The Rare Decay $K^+ \to \pi^+ \nu \overline{\nu}$ at BNL E787

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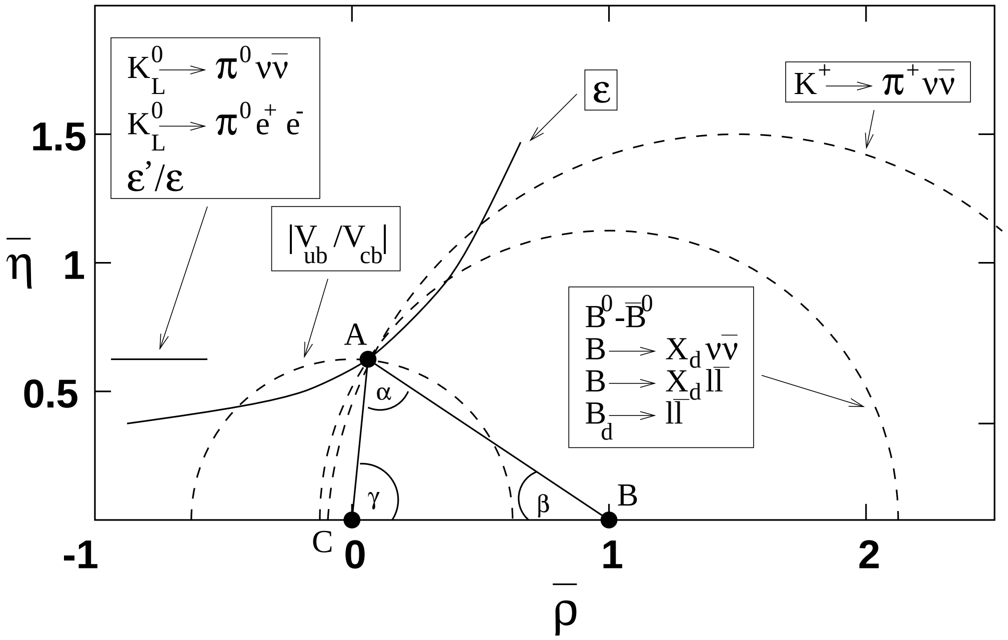
- Motivation
- E787
- Evidence for $K^+ \to \pi^+ \nu \overline{\nu}$
- Recent progress

In the SM: Quark Mixing $\Leftrightarrow$ CP Violation



Buras *et al.* hep-ph/9704376

- $K^+ \to \pi^+ \nu\bar{\nu} \quad \Rightarrow \quad$ Theoretically clean determination of $|V_{td}|$
  - Top quark dominates in loops
  - Hadronic matrix element: $< K|H|\pi >$ from BR$(K^+ \to \pi^0 e^+ \nu_e)$
  - "Long-distance" contributions suppressed by $> 10^3$
  - Charm contribution uncertainty to $|V_{td}| \sim 4\%$

$K^+ \to \pi^+ X^0$

X^0 is long-lived, non-interacting neutral object.

- Familon: Nambu-Goldstone boson from breaking global family symmetry

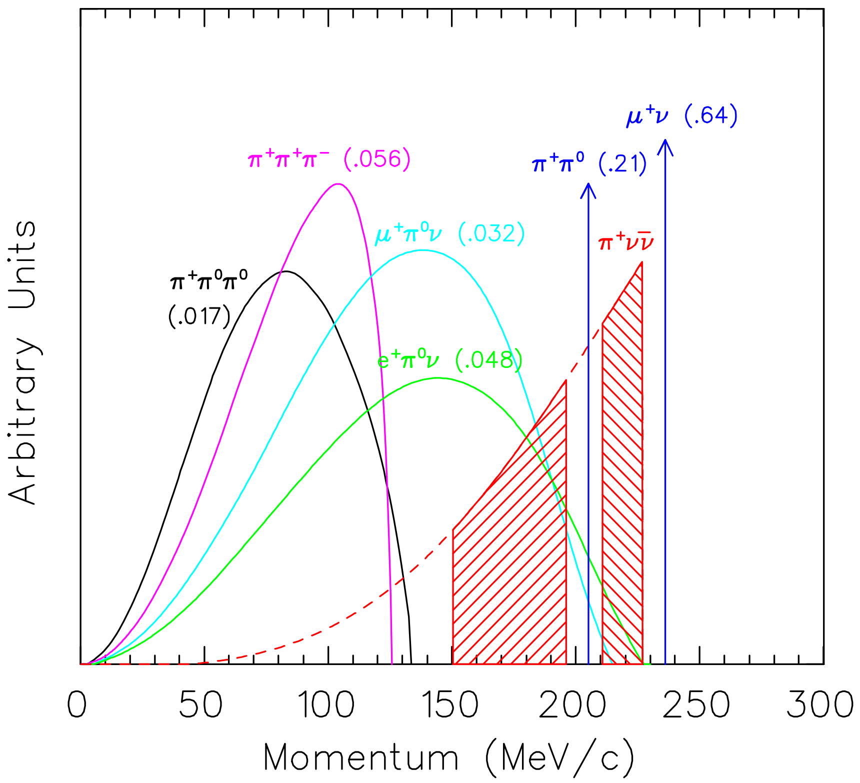
  (F. Wilczek, PRL 49 (1982) 1549)

