First results from BNL E949 on the rare decay $K^+ \to \pi^+ \nu\overline{\nu}$

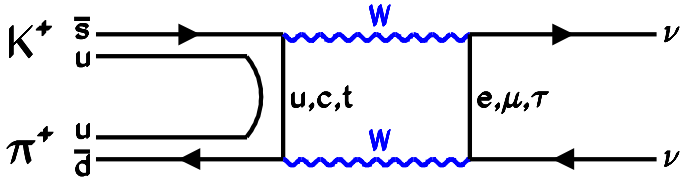
DPF04. Aug. 26-31, 2004

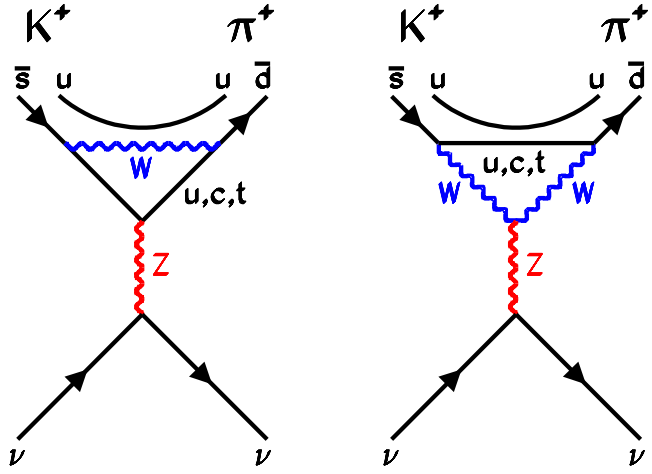
George Redlinger

Brookhaven National Laboratory

(on behalf of E949 collaboration)

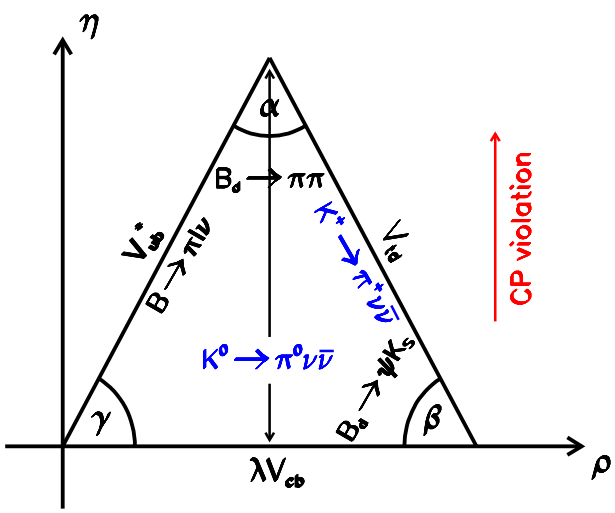
$K^+ \to \pi^+ \nu\overline{\nu}$ in the Std. Model





- Forbidden by GIM at first order
- Top quark dominates in loops $\Rightarrow$ sensitivity to $|V_{td}|$
- $\nu\overline{\nu}$ final state $\Rightarrow$ "long-distance" effects highly suppressed
- Hadronic matrix element: $\langle \pi^+ | \mathcal{H} | K^+ \rangle$ from $\mathcal{B}(K^+ \to \pi^0 e^+ \nu)$
- Charm contribution gives dominant theoretical uncertainty to $\mathcal{B}(K^+ \to \pi^+ \nu\overline{\nu})\sim 7\%$. Could be brought down to $\sim 2\%$ with NNLO QCD calculation (Buras *et al* hep-ph/0405132)
- Std. Model expectation: $(0.78 \pm 0.12) \times 10^{-10}$

Tests of the Unitarity Triangle



- $K^+ \to \pi^+ \nu\bar{\nu}$, $K_L \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^0 e^+ \nu$ completely determine the unitarity triangle
- If there is new physics in quark mixing, the effects could be different in the $b \to d$ sector compared to $s \to d$.
- These differences could give us clues to the flavor/CP structure of the new physics.

