Kaon and Pion Physics at the Proton Driver

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For the Kaon/Pion PD Working Group

Our working group covered:

- Rare K-decays
- Pion Physics
- Proton Baryon and Meson Spectroscopy
- Implications for the PD accelerator complex

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Work Done Since Last Review

- Restating the physics case for rare kaons
- Closer look at neutral kaon decays to $\pi^0 ee$ ($\mu\mu$)
- Proton Economics
- A More Complete Writeup

Our Main Conclusions

- The decays $K \to \pi\nu\nu$ are key to understanding CPV in the quark sector. They are also theoretically clean windows into possible new physics operating at much higher energy scales.

- The physics case for $K \to \pi\nu\nu$ at the Proton Driver depends on what is found at the TeV/LHC/b-factories, and with the 100-event $K \to \pi\nu\nu$ initiatives.

- The decays $K_L \to \pi\, ee\ (\mu\mu)$ could become important in unravelling the new physics scenarios.

Our Main Conclusions (continued)

- The 100-event $K \rightarrow \pi\nu\nu$ initiatives will be experimentally challenging. These will teach us how to do a 1000-event experiment at the Proton Driver.

- A measurement of 1000 $K^+ \rightarrow \pi^+\nu\nu$ events would statistically equal the expected SM theoretical uncertainties at that time.

- A measurement of 10000 $K_L \rightarrow \pi^0\nu\nu$ events would statistically equal the expected SM theoretical uncertainties at that time.

- Experiments have a long way before saturating the theory errors.

Motivation and Interest in $K \to \pi\nu\nu$ Remains High

- PL**B530**(2002)108: *$K^+ \to \pi^+\nu\nu$, A rising star on the stage of flavor physics*
- JHEP05(2003)053: *Shedding Light on the `Dark Side' of B-mixing... $K \to \pi\nu\nu$*
- NP**B660**(2003)225: *The Impact of Universal Extra Dimensions on the Unitarity Triangle and Rare K and B Decays*
- NP**B697**(2004)133: *Anatomy of Prominent B and K Decays and Signatures of CP Violating New Physics in the Electroweak Penguin Sector*
- hep-ph/0402191: *Waiting for Clear Signals of New Physics in B and K Decays*
- hep-ph/0404229: *$K^+ \to \pi^+\nu\nu$ and FCNC from non-universal Z' Bosons*
- hep-ph/0405132: *Waiting for Precise Measurements of $K^+ \to \pi^+\nu\nu$ and $K_L \to \pi^0\nu\nu$*
- hep-ph/0407021: *Constraints on New Physics from $K \to \pi\nu\nu$*
- hep-ph/0407216: *$K \to \pi\nu\nu$ from standard to new physics*
- hep-ph/0408125: *$K_L \to \pi^0\nu\nu$ in Little Higgs model*
- PL**B588**(2004)74: *Lepton Flavor Mixing and $K \to \pi\nu\nu$ Decays*
- hep-ph/0408142: *$K^+ \to \pi^+\nu\nu$ and $K_L \to \pi^0\nu\nu$ Decays in the General MSSM*

From Steve Kettell

Initiatives Aiming for ~ 100 events at the End of The Decade

$K_L \rightarrow \pi^0 \nu\nu$	$K^+ \rightarrow \pi^+ \nu\nu$
E391a at KEK	JPARC-LOI (Stopped Beam)
JPARC-LOI	NA48/3 at SPS (Unseparated Beam)
K0PI0 at BNL	P940 at Fermilab MI (Unseparated)

Summary of MI Proton Flux Requirement

Assuming that we know how to do a 1000 event measurement, the flux requirement is modest.

Mode	Sample	Physics	Number of Protons on Target
$K^+ \rightarrow \pi^+\nu\nu$	1000	3% $(V_{ts}*V_{td})$	1.5×10^{20}
$K_L \rightarrow \pi^0\nu\nu$	1000	1.5% $Im(V_{ts}*V_{td})$	1.6×10^{21}

Estimates are taken from the KAMI and P940 Proposals.

Critical to have DC beam and high duty cycle.

MI Protons Flux Requirement for $\pi^0 ee$

In some ways, they are probably easier experimentally than $K \rightarrow \pi\nu\nu$.