  BR$(K^+ \to \pi^+ f) = 2.7 \times 10^{13}\ \mathrm{GeV}^2/\mathrm{F}^2_{\mathrm{K}\pi}$

  $10^{11}\ \mathrm{GeV} < \mathrm{F}_{\mathrm{K}\pi} < 10^{12}\ \mathrm{GeV}$ from cosmology

  $$\Rightarrow \mathrm{BR}(\mathrm{K}^+ \to \pi^+ \mathrm{f}) >\sim 10^{-11}$$

<u>E787 strategy</u>



- Work in kaon rest frame $\Rightarrow$ stopped kaon beam
- Search in the high-momentum region
- Stop the decay pion
  - Redundant measurements of track kinematics: energy and range
  - π/μ separation
    - Observe $\pi^+ \to \mu^+ \to e^+$ decay sequence $\Rightarrow$ high-speed digitizers
    - dE/dx separation in scintillator
- π momentum measurement $\Rightarrow$ low-mass tracking
- Photon veto
  - 4π coverage
  - Good timing, low thresholds
  - CsI, Pb-scint, Pb-glass, Pb-scifi

- Beam instrumentation
  - $\mathrm{K} - \pi$ separation
  - Fine spatial segmentation, tracking, good timing
    - Scintillating fiber kaon stopping target
    - MWPC's
- Rate capability
  - 4-6 MHz of K^+
  - 500 MHz digitizers in barrel, endcap, target, beam hodoscopes