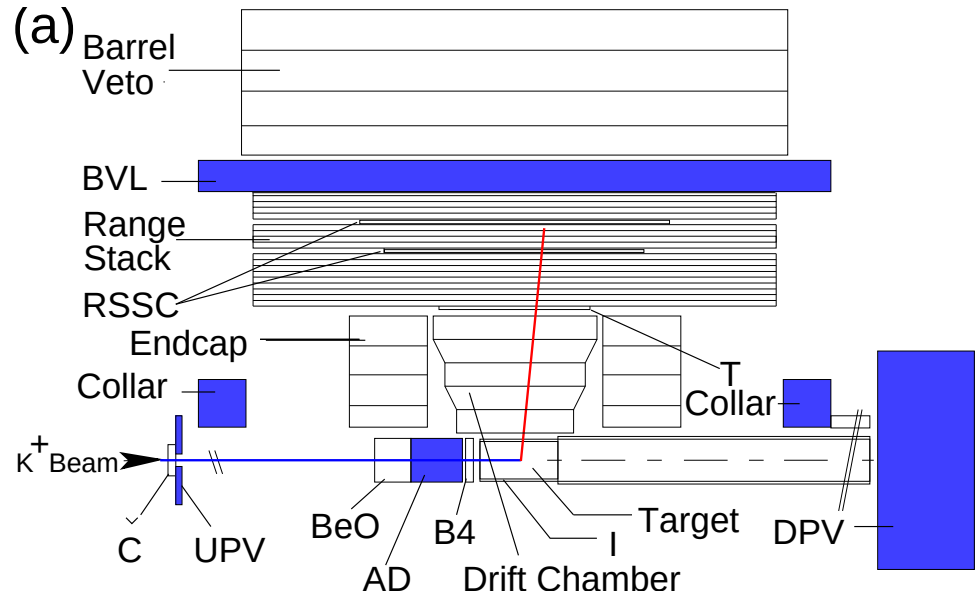
- Several promising comparisons between B and K decays:
  - $|V_{td}|$ from $\frac{\Delta m_d}{\Delta m_s}$ vs $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$
  - $\sin(2\beta)$ from $B_d \to \psi K_s$ vs $\frac{\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})}{\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu})}$ $\Leftarrow$ independent of A
    - KOPIO expt at BNL hopes to see 40 $K_L \to \pi^0 \nu\bar{\nu}$ events at SM level; construction expected to start next year
  - area of unitarity triangle from $K_L \to \pi^0 \nu\bar{\nu}$ vs B decays.
    "The prospects (for $K_L \to \pi^0 \nu\bar{\nu}$) are even better than for B physics at the LHC."
    [Buchalla: hep-ph/0110313, assuming 10% measurement of $\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu})$]

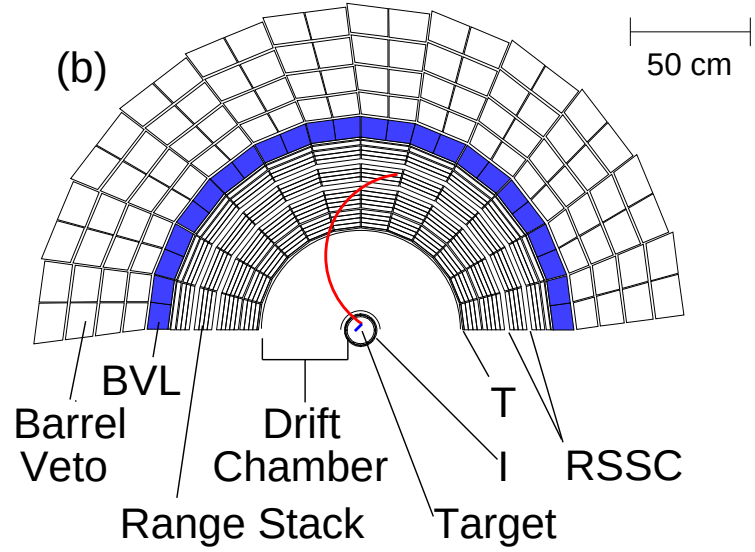
$K^+ \to \pi^+ \nu\overline{\nu}$ measurement