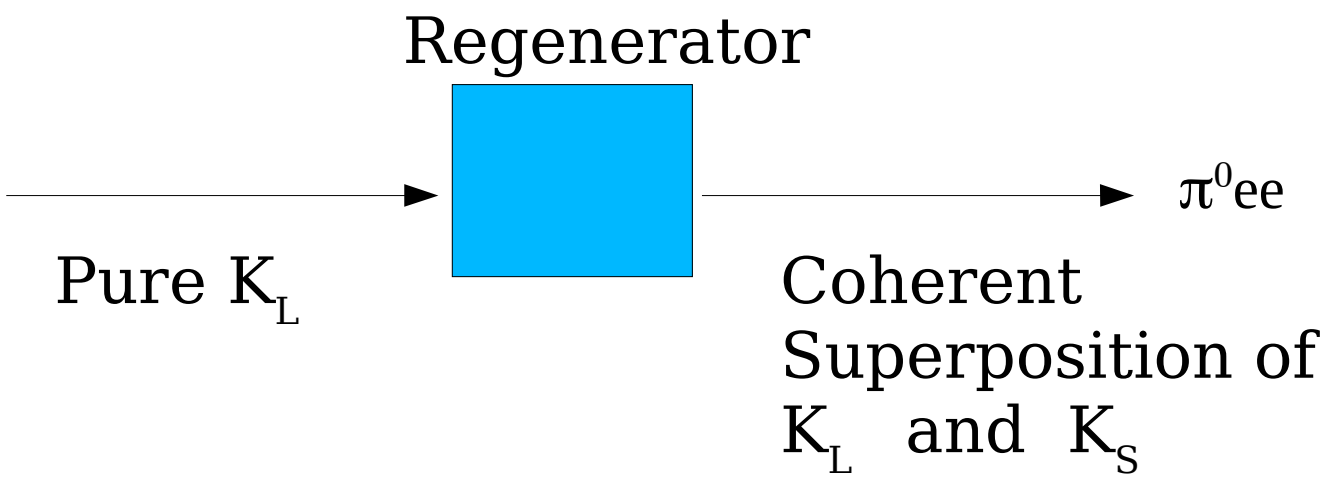
Mode	Sample	Physics	Protons on Target
$K_L \rightarrow \pi^0 ee$	2×10^4	10% $Im(V_{ts}^* V_{td})$	2.5×10^{20}
Target K_S-$K_L \rightarrow \pi^0 ee$	400×10^3	10% $Im(V_{ts}^* V_{td})$	2.4×10^{23}
Regen. K_S-$K_L \rightarrow \pi^0 ee$	400×10^3	10% $Im(V_{ts}^* V_{td})$	2.5×10^{23}

* Interference technique needs lots of protons.

** All of these need DC beam.

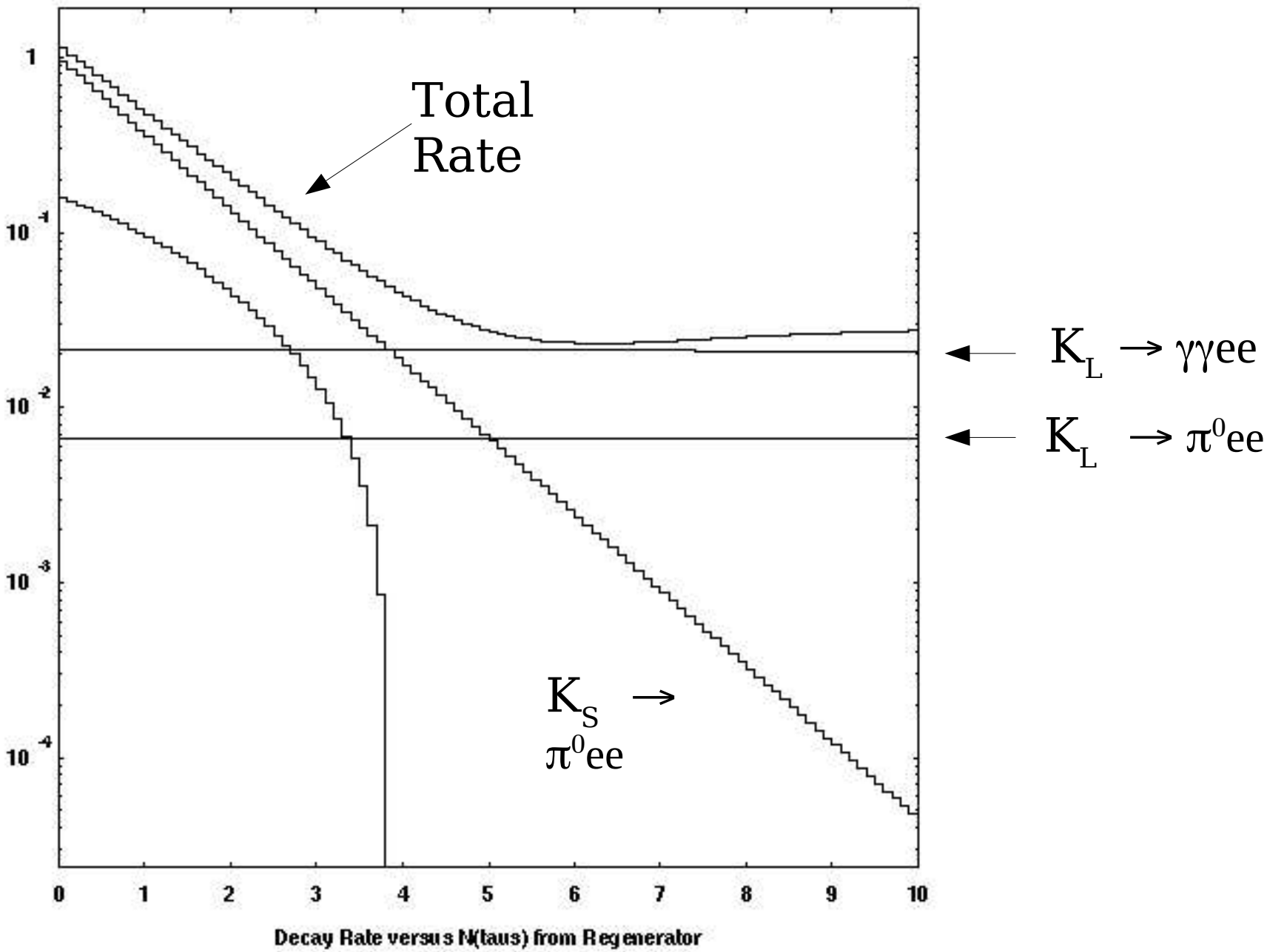
K_s-K_L Interference in the $\pi^0 ee$ in final state