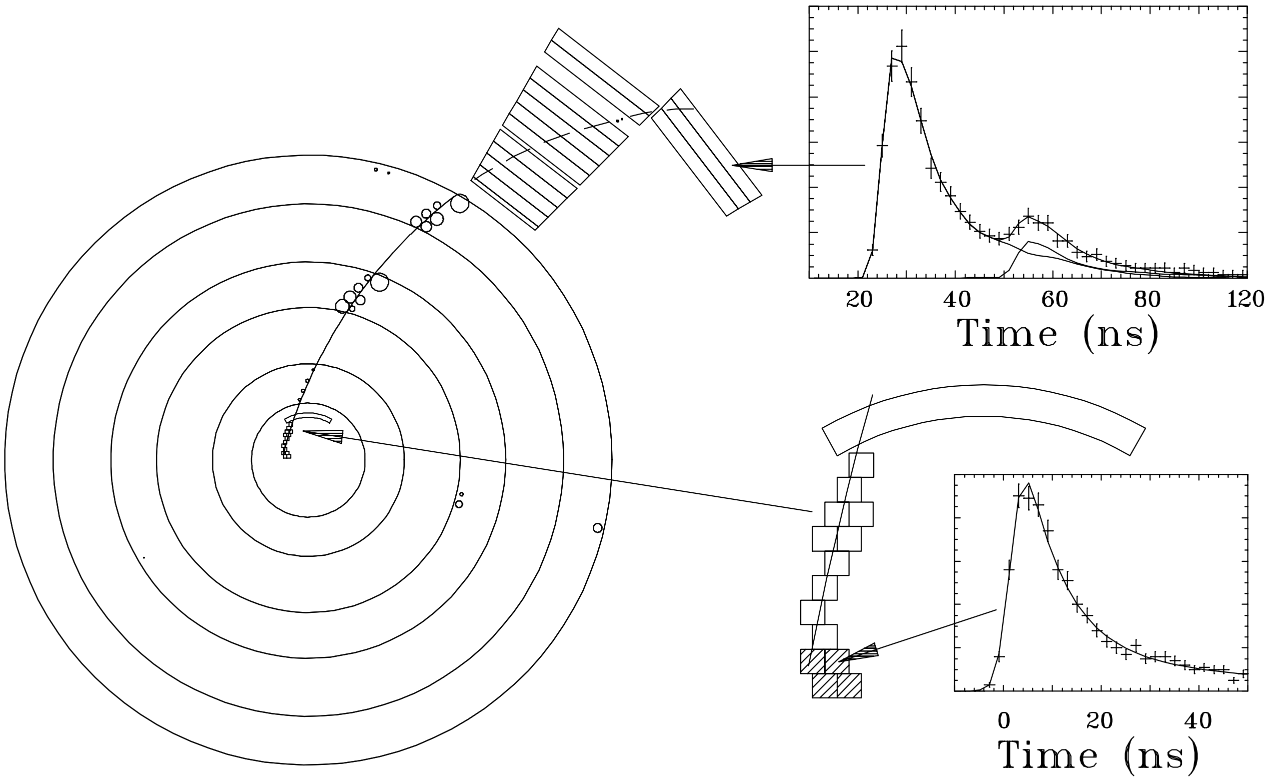
Offline analysis

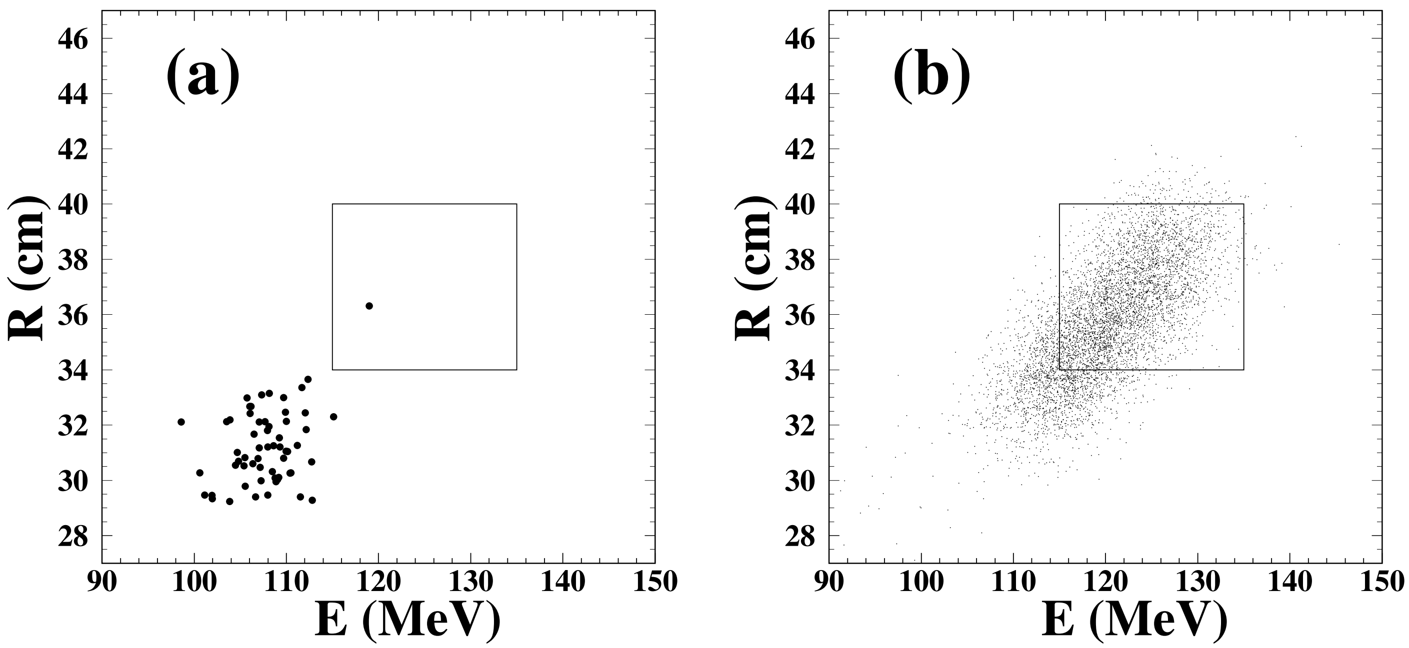
- Blind analysis
  - Signal region is hidden (by inverting cuts) while cuts are developed and background levels estimated
- "Bifurcated" analysis
  - A priori identification of background sources
  - Same dataset for background studies and signal search
  - Two independent cuts with high rejection for each background
  - Measurement of background levels in the signal region at the $10^{-3} - 10^{-2}$ event level
- Correlation studies
- Prediction of background levels around signal region (followed by confirmation)
- Background likelihood analysis (using predetermined likelihood functions) in the signal region for assessing candidate events.

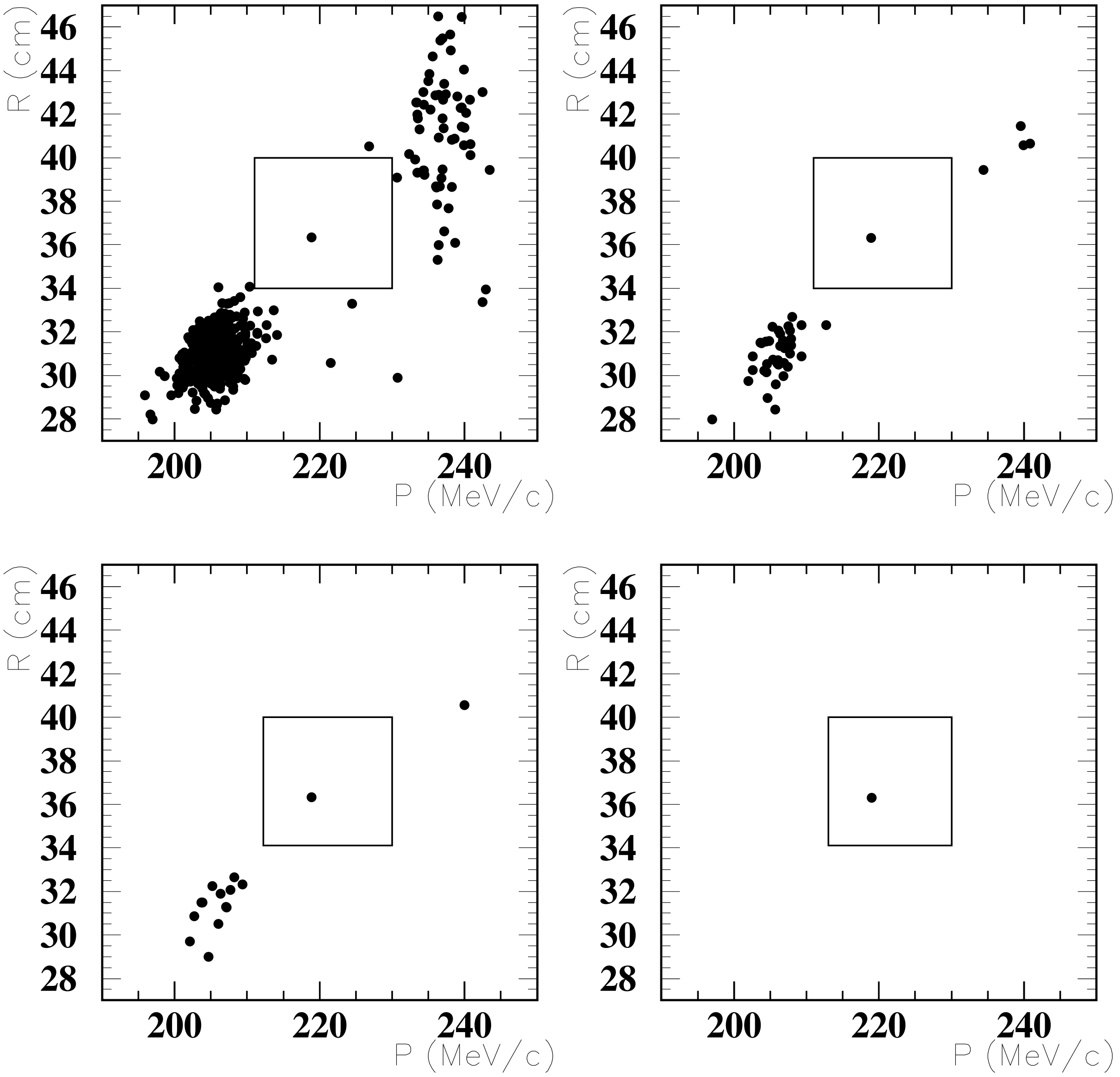
Background levels, 1995 dataset

Background	# events in signal region
$K_{\pi 2}$	0.03 ± 0.02
$K_{\mu 2}$	0.02 ± 0.02
Single beam	0.012 ± 0.009
Double beam	0.007 ± 0.007
CEX	0.01 ± 0.01
Total background	0.08 ± 0.03

One candidate event







R (cm)
P (MeV/c)
46
44
42
40
38
36
34
32
30
28
200
220
240

$K^+ \to \pi^+ \nu\overline{\nu}$ and related results from 1995 data

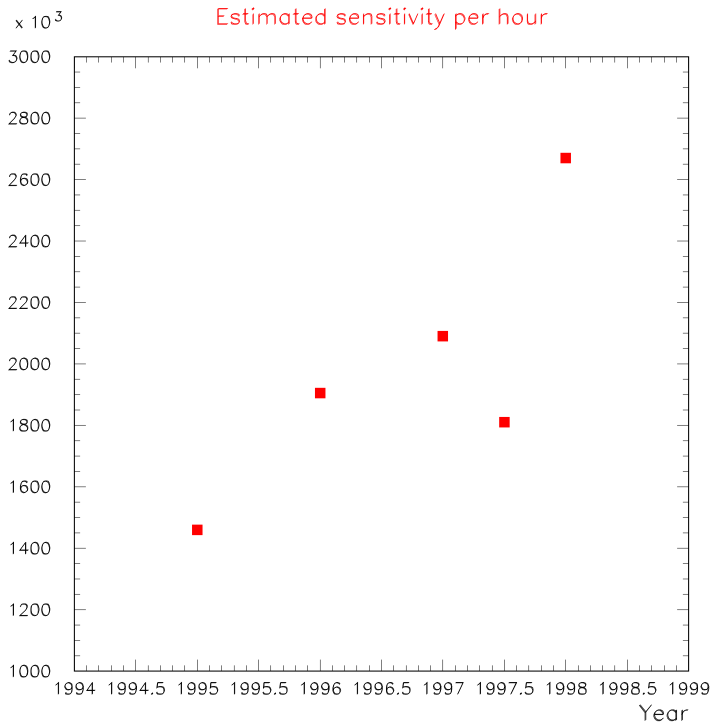
- Based on one event observed:

$$\mathrm{BR}(K^+ \to \pi^+ \nu\overline{\nu}) = 4.2^{+9.7}_{-3.5} \times 10^{-10}$$

$$0.006 < |V_{td}| < 0.06$$

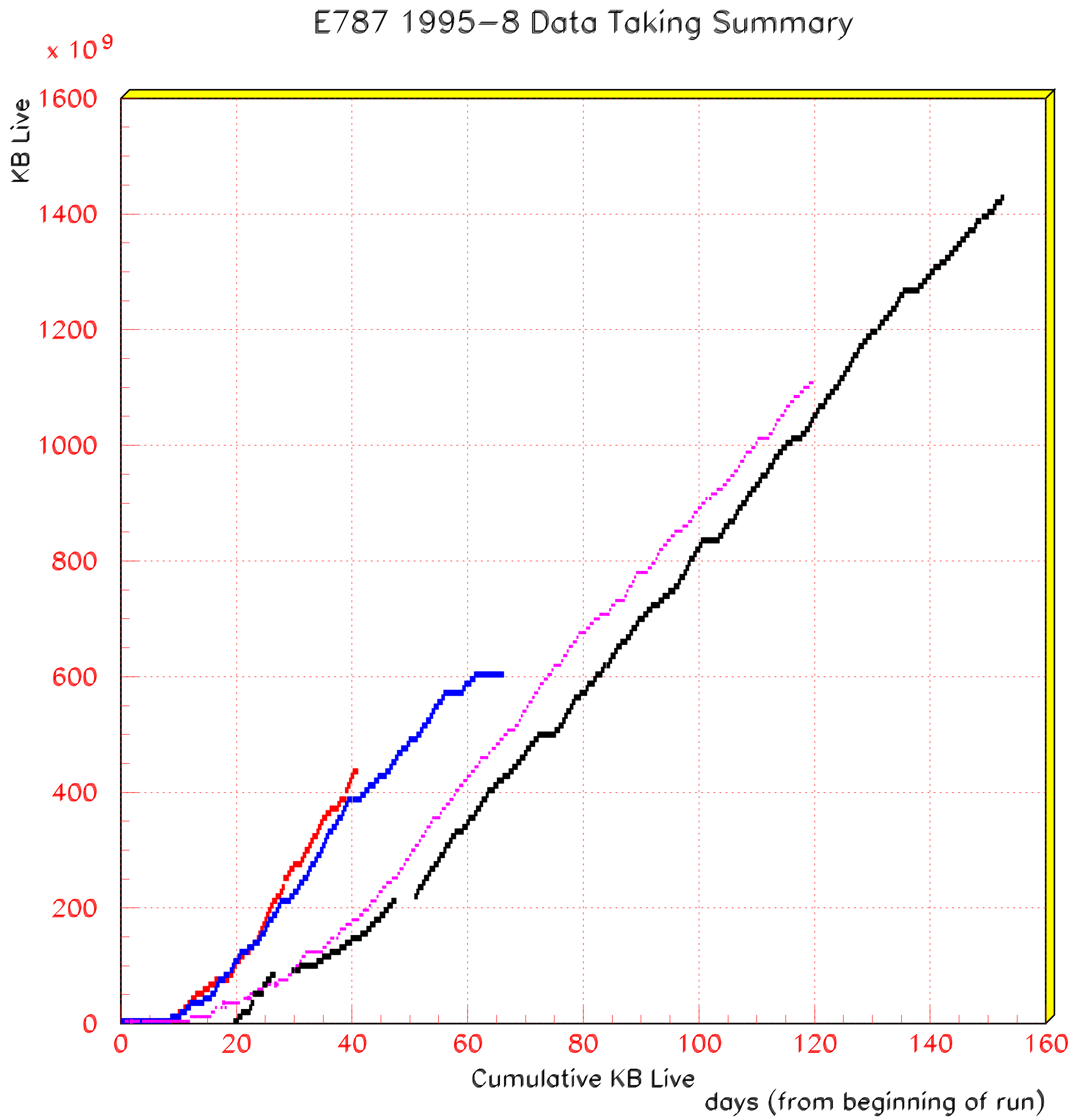
- Based on no events observed in $K^+ \to \pi^+ X^0$ region:

$$\mathrm{BR}(K^+ \to \pi^+ X^0) < 3.0 \times 10^{-10} \quad (90\%\ \mathrm{CL},\ \mathrm{M}_{\mathrm{X}^0}=0)$$



Main "online" improvements since 1995

- 1996
  - Lower K^+ momentum $\Rightarrow$ lower accidental loss
  - Higher acceptance in trigger
- 1997
  - Further lowered K^+ momentum
  - Lower deadtime from trigger improvements
  - Higher acceptance from TD readout
- 1998
  - Improved duty factor
  - Higher proton intensity
  - Optimization of running conditions



E787 1995–8 Data Taking Summary
x 10^9
KB Live
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
Cumulative KB Live
days (from beginning of run)

Offline analysis

Goals

- Increase rejection to maintain signal/noise as sensitivity grows
- Maintain (or possibly even increase) acceptance at the same time

$K_{\pi 2}$

- Tracking improvements in range stack and target $\Rightarrow$ better range resolution (core) and smaller tail

$K_{\mu 2}$

- Tracking improvements in drift chamber $\Rightarrow$ smaller momentum tail
- Range stack dE/dx likelihood analysis $\Rightarrow$ effective against interacting muons
- Optimized $\pi^+ \to \mu^+ \to e^+$ analysis

1 beam

- New cuts with redundancy against tails in timing

2 beam

- Bkg relatively low
- Transient digitizer analysis?
- Extra beam wire chamber segmentation (1998) will help

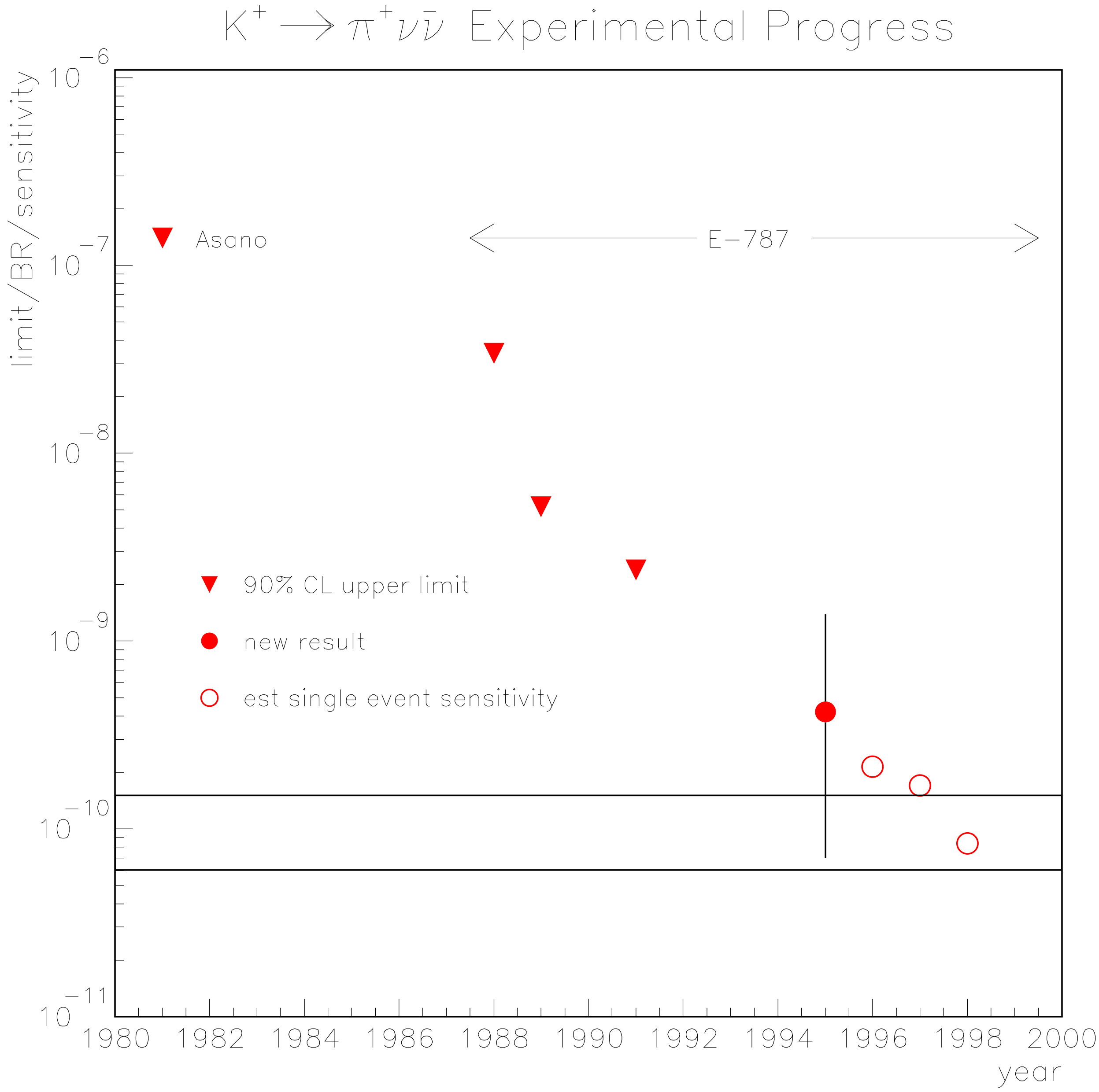
CEX

- Discriminant function analysis in target and beam hodoscopes

Current status

- Production jobs on all data 1995-1997 completed with all the latest code improvements
- Background studies advanced

Current sensitivity estimate



- Data in hand should clarify whether one event observed so far was a statistical fluctuation
- E787 has the capability to measure BR($K^+ \rightarrow \pi^+\nu\overline{\nu}$) at the SM level with the current capabilities of the AGS
- Ultimate result depends on priority of E787 at BNL and on AGS performance