- Theoretically, $K^+ \to \pi^+ \nu\overline{\nu}$ is a very attractive decay channel. Experimentally challenging, but do-able as shown by BNL E787.
- BNL E787 (1995-98) observed 2 $K^+ \to \pi^+ \nu\overline{\nu}$ candidates with a background of 0.15 ± 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. 15×10^{12} p/spill $\to 65 \times 10^{12}$
  - Longer AGS running during RHIC operation (≥ 25 weeks/yr)
  - Detector upgrades: photon veto, π^+ tracking and kinematic resolution, trigger/DAQ, K^+ tracking system
- Aimed at SES$\leq 10^{-11}$ or 5-10 SM events

Recall E787/E949 technique

- Incoming beam ($\sim 700 MeV/c$) tagged by Cerenkov, dE/dx counters.
- Stopped kaon beam. Delayed coincidence cut against scattered beam π. High geometrical acceptance.
- Stopped decay pion. Redundant measurements of kinematics. Observation of $\pi \rightarrow \mu \rightarrow e$ decay sequence for μ rejection.
- Photon veto counters surround everything. Minimize inactive material.





BNL E949: Beam

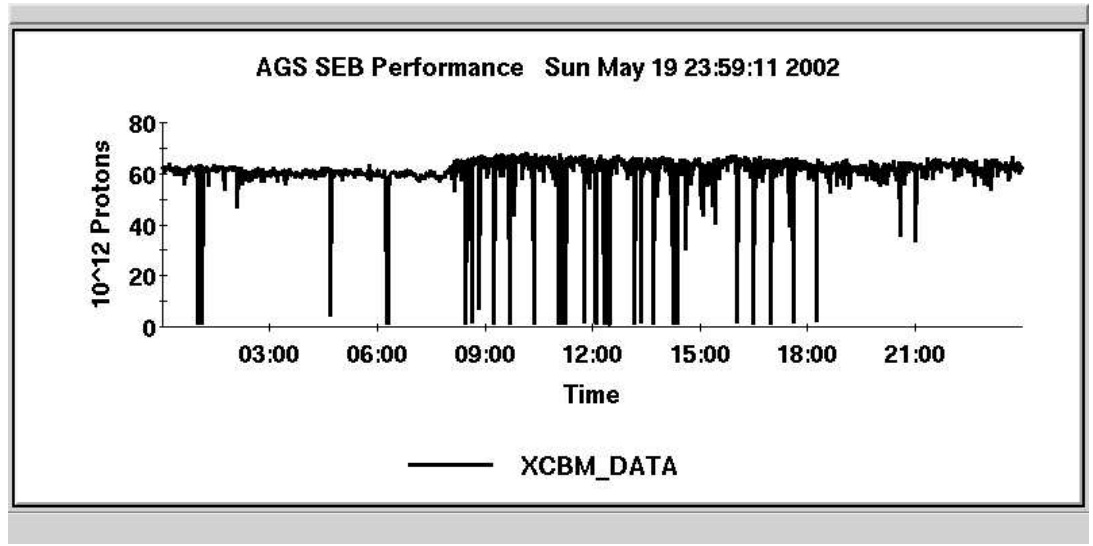
Proton intensity:

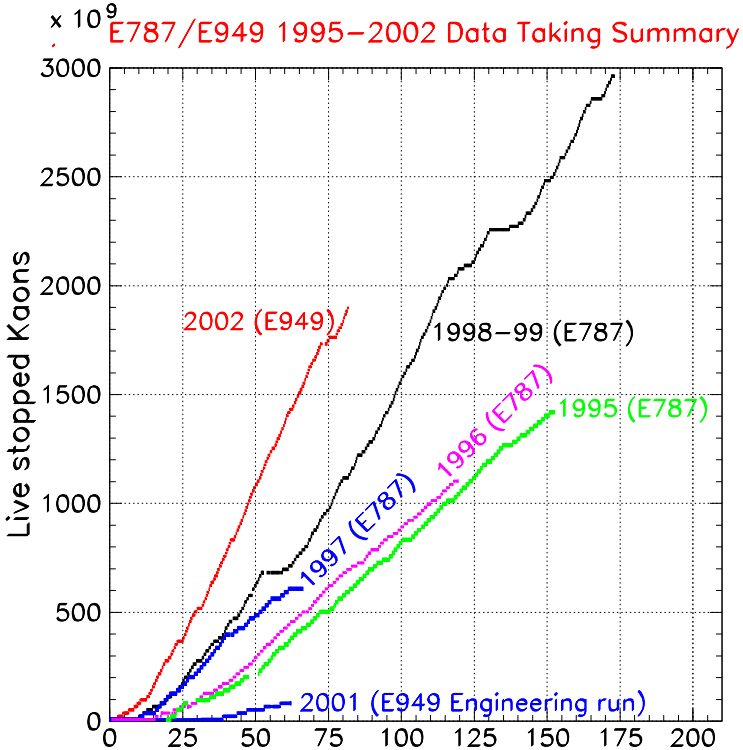
- 76×10^{12}/spill (peak)
- 65×10^{12}/spill (typical)

Kaons:

- Incoming: 6-7 MHz
- 'Stopping': ~ 2 MHz

E949 (2002) protons on target (typical day)



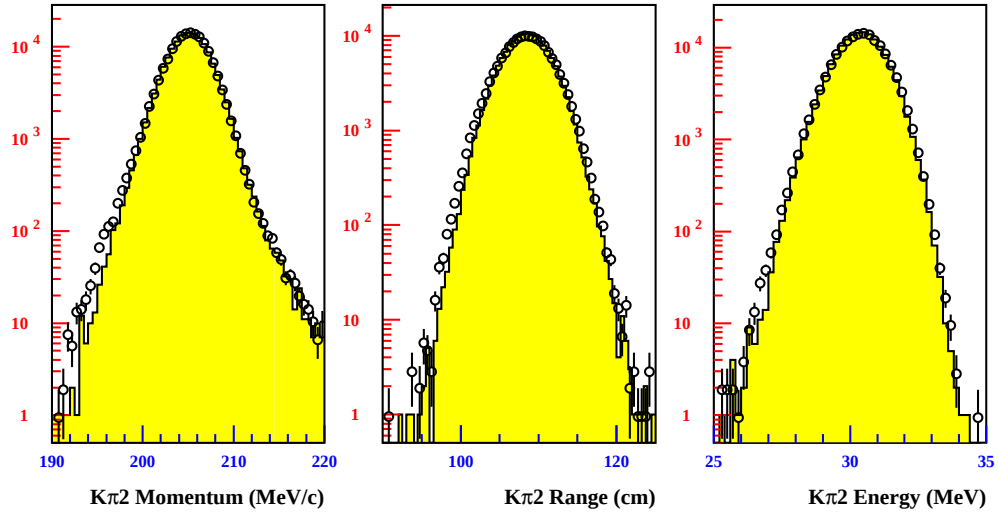


Not optimal in 2002:

- 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/π separator problems

BNL E949: Detector upgrades

Kinematic resolution (dots: E787, solid: E949)

