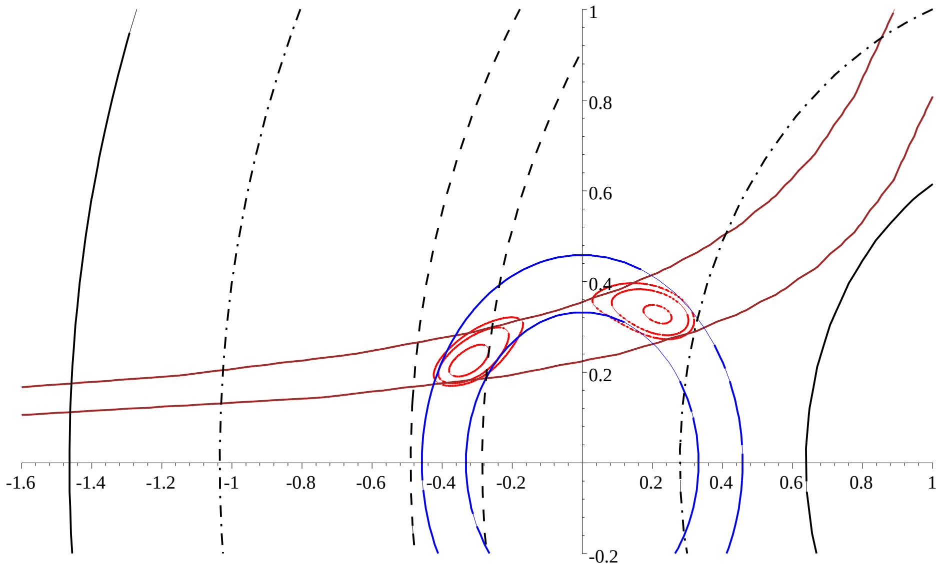
E949 (2002) + E787(95-98)




| | E787 | | E949 |
|---|---|---|---|
| $N_K$ | $5.9 \times 10^{12}$ | | $1.8 \times 10^{12}$ |
| Total Acceptance | $0.0020 \pm 0.0002$ | | $0.0022 \pm 0.0002$ |
| Total Background | $0.14 \pm 0.05$ | | $0.30 \pm 0.03$ |
| Candidate | 1995A | 1998C | 2002A |
| $S_i/b_i$ | 50 | 7 | 0.9 |
| $W_i$ | 0.98 | 0.88 | 0.48 |
| Background Prob. | 0.006 | 0.02 | 0.07 |

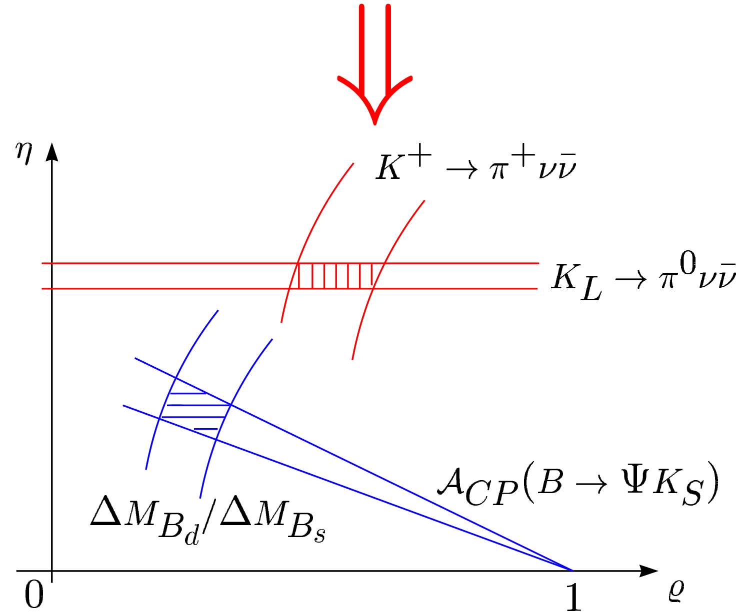
- BR($K^+ \to \pi^+ \nu\overline{\nu}$) = $(0.96^{+4.09}_{-0.47}) \times 10^{-10}$ (E949 alone)
- BR($K^+ \to \pi^+ \nu\overline{\nu}$) = $(1.47^{+1.30}_{-0.89}) \times 10^{-10}$ (E787+E949)
- Std Model expectation: BR($K^+ \to \pi^+ \nu\overline{\nu}$) = $(0.77 \pm 0.11) \times 10^{-10}$ (hep-ph/0307014)
- Backgrounds under good control, determined almost entirely from the data
- Ready/waiting to take more data (12 weeks in 2002; proposal: 60 weeks)

# $K^+ \to \pi^+ \nu\bar{\nu}$. Impact on unitarity triangle




(figure courtesy G. Isidori)

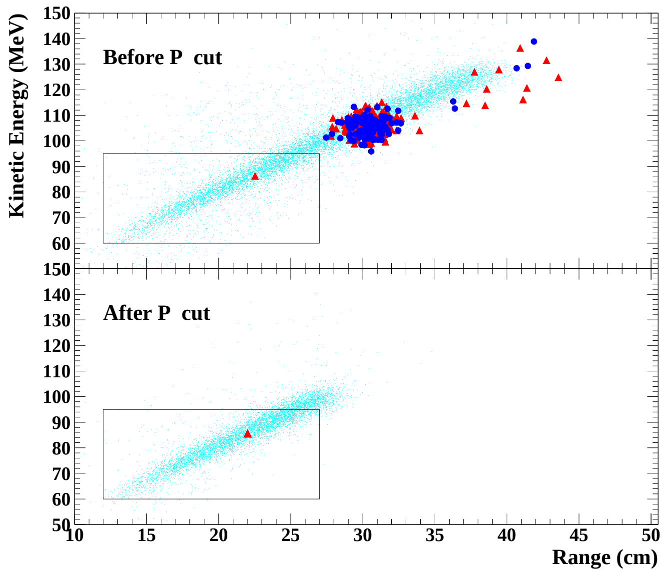
Perhaps one day?




- Remove B-mixing constraints from UT (assume new physics is present in B-mixing)
- Dark circles show constraints from BR($K^+ \to \pi^+ \nu\bar{\nu}$)
- Obviously needs more statistics

# $K^+ \to \pi^+\nu\overline{\nu}$. Recent results

New E787 result on kinematic region below $K^+ \to \pi^+\pi^0$ peak from analysis of 1997 data



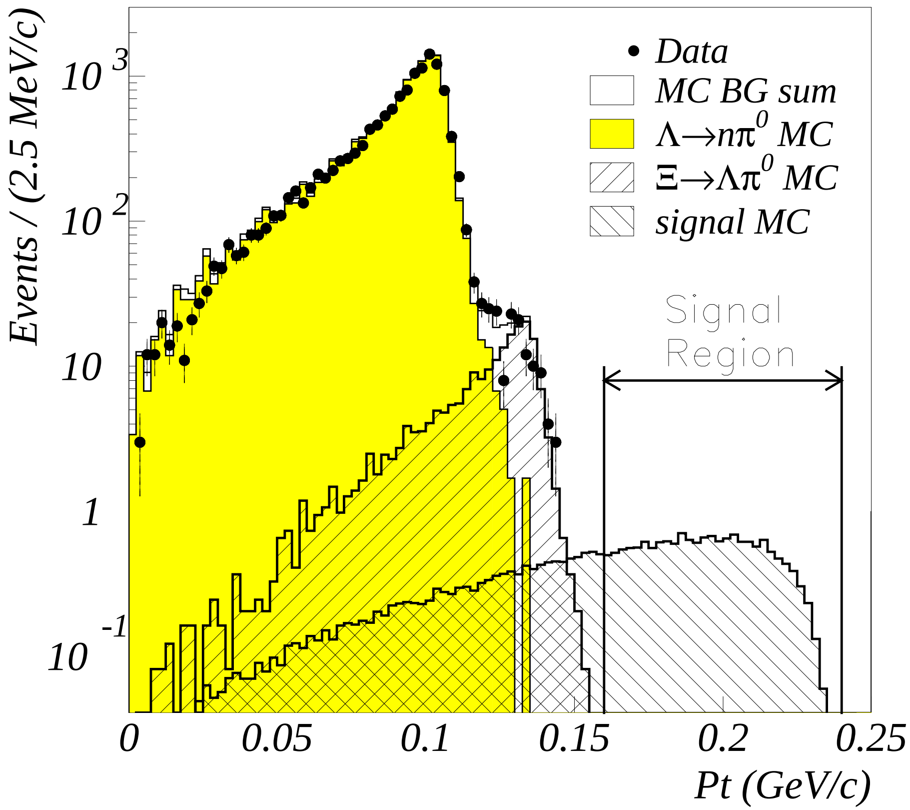

| | E787 (1996) | E787 (1997) |
|---|---|---|
| $N_K$ | $1.12 \times 10^{-12}$ | $0.61 \times 10^{-12}$ |
| Total Acceptance | $7.65 \times 10^{-4}$ | $9.7 \times 10^{-4}$ |
| Total Background | $0.73 \pm 0.18$ | $0.49 \pm 0.16$ |
| # events seen | 1 | 0 |

- E787(96+97): BR($K^+ \to \pi^+\nu\overline{\nu}$) $< 2.2 \times 10^{-9}$ ($p_\pi < 195$ MeV/c) $\Rightarrow \times 2$ improvement
- Backgrounds more difficult ($K^+ \to \pi^+\pi^0$ with $\pi^+$ scatter in K stopping target; $\pi^0$ heads towards region of weak photon coverage)
- Photon veto is improved in E949. Improvement in barrel region already demonstrated in analysis above $K^+ \to \pi^+\pi^0$ peak. Improvement in beam region (crucial for this analysis) remains to be seen. Other ideas to increase acceptance (or rejection) under study.

# $K_L \to \pi^0 \nu\overline{\nu}$

Best experimental limit so far comes from KTeV (1997) utilizing Dalitz decay of $\pi^0$

KTeV ($K_L \to \pi^0 \nu\overline{\nu}$, $\pi^0 \to \gamma e^+ e^-$)




- BR($K_L \to \pi^0 \nu\overline{\nu}$) < $5.9 \times 10^{-7}$
- KTeV also has a result from a one day run with $\pi^0 \to \gamma\gamma$: BR < $1.6 \times 10^{-6}$
- Grossman-Nir bound:

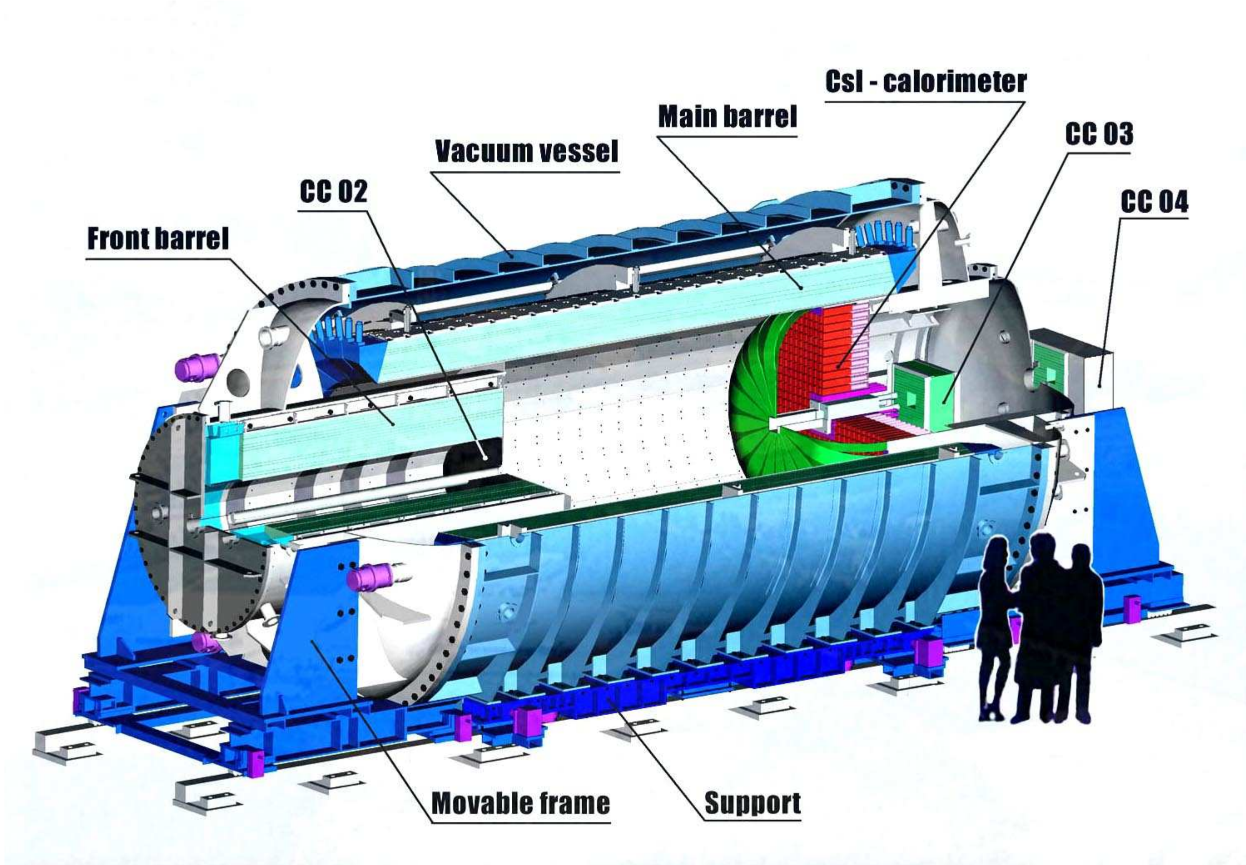
$$\frac{BR(K_L \to \pi^0 \nu\overline{\nu})}{BR(K^+ \to \pi^+ \nu\overline{\nu})} < \frac{\tau_{K_L}}{\tau K^+} \times \frac{1}{r_{is}} \sim 4.4$$

$$or\ BR(K_L \to \pi^0 \nu\overline{\nu}) < 1.4 \times 10^{-9}$$

- Std. Model expectation: $(0.26 \pm 0.05) \times 10^{-10}$ (hep-ph/0307014)

# $K_L \to \pi^0 \nu \overline{\nu}$. Recent progress

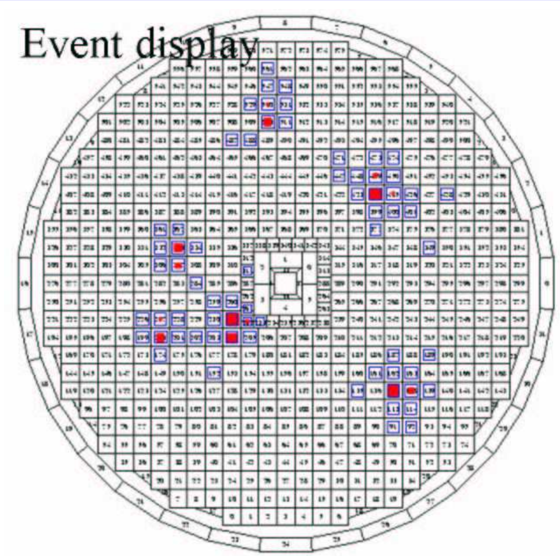
KEK E391a is the first dedicated experiment to search for $K_L \to \pi^0 \nu \overline{\nu}$.

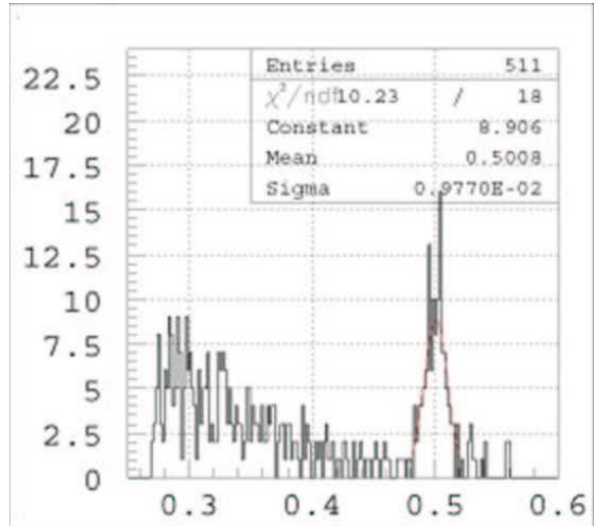



- “Pencil” beam, high acceptance.
- Running Now! since mid-February 2004 through June. Could reach SES $\sim 4 \times 10^{-10}$ (below Grossman-Nir bound) assuming very loose photon veto cuts.
- Prototype for future experiments at e.g. JPARC. Photon veto performance will be very interesting for e.g. KOPIO.

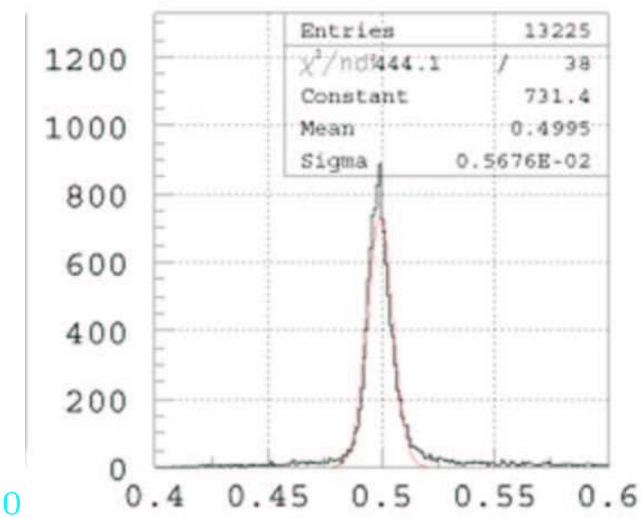
# E391a Data Taking (from 18 Feb 2004)

| | | E391a | E787 |
|---|---|---|---|
| Ev size | Bytes | 6K | 100K |
| | | ADCs | TDs |
| Tr rate | Hz | 500 | 100 |
| Data flow | B/spill | 6M | 10M |
| | B/Day | 120G | 240G |

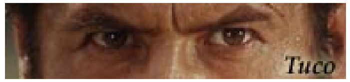


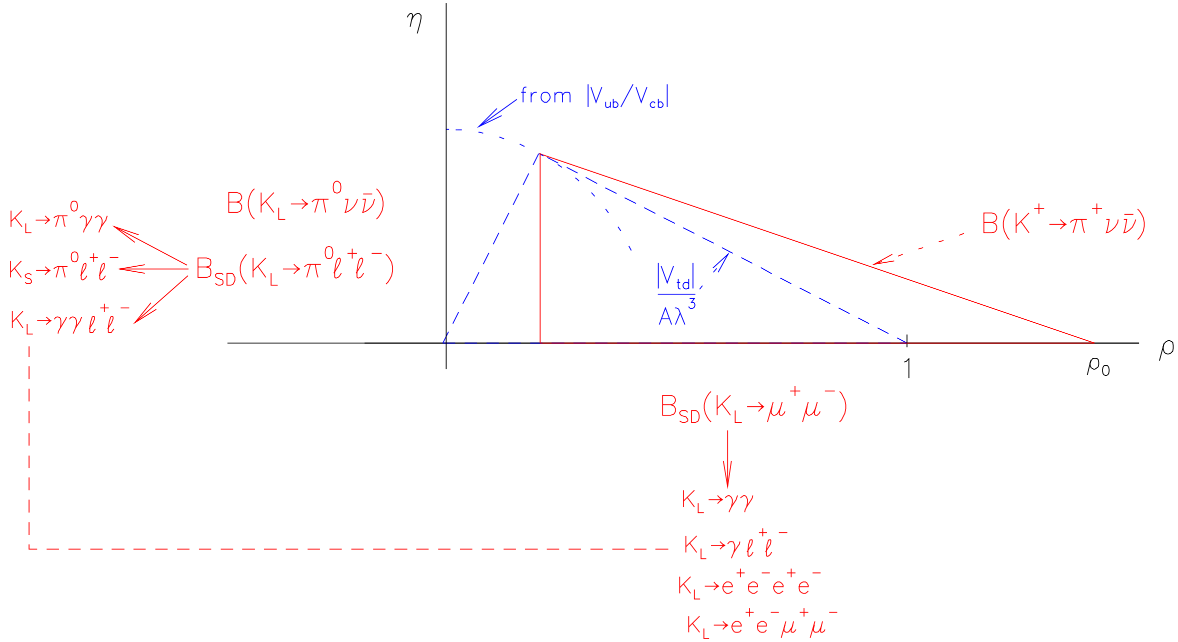

$K_L^0 \to \pi^0\pi^0$




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




# Other CKM modes




Relative contributions (Direct CPV=1)

| Mode | Indirect CPV | CP cons | Int |
|---|---|---|---|
| $\pi^0\nu\overline{\nu}$ | $10^{-2}$ | $\leq 10^{-4}$ | |
| $\pi^0 e^+e^-$ | 5.1 | $< 0.25$ | 2.3 |
| $\pi^0\mu^+\mu^-$ | 2.9 | 2.8 | 1.4 |

Buchalla, Isidori: hep-ph/9806501
Isidori, Smith, Unterdorfer: hep-ph/0404127

$$\mathcal{A}(K_L \to \mu^+\mu^-) \propto \mathcal{A}_{\gamma\gamma} + \mathrm{Re}(\mathcal{A}_{\mathrm{short}})$$

- BR($K_L \to \mu^+\mu^-$) = $(7.18 \pm 0.17) \times 10^{-9}$
- From BR($K_L \to \gamma\gamma$): contrib. of $|Im(\mathcal{A}_{\gamma\gamma})| = (7.07 \pm 0.18) \times 10^{-9}$
- Huge subtraction needed to get at $\mathcal{A}_{short}$

# $K_S \to \pi^0 e^+ e^-$. Recent results

$K_S \to \pi^0 l^+ l^-$ are crucial measurements for computing the contributions of indirect CPV and direct/indirect interference to $K_L \to \pi^0 l^+ l^-$. NA48/1 has recently made the first observation of both $K_S \to \pi^0 e^+ e^-$ and $K_S \to \pi^0 \mu^+ \mu^-$.

Main backgrounds

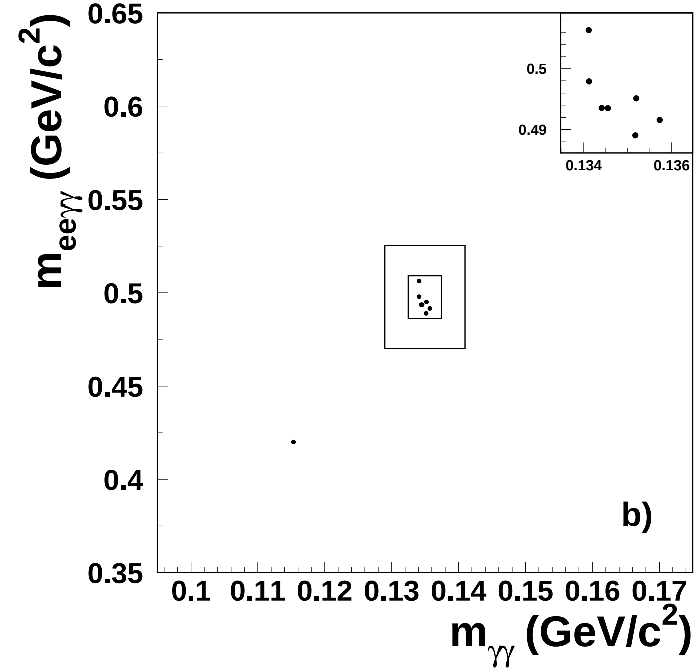
- $K_L \to e^+ e^- \gamma$: $0.08^{+0.03}_{-0.02}$
  Estimated with 2001 $K_L$ data
  ($\times 10$ statistics).
- Accidentals ($\pi^\pm e^\mp \nu + \pi^0$): $0.07^{+0.07}_{-0.03}$
  Estimated from timing sidebands.
- $K_S \to \pi^0_D \pi^0_D$: $< 0.01$
  Estimated from Monte Carlo.

Backgrounds verified in control region: 0.33 events expected, 0 seen

$K_S$ flux from $K_S \to \pi^0 \pi^0_D$: $(3.51 \pm 0.17) \times 10^{10} K_S$ decays

Acceptance from MC: $0.066 \pm 0.0004$

NA48/1 $K_S \to \pi^0 e^+ e^-$ (2002 data)




| BR($K_S \to \pi^0 e^+ e^-$) ($10^{-9}$) | |
|---|---|
| $(3.0\ ^{+1.5}_{-1.2} \pm 0.2)$ | $(m_{ee} > 165 MeV/c^2)$ |
| $(5.8\ ^{+2.8}_{-2.3} \pm 0.8)$ | vector M.E.,no form fact |

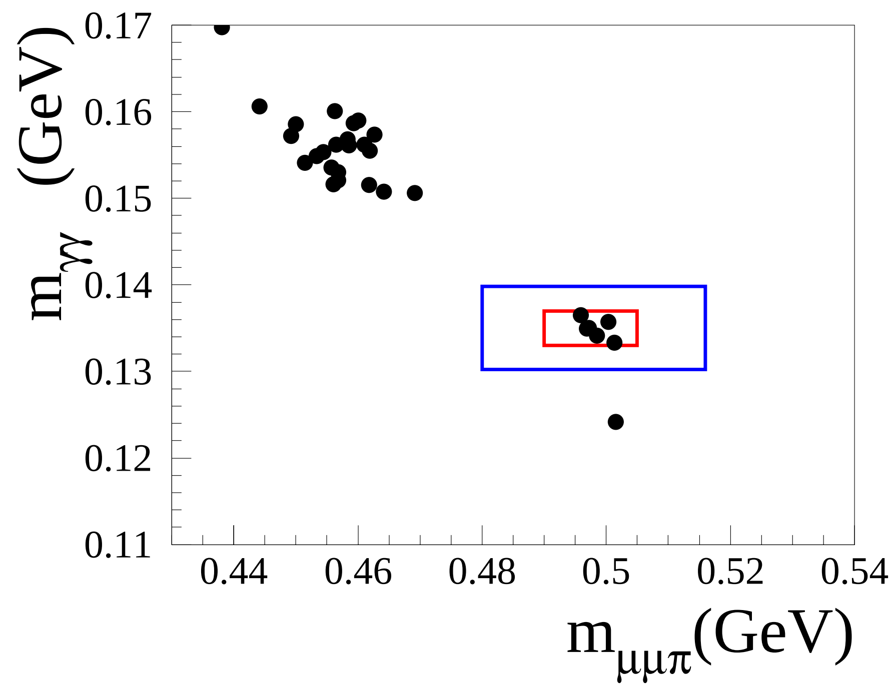
# $K_S \to \pi^0\mu^+\mu^-$. Recent results

NA48/1 $K_S \to \pi^0\mu^+\mu^-$ results have been shown e.g. at Moriond EWK 04

Main backgrounds:

- $K_L \to \mu^+\mu^-\gamma\gamma$: $0.04 \pm 0.04$
  Estimated by MC
- Accidentals
  ($\pi^\pm\mu^\mp\nu + \pi^0$ $or$ $\pi^+\pi^- + \pi^0$):
  $0.18^{+0.18}_{-0.11}$ from timing sidebands

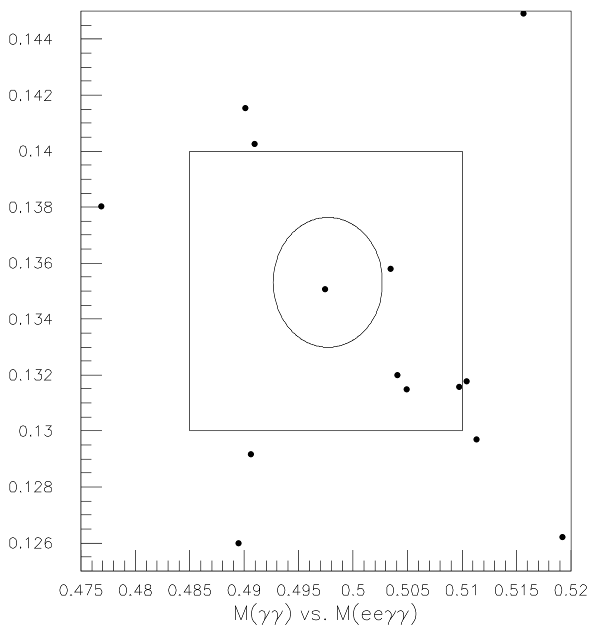
NA48/1 $K_S \to \pi^0\mu^+\mu^-$ (2002 data)




- 6 events seen
- BR($K_S \to \pi^0\mu^+\mu^-$) = $(2.9\ ^{+1.4}_{-1.2} \pm 0.2) \times 10^{-9}$ (vector matrix element, no form factor)

# $K_L \to \pi^0 e^+ e^-$. Recent results

KTeV $K_L \to \pi^0 e^+ e^-$(1999)




| | KTeV 1997 | KTeV 1999 |
|---|---|---|
| $N_K$ | $2.63 \times 10^{11}$ | $3.50 \times 10^{11}$ |
| Total Acc | $3.609 \pm 0.087$ | $2.749 \pm 0.013$ |
| Total Bkg | $1.06 \pm 0.41$ | $0.99 \pm 0.35$ |
| # events seen | 2 | 1 |
| BR($\pi^0 e^+ e^-$) | $< 5.1 \times 10^{-10}$ | $< 3.50 \times 10^{-10}$ |

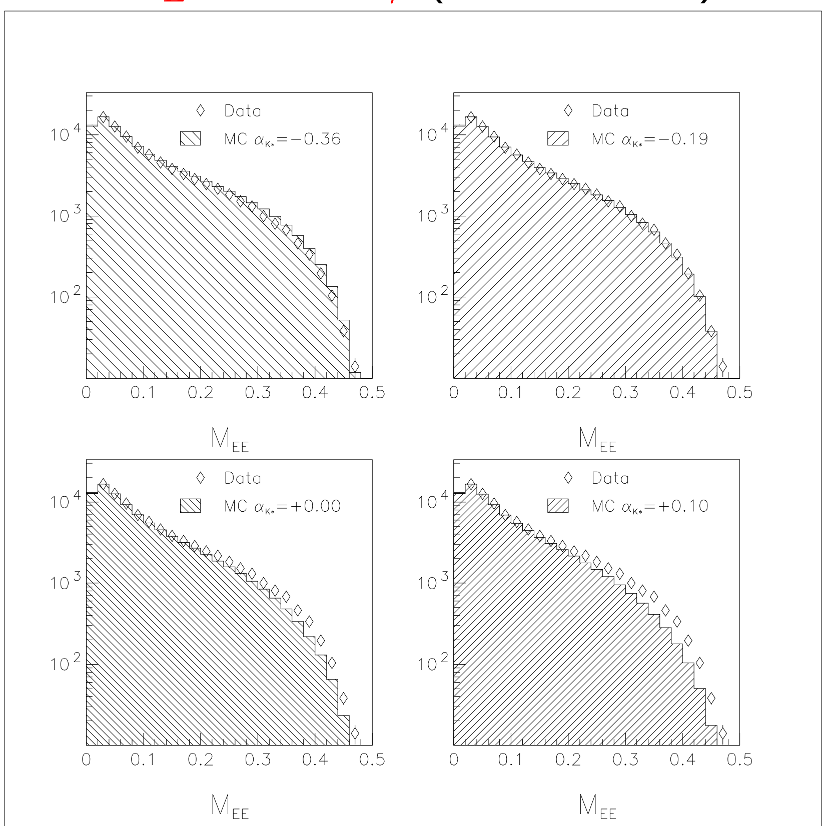
SM: BR($K_L \to \pi^0 e^+ e^-$) = $(3.7^{+1.1}_{-0.9}) \times 10^{-11}$ (hep-ph/0404127)

- KTeV(1997+1999): BR($K_L \to \pi^0 e^+ e^-$) $< 2.8 \times 10^{-10}$ (3-body phase space)
- Seems very difficult to beat down the $K_L \to e^+ e^- \gamma\gamma$ background. Tracking and calorimetry are already state of the art. High statistics + bkg subtraction?
- Interference analysis? (Buchalla, d'Ambrosio, Isidori: hep-ph/0308008)
- $K_L \to \pi^0 \mu^+ \mu^-$ has less severe background from $K_L \to \mu^+ \mu^- \gamma\gamma$, but BR is lower. Still awaiting KTeV result from analysis of 1999 data.

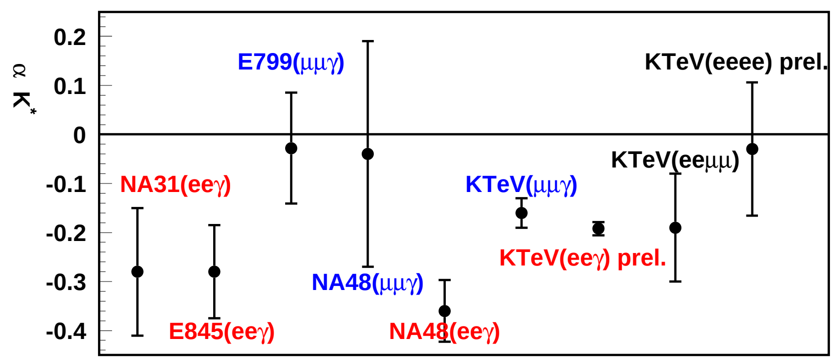
# $K_L$ Dalitz modes

- Study of $K_L \to \gamma\gamma^*$ and $K_L \to \gamma^*\gamma^*$ constrains Re$(\mathcal{A}_{\gamma\gamma})$, needed to extract short distance part of $K_L \to \mu^+\mu^-$.
- Two models available to parametrize the form factor:
  - BMS: $\alpha_{K^*}$
  - DIP: $\alpha_{DIP}, \beta_{DIP}$. (Experiments so far are not really sensitive to $\beta_{DIP}$.)
- $K_L$ decays to $e^+e^-\gamma,\ e^+e^-e^+e^-,\ \mu^+\mu^-\gamma,$ and $\mu^+\mu^-e^+e^-$ have been studied by KTeV. NA48 analysis on $ee\gamma$ and $eeee$ ongoing (98-99,2001 data).

KTeV $K_L \to e^+e^-\gamma$ (LaDue thesis)



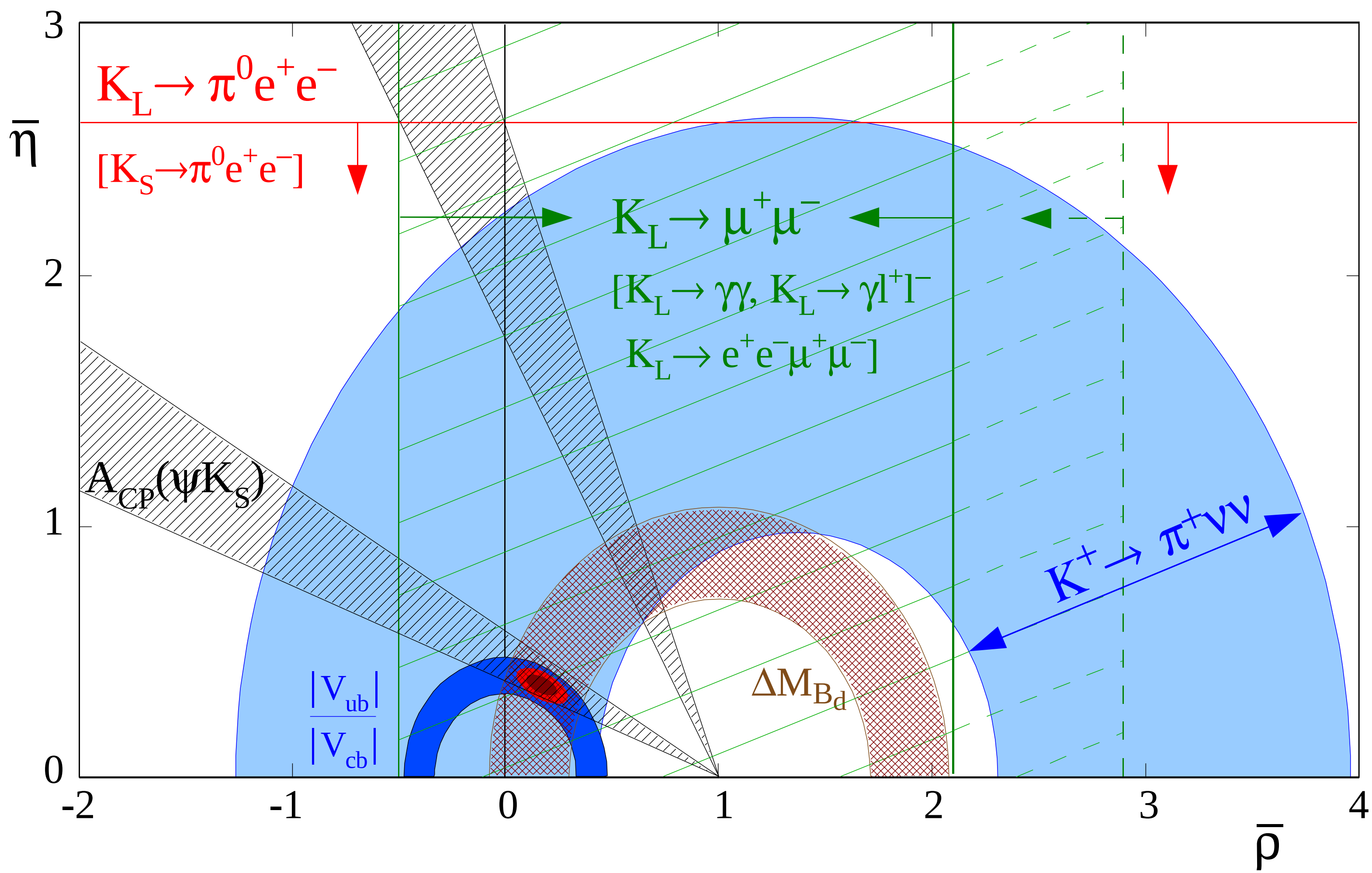

LP2003 summary (Ceccucci)




- Isidori,Unterdorfer (hep-ph/0311084): $-0.5 < \overline{\rho} < 2.1$ (negative interference) or $< 2.9$ (no assumption)

# CKM constraints from rare K decays

from Isidori, Unterdorfer: hep-ph/0311084



# Other rare K decay results

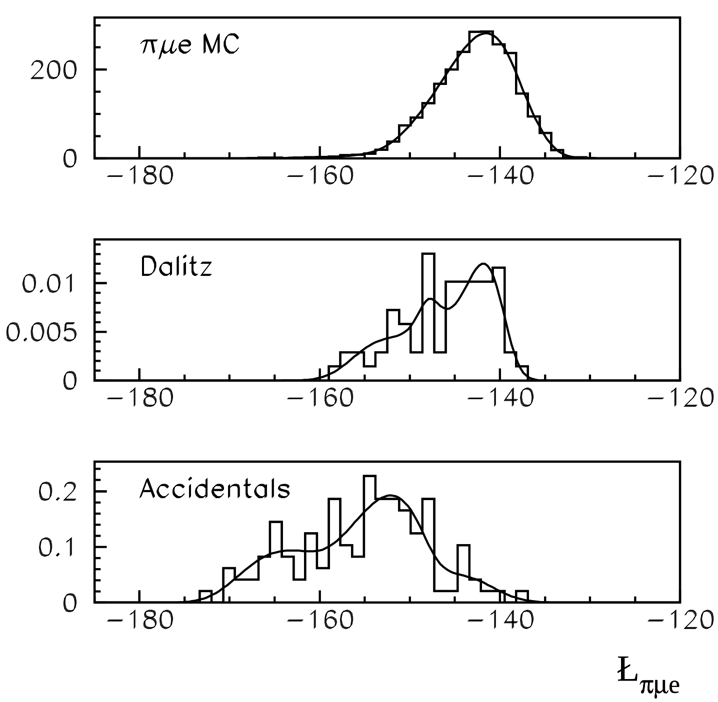
| Mode | Expt | BR or other result | Comment |
|---|---|---|---|
| $K_L \to \pi^0\gamma\gamma$ | NA48 | [a] $< 0.6 \times 10^{-8}$ | $(\pi^0 e^+ e^-)_{CPC}$ ("Model ind") |
| $K_S \to \pi^0\pi^0\pi^0$ | KLOE | $< 2.1 \times 10^{-7}$ | CP, CPT tests |
| | NA48/1 | $Re(\eta_{000}) =$ | |
| | | $(-2.6 \pm 1.0 \pm 0.5) \times 10^{-2}$ | |
| | | $Im(\eta_{000}) =$ | |
| | | $(-3.4 \pm 1.0 \pm 1.0) \times 10^{-2}$ | |
| $K_S \to \pi^+\pi^- e^+ e^-$ | NA48 | $A_\phi = (-1.1 \pm 4.1)\%$ | $\times$ 10 gain in statistics |
| $K_L \to \pi^0\pi^0 e^+ e^-$ | KTeV | $< 6.6 \times 10^{-9}$ | First attempt to see it |
| $K_S \to \pi^0\gamma\gamma$ | NA48 | $(4.9 \pm 1.6 \pm 0.9) \times 10^{-8}$ | First observation |
| $K_S \to \gamma\gamma$ | NA48 | $(2.78 \pm 0.06 \pm 0.04) \times 10^{-6}$ | $\times 40$ statistics; req. O($p^6$) |
| $K^+ \to e^+ \nu e^+ e^-$ | E865 | [b] $(2.48 \pm 0.14 \pm 0.14) \times 10^{-8}$ | $\times 100$ gain in statistics |
| $K^+ \to \mu^+ \nu e^+ e^-$ | E865 | [c] $(7.06 \pm 0.16 \pm 0.26 \times 10^{-8}$ | $\times 150$ gain in statistics |
| $K^\pm \to \pi^\pm \mu^+ \mu^-$ | HypCP | $(9.8 \pm 1.0 \pm 0.5) \times 10^{-8}$ | agrees w E865, theory. $K^-$ |

[a] $m_{3,4} = [30 - 110] MeV, \; y = [0, 0.2]$
[b] $m_{ee} > 150 MeV$
[c] $m_{ee} > 145 MeV$

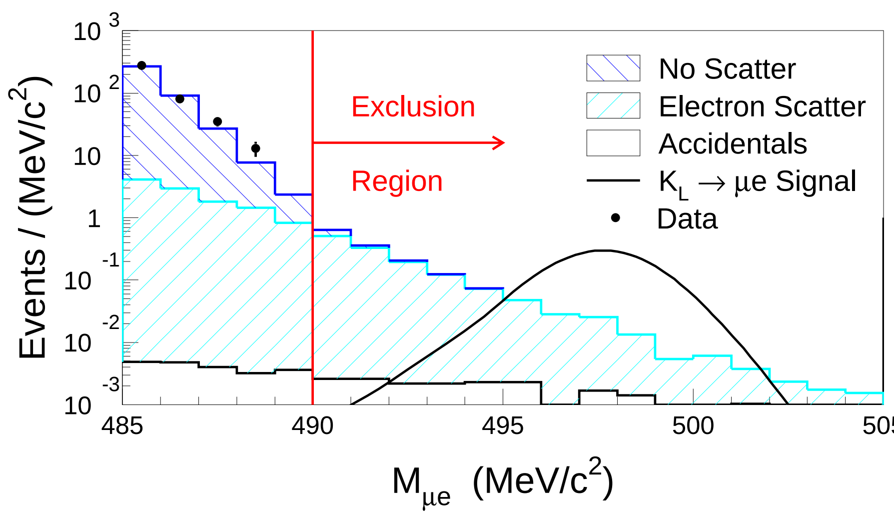
# Outlook for lepton flavor violation

- Existing data is more-or-less all analyzed. Awaiting results from KTeV on $K_L \to \pi^{\pm}\pi^{\pm}\mu^{\mp}e^{\mp}$ and $K_L \to \pi^0\pi^0\mu^{\pm}e^{\mp}$.
- There are no currently running or proposed LFV experiments in the kaon sector. Big reason is the experimental difficulty.

E865 (96 data)




E871 (95+96)




Molzon (KAON99) estimated that factor 40 improvement with current technique for $K_L \to \mu^{\pm}e^{\mp}$ would be a challenge but not obviously impossible

# Outlook for LFV

- Possibility of huge sensitivity gains in $\mu$ decays
  - MEG collaboration at PSI hopes to reach $10^{-14}$ on $\mu \to e\gamma$ ($\times$ 1000 gain over PDG02)
  - MECO collaboration at BNL hopes to reach $5 \times 10^{-17}$ on $\mu^- N \to e^- N$ ($\times$ 10000 gain over PDG02)
- SUSY models generally put LFV far out of reach of kaon experiments, but large parts of parameter space would be accessible by $\mu$ decays. (e.g. Belyaev et al: hep-ph/0008276)
- On the other hand, LFV K decays can probe interesting areas of parameter space in ETC models (Applequist, Piai, Shrock: hep-ph/0308061)
- LFV K decays involve both quarks and leptons and would provide information complementary to that obtained in $\mu$ decays...
- In the end it seems to come down to whether or not sensitivity on LFV K decays can be improved. (Marciano: “New forbidden decay searches should generally strive for at least 2 orders of magnitude improvement.”)

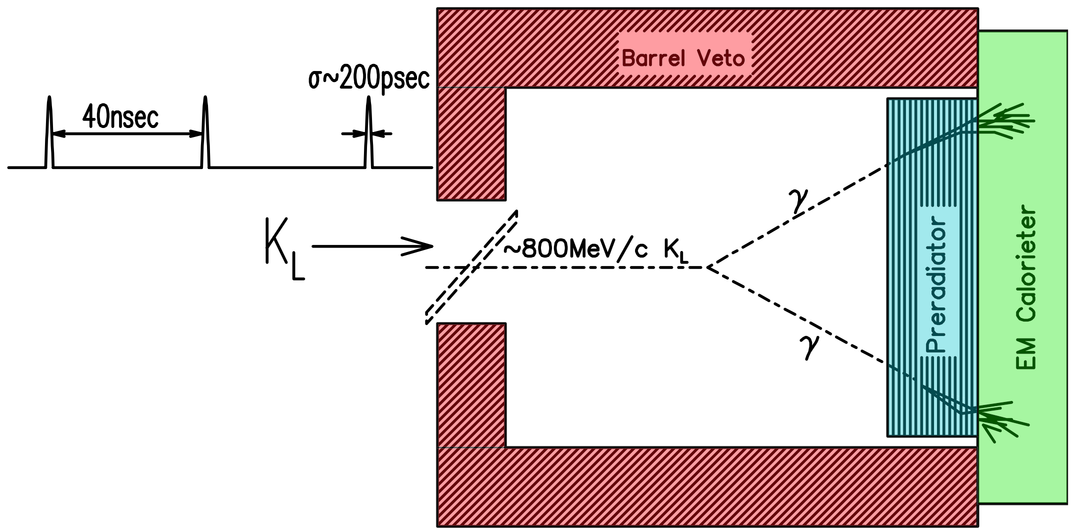
# Outlook for precision CKM tests: $K^+ \to \pi^+ \nu\overline{\nu}$

Future direction in this area is concentrating on the "golden" modes: $K^+ \to \pi^+ \nu\overline{\nu}$ and $K_L \to \pi^0 \nu\overline{\nu}$

- BNL E949 ready to complete its program: 5-10 events (SM) with $< 1$ event of background. Approved: 60 weeks. Ran 12. DOE funding terminated. NSF proposal submitted.
- CKM was approved at FNAL. $\sim 100$ events with $S/N = 10$ in 2 years. $|V_{td}|$ to 10%.
  - Decay-in-flight technique: 22 GeV/c kaons. RF-separated beam: 30 MHz, 70% K's. Redundant kinematic measurements with magnetic spectrometer, RICH.
  - Killed by P5. Revised as P940 with lower cost. Unseparated beam $\sim 45$ GeV. 230 MHz total rate ($\sim 30$ MHz/cm$^2$). 4% K's. Recycle as much of KTeV as possible. Redesign ongoing.
- NA48/3 EOI (April 2004). Goal: $\sim 50$ events in 2 years with $S/N = 10$.
  - Decay-in-flight technique: 75 GeV/c kaons. 1 GHz total beam rate ($\sim 40$ MHz/cm$^2$). 6% K's. Redundant kinematic measurements with two magnetic spectrometers. Recycle as much of NA48/2 as possible.
  - Many tests scheduled with beam in 2004.
- LOI for stopped kaon experiment at JPARC (Dec. 2002). Goal: $\sim 50$ events.
  - Build on the experience from E787/E949.
  - Possibly use "high B field" design discussed for $\pi^+ \nu\overline{\nu}$ expt. at KAON (at Triumf, early 90's, remember?).

# Outlook for precision CKM tests: $K_L \to \pi^0 \nu \overline{\nu}$

- KEK E391a running now. Might reach SES $\sim 4 \times 10^{-10}$. Another run in 2005?
- LOI for JPARC experiment with similar technique. “Goal”: SES $\sim 3 \times 10^{-14}$ or 1000 events! To be revisited based on E391a experience.
- KOPIO at BNL. Goal: 40 events with $S/N = 2$ in 4 years. Construction start next year!




- KOPIO concepts
  - Low energy beam. $\sim 45^\circ$ production angle. TOF to get $K_L$ momentum
  - Photon angle measurement to get $K_L$ decay vertex and $\pi^0$ direction
  - Kinematic rejection relaxes photon veto requirements, provides redundancy needed to measure the dominant background from data (a la E787). Full kinematic reconstruction suppresses many other backgrounds.
  - Large angle production suppresses hyperons, $\pi^0$ production via neutron halo

# Summary

Tried to present a survey of recent trends in rare kaon decays

- Rare kaon decays continue to be an active area of study
- LFV decays have reached the $(5-10)\times 10^{-12}$ level. Further progress requires new ideas from experimental side.
- Heroic efforts towards understanding short distance components of $K_L \to \pi^0 l^+ l^-$ and $K_L \to \mu^+\mu^-$.
  - New ideas from experimental side needed for $K_L \to \pi^0 l^+ l^-$. Current efforts fall short of SM by factor $\sim 10$, backgrounds severe. But potential exists for BSM effects complementary to $K^+ \to \pi^+\nu\overline{\nu}$.
  - New theoretical ideas needed for $K_L \to \mu^+\mu^-$
- Focus of the community converging on $K \to \pi\nu\overline{\nu}$ for precision CKM tests. Many ideas for experiments at various labs; some appear to be funded. Comparison with B factories could provide decisive tests in the flavor sector.

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Thanks to the individual experiments for their excellent websites and access to results. Also D. Jaffe, S. Kettell, L. Littenberg for comments.

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- Translation: experimentalists and theorists share the Big Prize

Blondie outsmarts Tuco, hangs him and rides off, but stops at a distance and shoots the rope down

- Translation: flavor sector problems appear to be solved, experimentalists ride off to new challenges, but more data provokes new physics questions, and the game is on again