Novel idea to beat down the Greenlee background and has potentially better theoretical uncertainties than just $K_L \rightarrow \pi^0 ee$



$\pi^0 ee$ will have contributions from both K_L and K_S

π^0ee versus propertime behind a regenerator



There are important items that we did not cover.

- Charged and Neutral Kaon program using 8 GeV protons, taking advantage of time-of-flight techniques to tag kaons and using the Recycler as a stretcher ring .

- New round of Lepton Flavor Violation in the Kaon sector.

- Simulation of a pion decay-in-flight experiment.

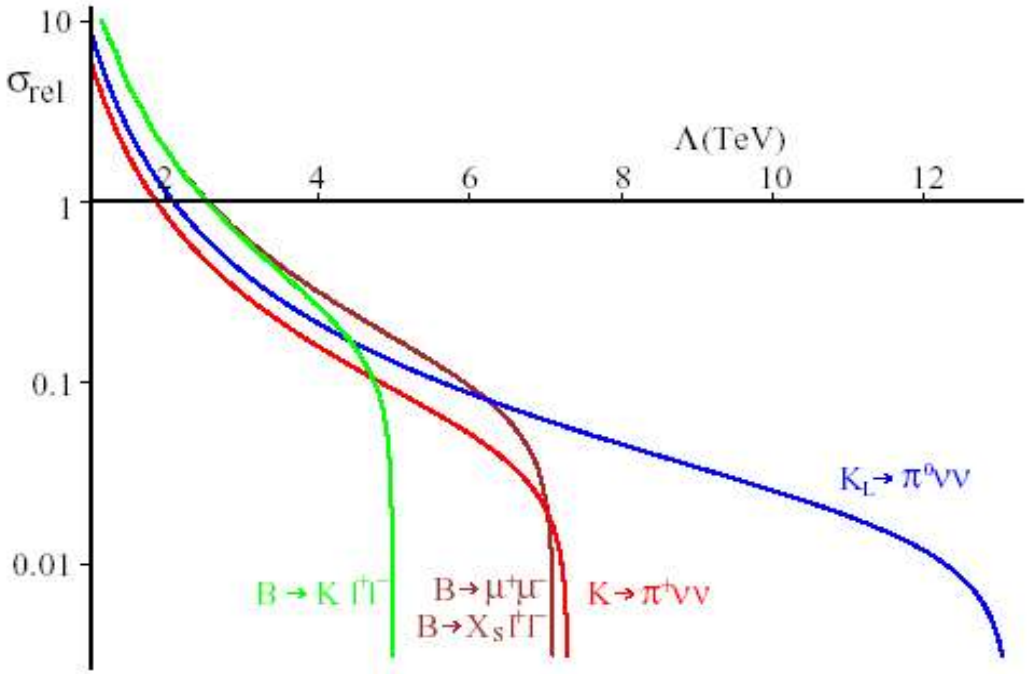
Back Up Slides

Mode is So Clean that it is Extremely Constraining on New Physics Models

Minimal flavor violation

- One effective new parameter: the new physics scale
- Small effects, but $K \to \pi\nu\bar{\nu}$ have very high sensitivity

D'Ambrosio, et al.



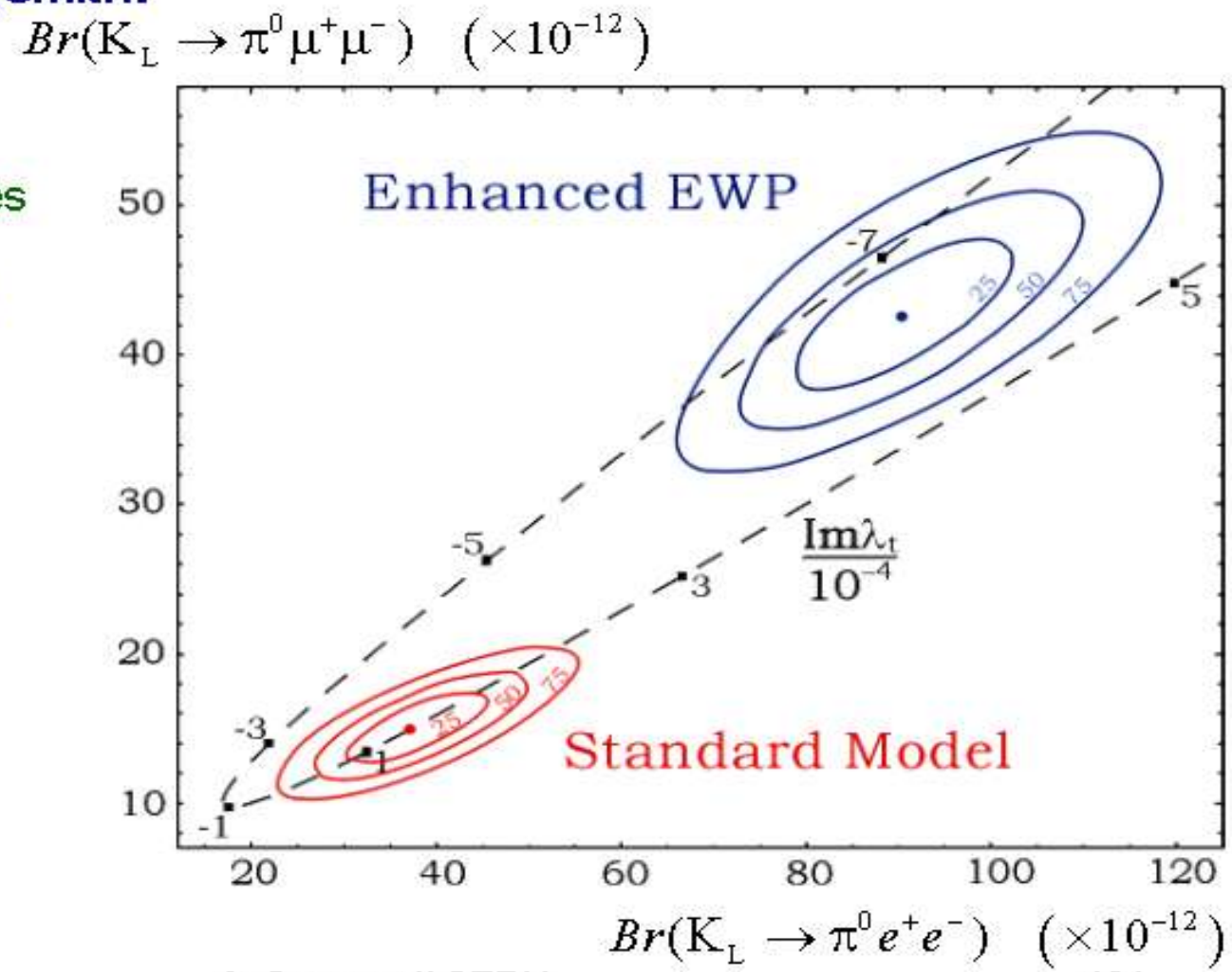
$K^0_L \to \pi^0 ee\ (\mu\mu)$: Sensitivity to New Physics

Isidori, Unterdorfer, Smith:

Fleisher et al:

Ratios of $B \to K\pi$ modes could be explained by enhanced electroweak penguins

and enhance the BR's:

$$B^{NP}_{e^+e^-} = 9.0^{+1.6}_{-1.6} \times 10^{-11}$$

$$B^{NP}_{\mu^+\mu^-} = 4.3^{+0.7}_{-0.7} \times 10^{-11}$$