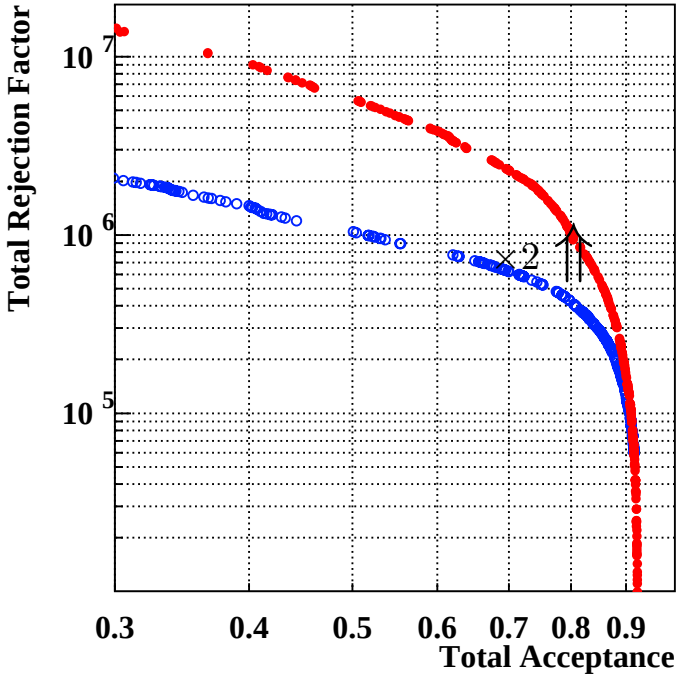


σ_P: 2.3 MeV/c

σ_E: 3.0 MeV

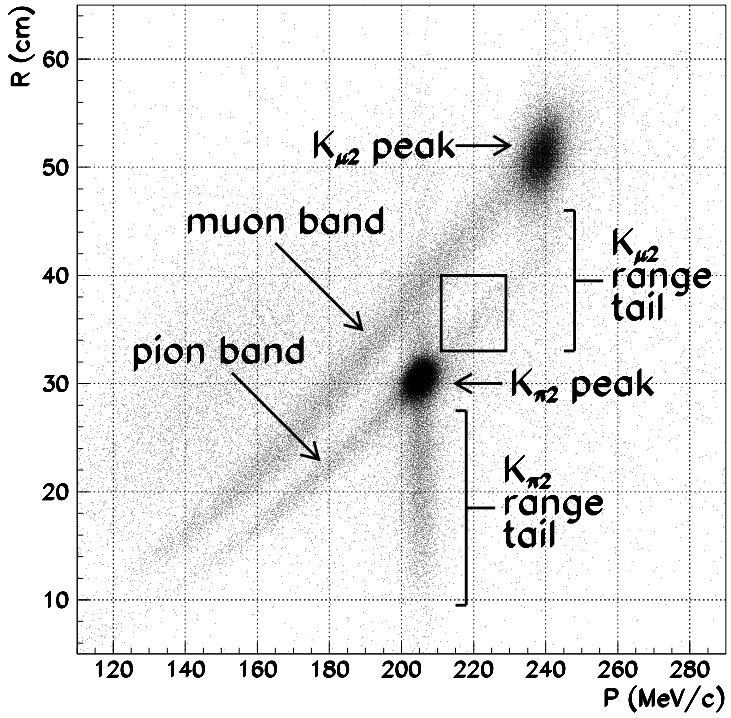
σ_R: 0.9 cm

PV rejection (E787 & E949)



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

Offline analysis



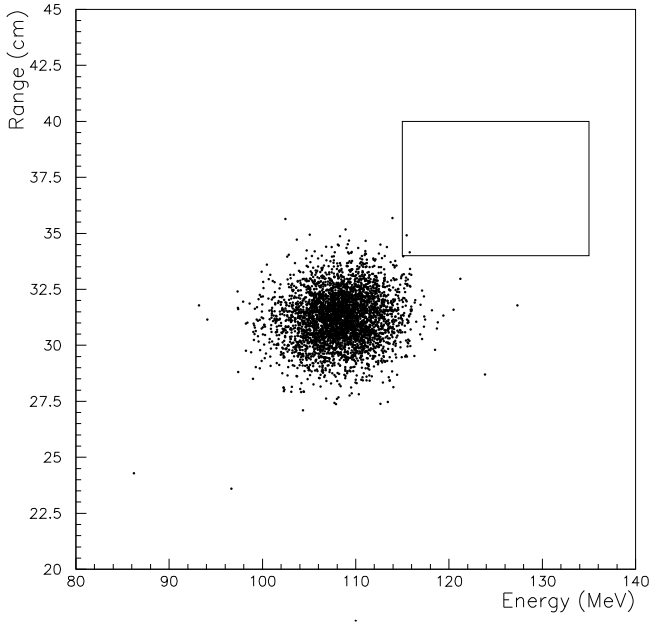
- Blind analysis
- Two independent cuts with high rejection for each background

Background	Independent cuts
$K^+ \to \pi^+\pi^0$	kinematics, photon veto
$K^+ \to \mu^+\nu(\gamma)$	kinematics, π/μ ID, (photon veto)
Beam pion	timing, PID in beamline
2 beam particles	target pattern, tracking in beamline
$K^+n \to K^0p$, $K^0_L \to \pi^+l^-\nu$	timing, target pattern

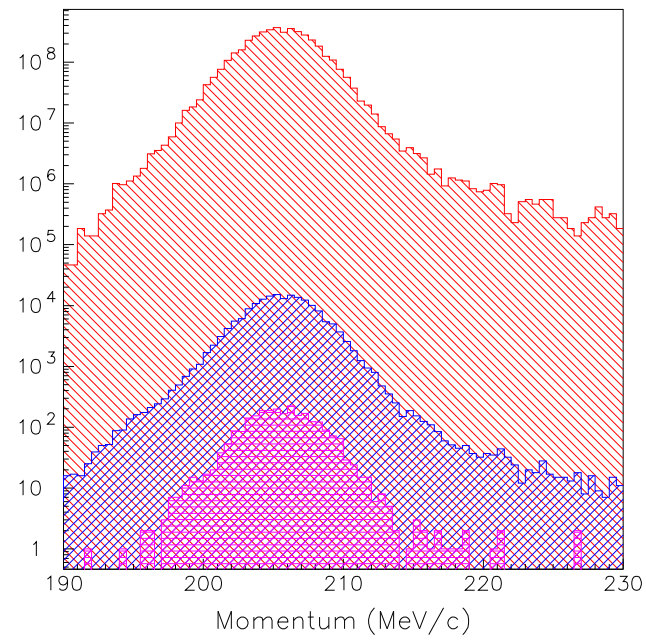
Background estimation

$K^+ \to \pi^+\pi^0$ background as an example:

Events tagged with presence of γs



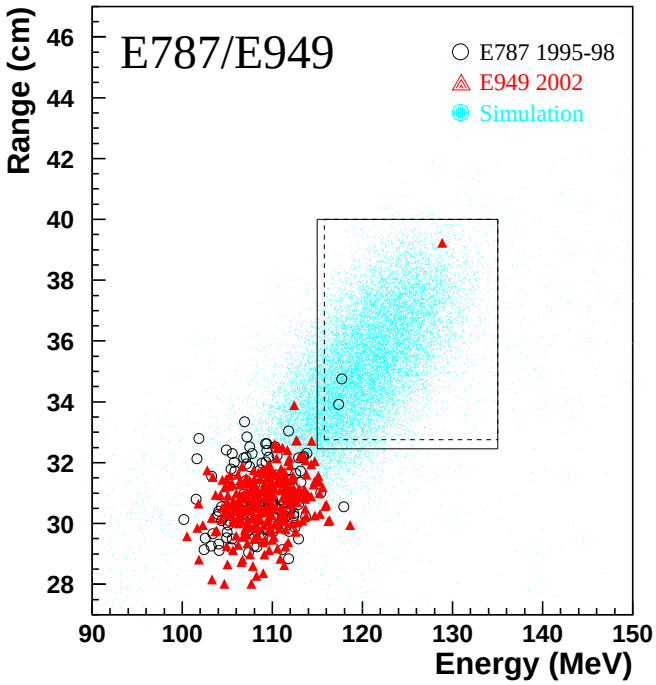
Events tagged by $K_{\pi 2}$ kinematics



$$N_{bkg} = \frac{N}{R_{PV} - 1}$$

$K^+ \to \pi^+ \nu\overline{\nu}$. First result from E949

E949 (2002) + E787(95-98)

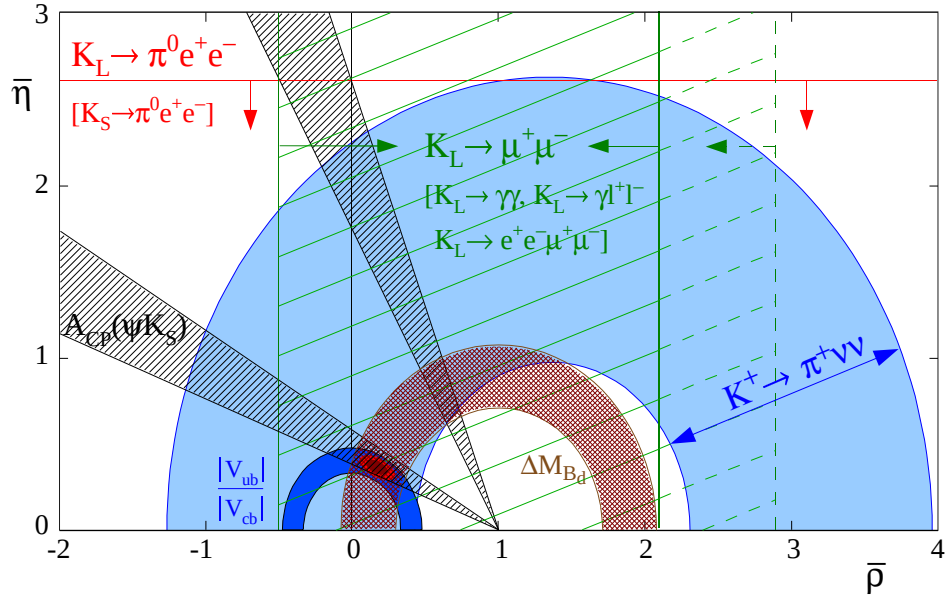


	E787		E949
N_K	5.9×10^{12}		1.8×10^{12}
Total Acceptance	0.0020 ± 0.0002		0.0022 ± 0.0002
Total Background	0.14 ± 0.05		0.30 ± 0.03
S_i/b_i	50	7	0.9
W_i	0.98	0.88	0.48
Background Prob.	0.006	0.02	0.07

- Signal region enlarged in E949, compared to E787. Lets in more background; rely on likelihood analysis.
- 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)

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

Unitarity constraints from K decays:



(Isidori & Unterdorfer, hep-ph/0311084)

- Still room for new physics to appear in comparisons with B decays!
- Current central value for $\mathcal{B}(K^+ \to \pi^+ \nu\overline{\nu})$ intersects V_{ub} and ϵ_K in a region of $\gamma > 90°$. There is also a tension with B_s mixing.
- Will be interesting to see if it holds up with more statistics.

Conclusion and outlook

- E949 detector is working well. Backgrounds well understood. Analysis of data on $K^+ \to \pi^+ \nu\overline{\nu}$ (above $K^+ \to \pi^+\pi^0$ peak) completed. Central value of BR remains high, but needs more statistics.
- Analysis of data below $K^+ \to \pi^+\pi^0$ peak in progress. $K^+ \to \pi^+\pi^0$ background was a problem in E787, but hopefully photon veto upgrades in E949 will help.
- Main limitations right now do not come from physics but are more “sociological”
- DOE had approved running E949 for 60 weeks, but terminated HEP at BNL after 12 weeks. Proposal submitted to NSF.
- If not at BNL, hopefully $K^+ \to \pi^+ \nu\overline{\nu}$ will get measured somewhere:
  - Fermilab: P940 (formerly CKM). Decay-in-flight technique. 100 events with S/B=10
  - CERN: NA48/3 (EOI). 50 events with S/B=10. Also decay-in-flight.
  - JPARC (LOI): extension of E787/E949 technique. Goal ~ 50 events.
- Possible future outcome: