KEK-IPNS

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NP01 International Workshop @KEK December'01

Stopped-kaon experiments for $K^+ \to \pi^+ \nu\bar{\nu}$

Outline

- Introduction
- Current status: final results from E787
- FNAL CKM experiment
- Stopped-kaon experiments
  - BNL E787/E949 experiments
  - $K^+ \to \pi^+ \nu\bar{\nu}$ below $K_{\pi 2}$
- a new experiment at 50-GeV PS:
  things_to_do (beamline and detector) for EoI/LoI

* XXI Physics in Collision
@Seoul June'01
"Kaon rare decays"

Summary:

		PDG '86	PDG '96	PIC '01
$K_L \to \mu^+\mu^-$	in 10^{-9}	9.1 ± 1.9	7.2 ± 0.5	7.18 ± 0.17
$K_L \to \pi^0 e^+ e^-$	in 10^{-10}	< 23000	< 43	< 5.1
$K_S \to \pi^0 e^+ e^-$	in 10^{-7}	-	< 11	< 1.4
$K^+ \to \pi^+ \nu\bar{\nu}$	in 10^{-10}	< 1400	< 24	$1.5^{+3.4}_{-1.2}$
$K_L \to \pi^0 \nu\bar{\nu}$	in 10^{-7}	-	< 580	< 5.9
$K_L \to \mu^\pm e^\mp$	in 10^{-12}	< 6000000	< 33	< 4.7
$K_L \to \pi^0 \mu^\pm e^\mp$	in 10^{-10}	-	-	< 4.4
$K^+ \to \pi^+ \mu^+ e^-$	in 10^{-11}	< 500	< 21	< 2.8

We expect further improvements (and discoveries)
in the next 5-10 years !

News updates

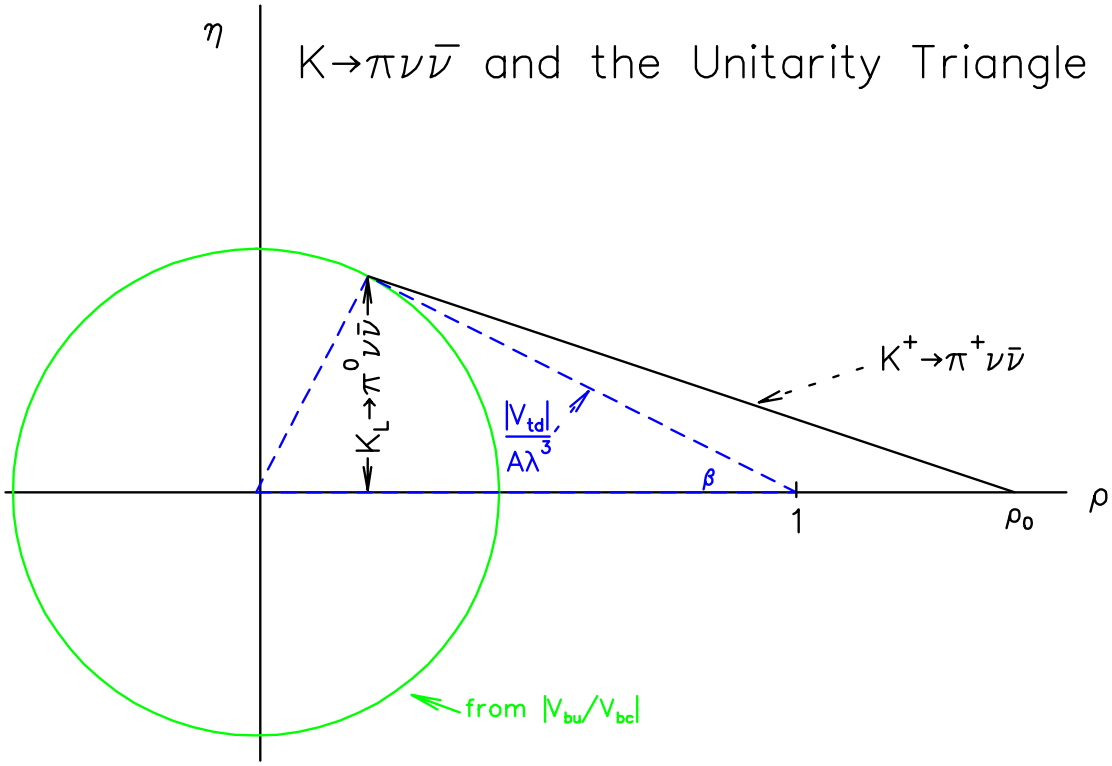
- FNAL-CKM:
  in-flight $K^+ \to \pi^+ \nu\bar{\nu}$ experiment
  Scientific (Stage I) approval

- BNL-E787
  (data-taking completed in '98)
  "Further Evidence for the Decay"

  hep-ex/0111091, to be published in PRL

B.R.($K^+ \to \pi^+ \nu\bar{\nu}$)

$$4.11 \times 10^{-11} \cdot A^4 \cdot X(x_t)^2 \cdot [\ (\rho_0 - \rho)^2 \ + \ \eta^2\ ]$$



(ρ, η) from ϵ_K, $|V_{ub}/V_{cb}|$, ΔM_{Bd}, ΔM_{Bs}

$\Downarrow$

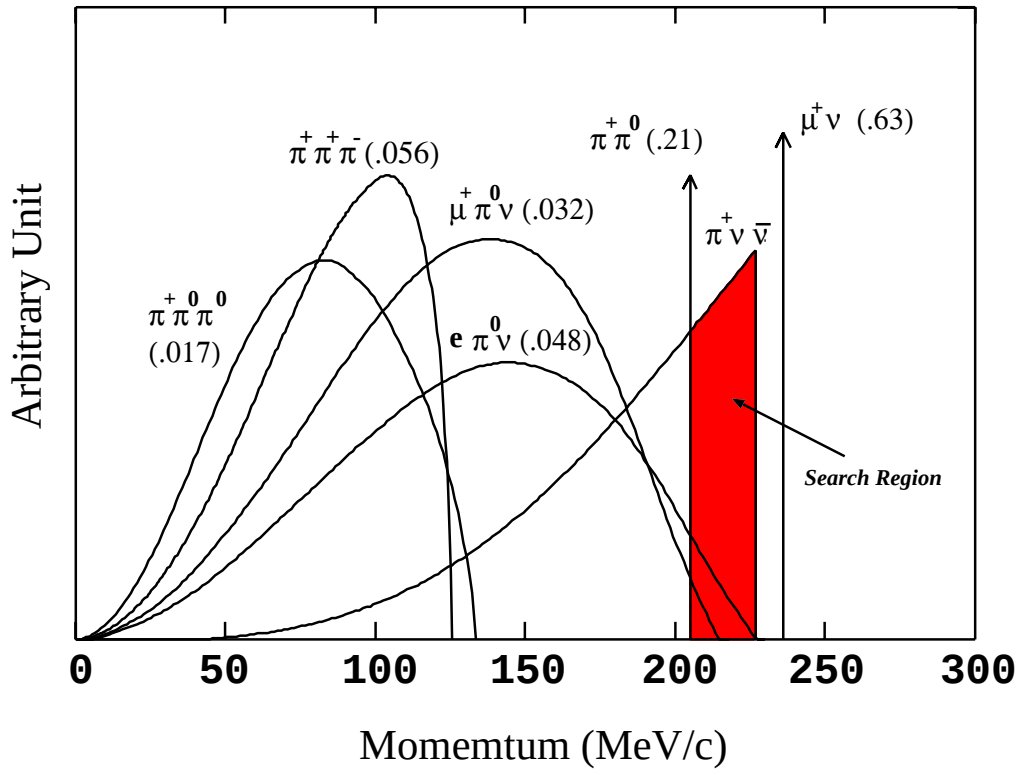
Standard Model prediction: $(0.75 \pm 0.29) \times 10^{-10}$

* $|\Delta M_{Bd}/\Delta M_{Bs}| \Rightarrow < 1.15 \times 10^{-10}$

A measurement at 1.5×10^{-10}
would be beyond the SM.

Buras: *hep-ph/0101336*
Isidori: *hep-ph/0110255*
Buchalla: *hep-ph/0110313*

K^+ decay to π^+ plus "nothing" (in CMS)



the π^+ ($< 227\text{MeV}/c$) from 3-body decay

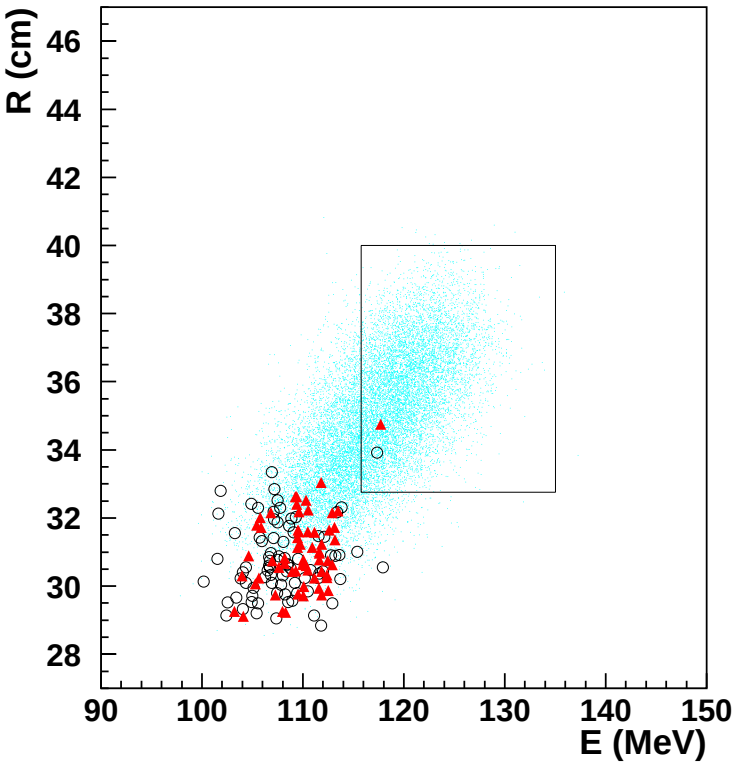
Background rejection is essential in this experiment.

- Kinematics : Momentum/Energy/Range
- μ^+ rejection $\Longleftrightarrow K^+ \to \mu^+\nu$
- Extra particles (γ) Veto $\Longleftrightarrow K^+ \to \pi^+\pi^0$

each weapon should have rejection of $10^5 \sim 10^6$

$\leftarrow$ reliable estimation using real data

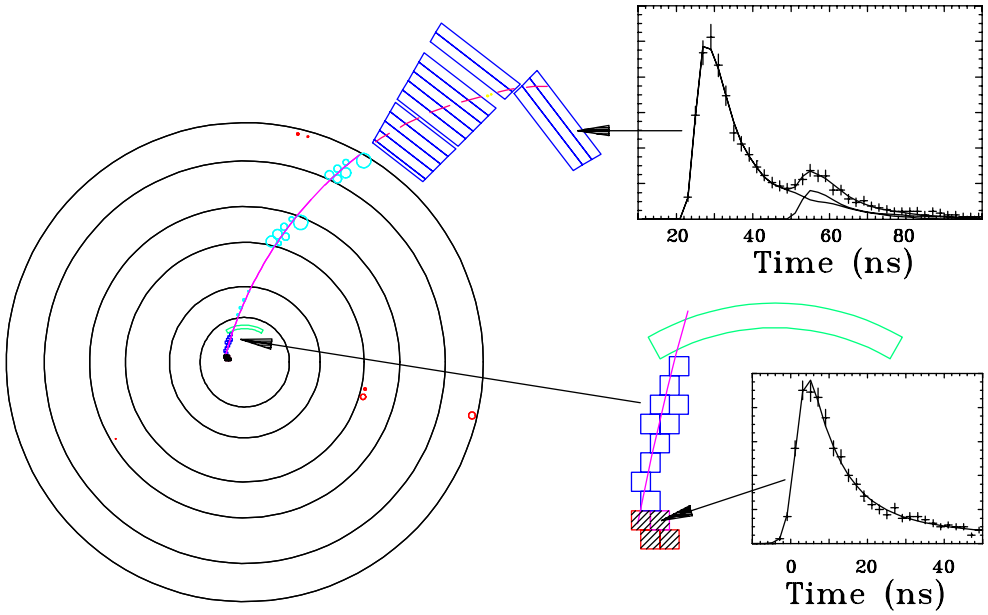
Final results on $K^+ \to \pi^+ \nu\bar{\nu}$ from E787

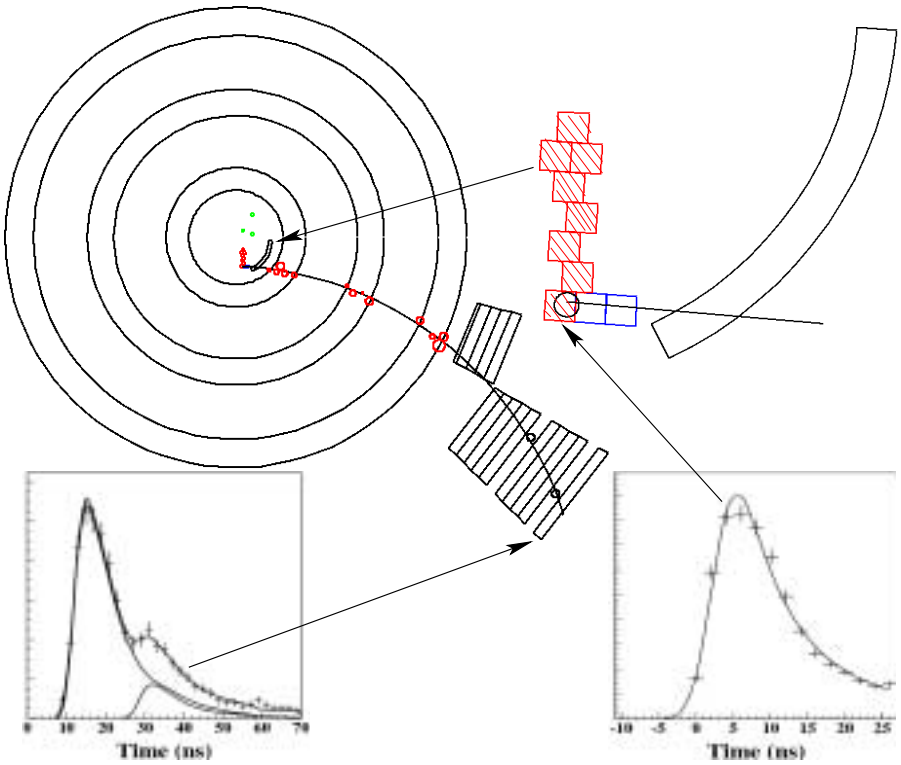


	1995-97	1998
N_K	3.2×10^{12}	2.7×10^{12}
Acceptance $(\times 10^{-2})$	0.21 $\pm 0.01_{\text{stat}} \pm 0.02_{\text{syst}}$	0.196 $\pm 0.005_{\text{stat}} \pm 0.010_{\text{syst}}$
Sensitivity	1.50×10^{-10}	1.89×10^{-10}
Observation (evt)	1	1
Background (evt)	0.08 ± 0.03	$0.066^{+0.044}_{-0.025}$

$$\text{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = 1.57^{+1.75}_{-0.83} \times 10^{-10}$$

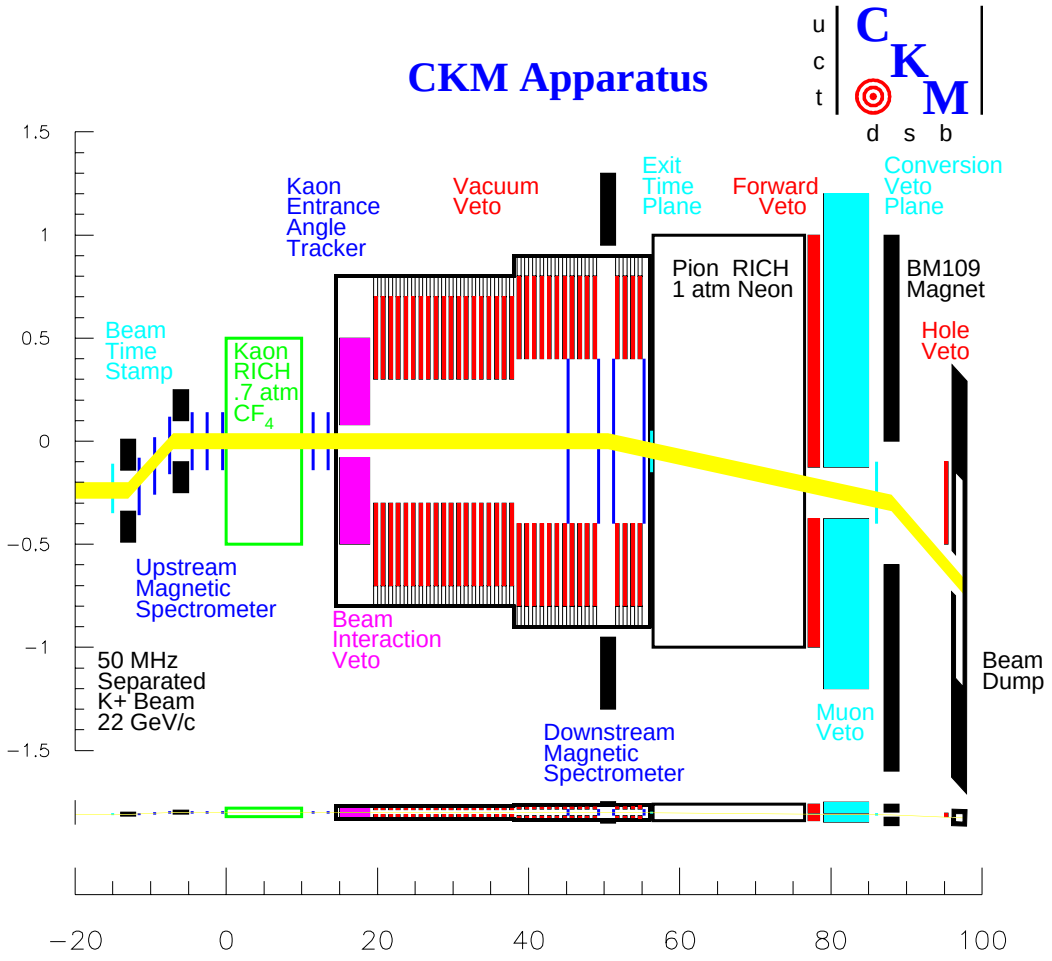
(68% C.L. interval)

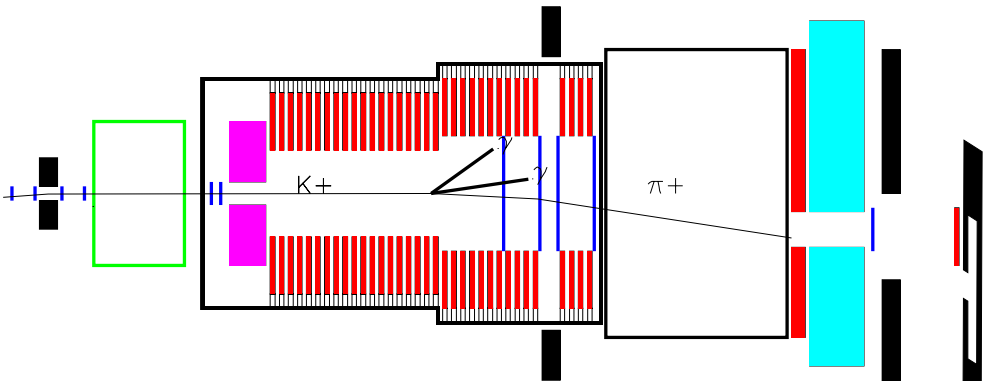

20
40
60
80
Time (ns)
0
20
40
Time (ns)

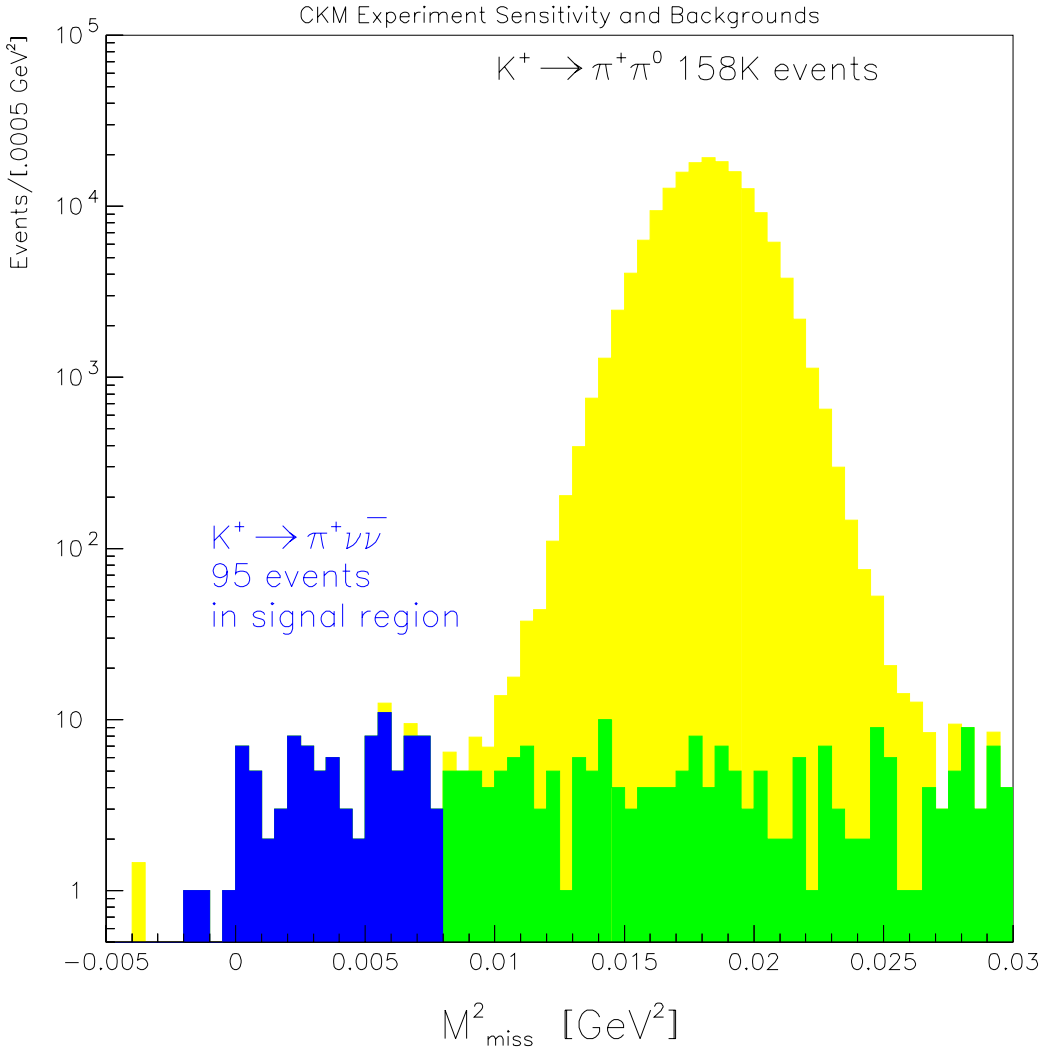

Time (ns)
Time (ns)

FNAL CKM experiment

in-flight K^+ decay to π^+ plus "nothing"



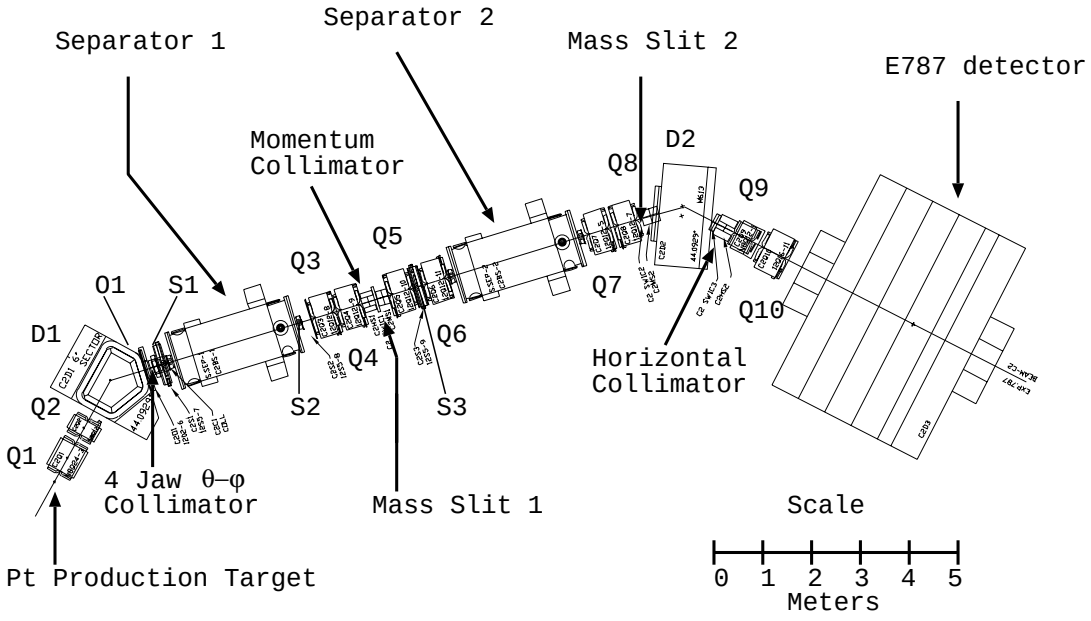




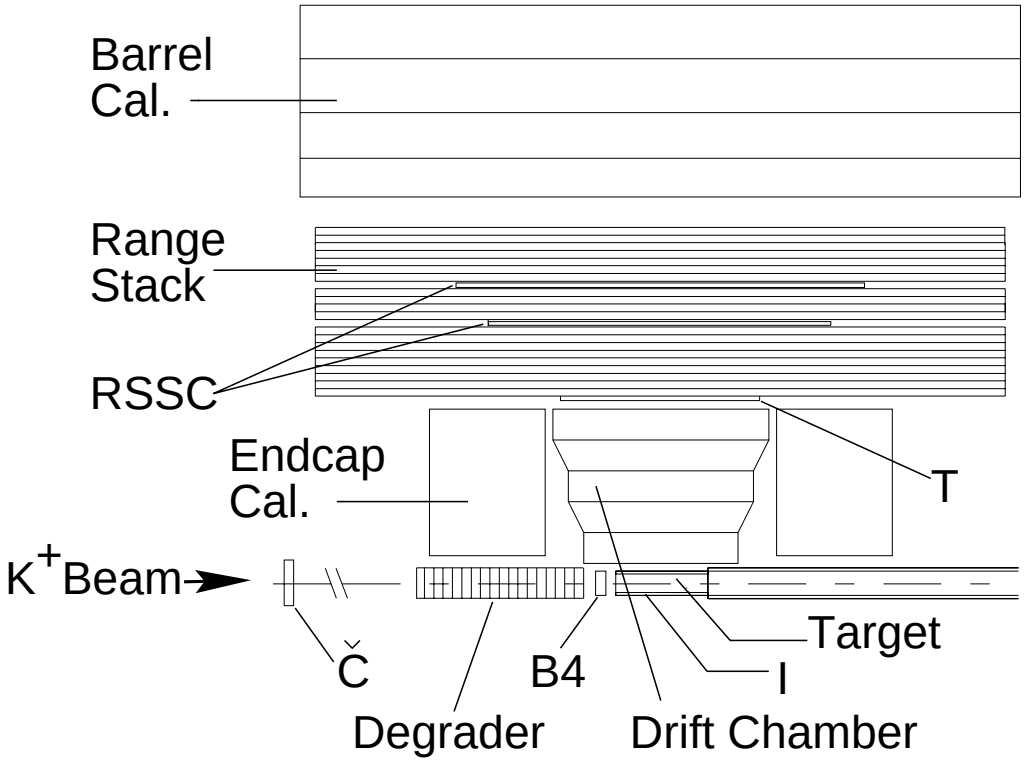
- higher energy $\rightarrow$ γ/μ^+ rejection better
- **in-flight K^+ decay** to π^+ plus "nothing":
  $\Longleftarrow$ The technique is not proved yet.
- benchmark for a new proposal:
  100 signal events (10% precision) around the year 2010

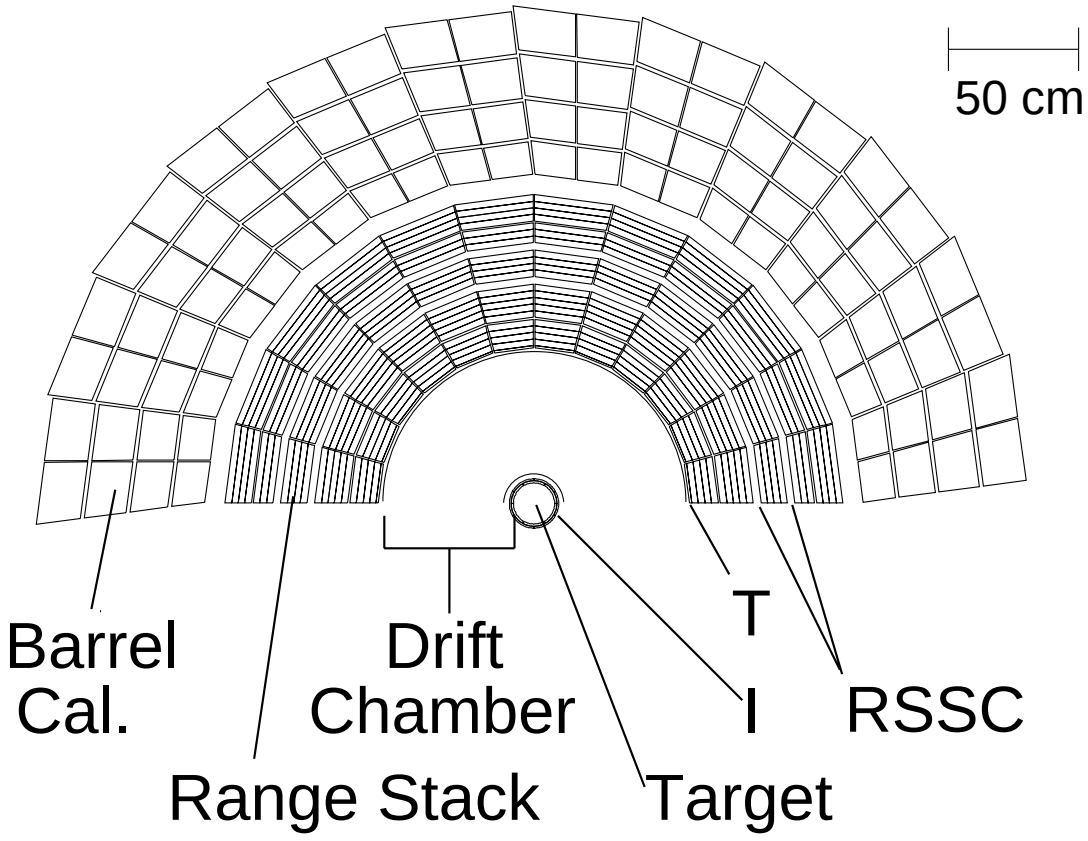
LESB3: a two-stage separated 800-MeV/c kaon beamline

J. Doornbos et al., NIM A 444, 546 (2000)

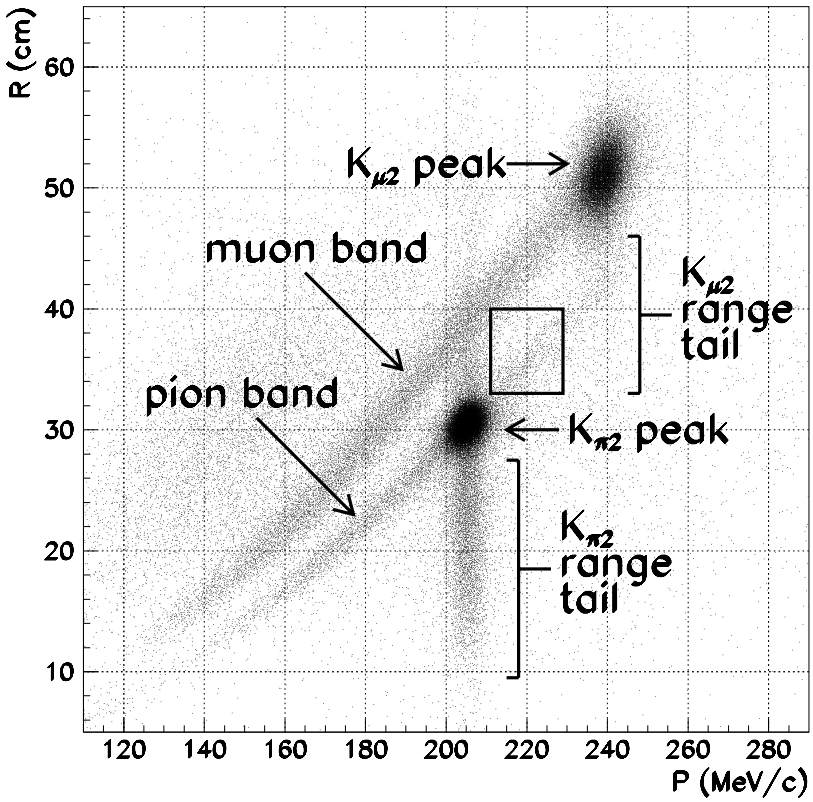


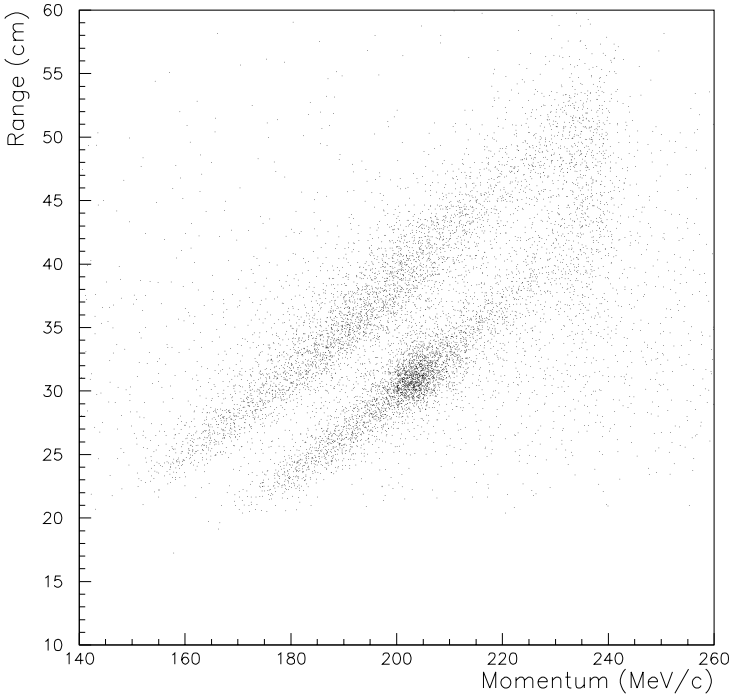
- $\sim$ 5 $\times$ 10^5 $K^+/10^{12}$ protons on target
- K/π ratio > 3


Barrel
Cal.
Range
Stack
RSSC
Endcap
Cal.
T
K+Beam
Target
Č
B4
I
Degrader
Drift Chamber


50 cm
Barrel
Cal.
Drift
Chamber
T
I
RSSC
Range Stack
Target

Charged tracks in the spectrometer





$\pi^+\nu\bar{\nu}$ trigger, 1st-pass reconstruction

Acceptance

Acceptance factors	method	1995-97	1998
K^+ stop efficiency	BR($K_{\mu 2}$)	0.704	0.702
K^+ decay after 2 ns	$K_{\mu 2}$	0.850	0.851
$K^+ \to \pi^+ \nu\bar{\nu}$ phase space	M.C.	0.155	0.136
Solid angle acceptance	M.C.	0.407	0.409
π^+ stop efficiency	M.C.	0.513	0.527
Reconstruction efficiency	$K_{\mu 2}$	0.959	0.969
Other kinematic constraints	π_{scat},$K_{\pi 2}$	0.665	0.554
$\pi - \mu -$ e decay acceptance	π_{scat}	0.306	0.392
Beam and target analysis	$K_{\mu 2}$	0.699	0.706
Accidental loss	$K_{\mu 2}$	0.785	0.751
Total acceptance		0.21%	0.196%

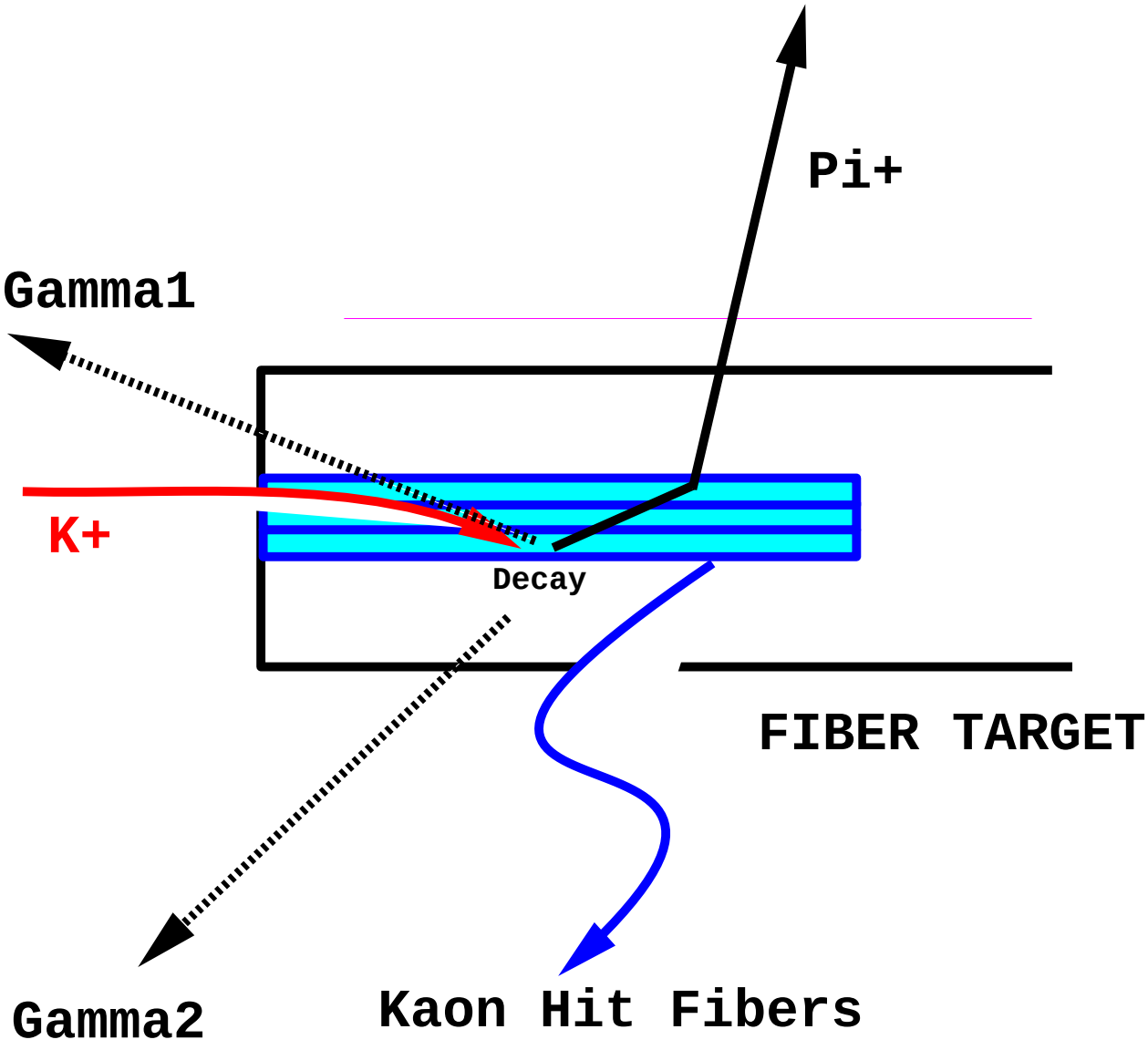
"π^+ stop" (Range) and "$\pi - \mu -$ e decay" vs. μ^+ background

- π^+/μ^+ non-destructive measurement
  in destructive Target, Range Stack
- waveform digitization $\Leftarrow$ huge event size
- wait K^+, π^+, and μ^+ decays $\Leftarrow$ accidental loss

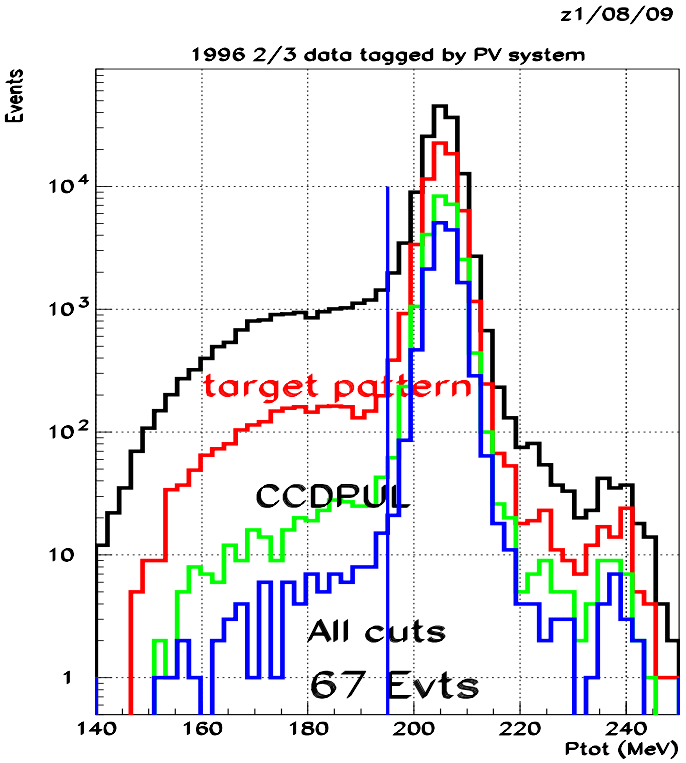
"beam and target analysis" and "Accidental loss"
$\Rightarrow$ duty factor and beam line

"$K^+ \to \pi^+ \nu\bar{\nu}$ phase space"
$\Rightarrow$ below $K^+ \to \pi^+\pi^0$ peak (205MeV/c) ??

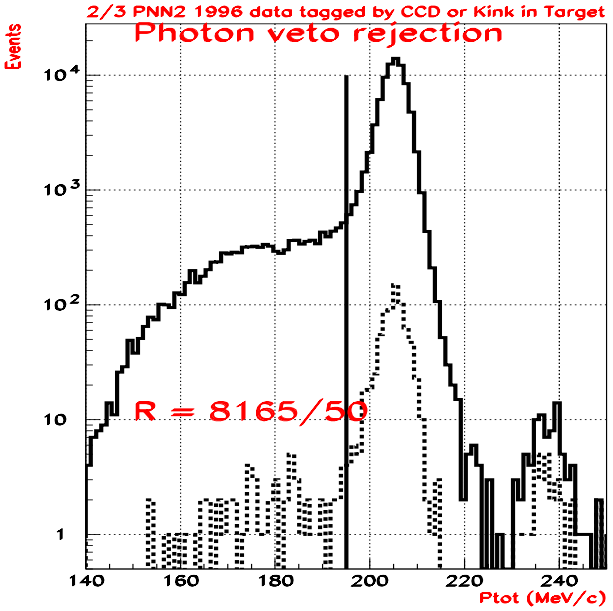
$K^+ \to \pi^+\nu\bar{\nu}$ "below $K^+ \to \pi^+\pi^0$ peak (205MeV/c)"



Momentum distribution of the $K_{\pi 2}$ background



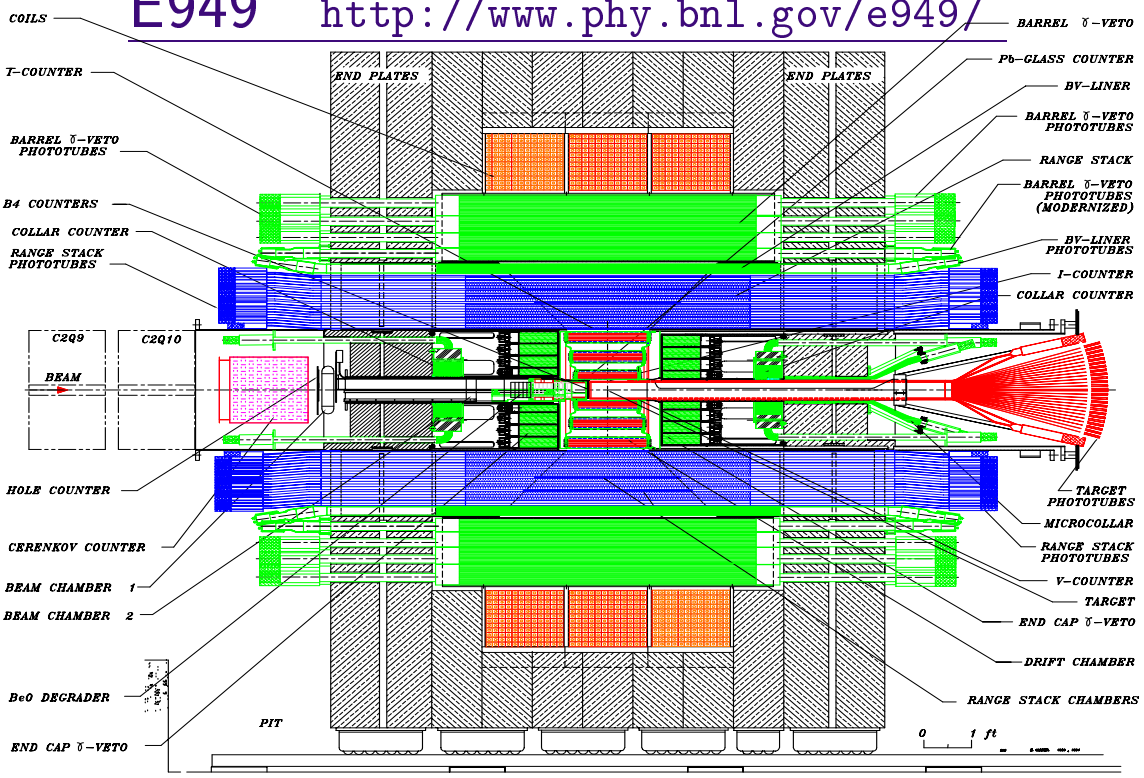
$K_{\pi 2}$ background reduction due to Photon Veto



$\times 0.20$ of N_K, $\times 1/2$ of the acceptance:

$K_{\pi 2}$ background 0.62 ± 0.17

E949 http://www.phy.bnl.gov/e949/

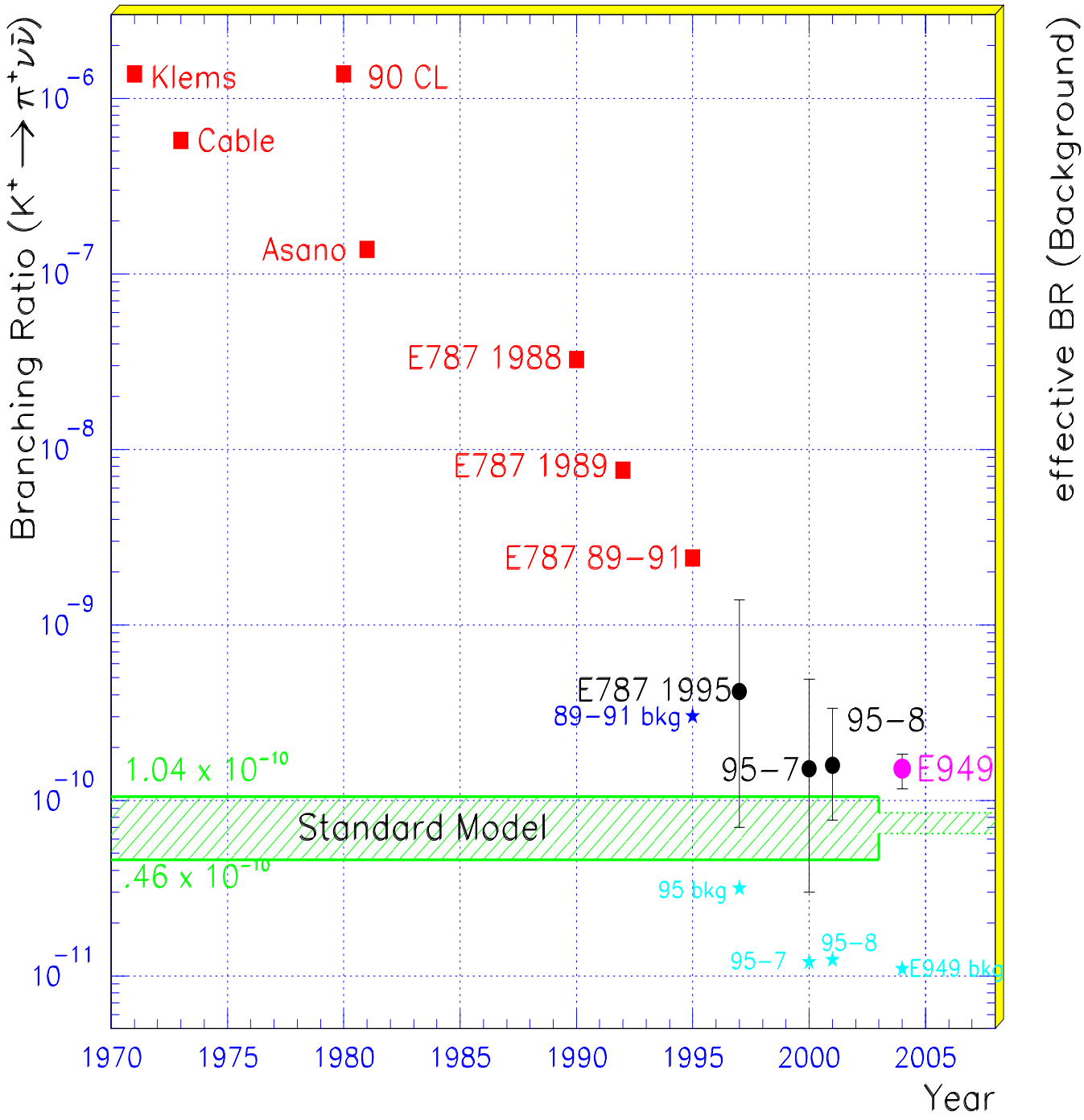


Detector upgrade from E787

1. Barrel Liner shower counter
2. new/improved Photon Veto counters around the beamline
3. new B4 counter, degrader
4. Trigger: programable Level0 board, Mean Timers
5. RS TDC readout (tag $\mu^+ \to e^+$ without TD):
   $\Longrightarrow$ deadtime reduction
6. RS Monitor system using LEDs
7. ...

- Optimization of running mode and analysis
- Sensitivity (8–14)$\times 10^{-12}$ in 6000 hr
  ($\sim$ 2 years of running with RHIC;
  engineering run Sep-Nov '01, physics run from '02).
- Determine $|V_{ts}^* \cdot V_{td}|$ to 20–30%.

History of the Search for $K^+ \to \pi^+ \nu\overline{\nu}$



Stopped Kaon decay: can we improve the E949-type detector further and compete with CKM ?

- The JHF-50GeV Slow-Ext. is not optimized to the stopped $K^+ \to \pi^+ \nu\bar{\nu}$ experiment (or any type of coincidence experiment).

PS operation		AGS	JHF-0		KAON	
proton energy	GeV	24	50		30	
protons on Tgt	10^{12}/spill	65	330	$\times 5.0$	62.5	$\times 0.96$
machine cycle	sec	6.4	3.42	$\times 1/1.87$	0.1	$\times 1/64$
average current	μA	1.63	15.6	$\times 9.6$	100	$\times 61$
slow extraction	sec	4.1	0.7	$\times 1/6$	0.085	$\times 1/48$
duty factor		0.64	0.20	$\times 0.31$	0.85	$\times 1.33$
instantaneous rate	10^{12}/sec	16	470	$\times 29$!!	735	$\times 46$

Key 1: K^+ Beam
optimization of the accelerator and beam line

PS operation		AGS to LESB3 E949	JHF-mod to K550 pnnJHF	[1/3]
proton energy	GeV	24	30	
protons on Tgt	10^{12}/spill	65	100	$\times$ 1.54
machine cycle	sec	6.4	3.42	$\times$ 1/1.87
average current	μA	1.63	4.68	$\times$ 2.88
slow extraction	sec	4.1	1.8	$\times$ 1/2.3
duty factor		0.64	0.53	$\times$ 0.83
instant. rate	10^{12}/sec	16	55.6	$\times$ 3.5
K^+ momentum	MeV/c	730	550	(no lose)
stopping fraction		0.26	0.4	$\times$ 1.5

- For EoI/LoI,
  get our opinions together and
  request better duty-cycle for Kaon experiments
- start designing K1.1 beamline $\Longleftarrow$ J. Imazato, T. Sato
  - limited budget, resource...
    KEKPS K5 beamline (single stage) to JHF ?
  - possible to build K550 ?
  - other stopped-kaon experiments ?

Key 2: Detector
Upgraded Target and Range Stack
[better measurement, rate capability]

- RS segmentation (chopping : $< 1/4$)
- scintillator/SCF readout with more light outputs

start conceptual design
based on the E787/E949 experience

Key 3: Waveform digitization (300$\sim$500 MHz)
have our own technology
[faster online decision, cheaper]

stopped $K^+ \to \pi^+ \nu\bar{\nu}$ experiment at JHF

Improvement (compared to the BNL-E949 proposal)

- Running mode $\times 1.9$:
  - stopping fraction ($\times 1.5$ by K550)
  - duty factor ($\times 0.83$)
  - beam hours : $\sim$3 years of running ($\times 1.5$)
- New Detector [segmented, faster, ...] $\times 2.0$:
  - rate capability for higher intensity
- re-optimization $\times 1.5$:
  - S/N = 5 $\Rightarrow$ TD electron cut, ... ($\times 1.2$)
  - brighter detector $\Rightarrow$ better E resoluton, ... ($\times 1.2$)
  - pipeline trigger, faster DAQ, ... ($\times 1.1$)
- $K^+ \to \pi^+ \nu\bar{\nu}$ below the $K_{\pi 2}$ peak $\times 2$
  measure the π^+ spectrum to confirm the SM prediction.
  (do the best efforts in E949)

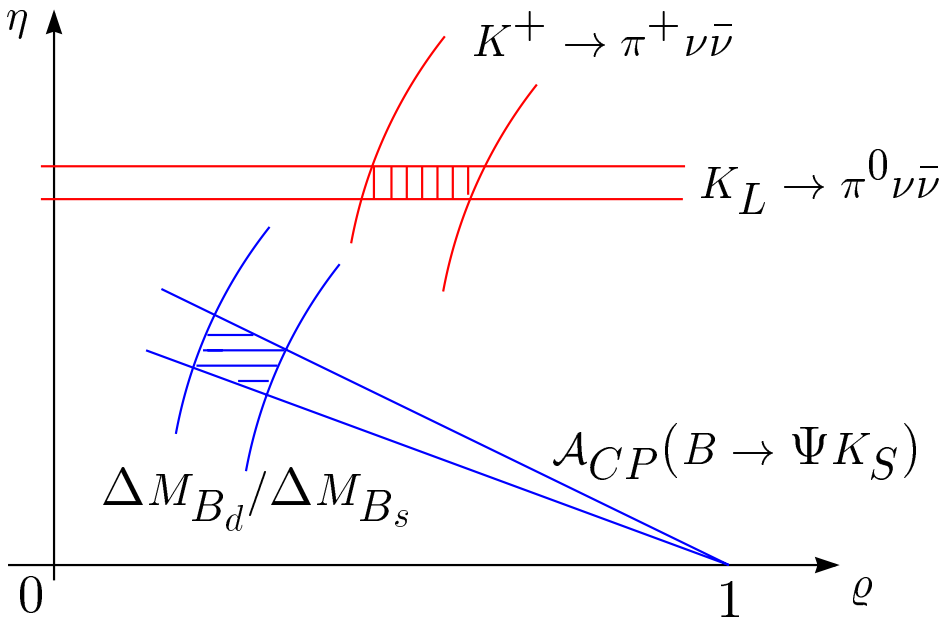
Goals:

- Sensitivity 1 $\times 10^{-12}$ (Background 2 $\times 10^{-11}$)
- $\sim$ 100 SM signals , S/N = 5.
- competition with the "in-flight" experiment

Summary:

$K^+ \to \pi^+ \nu\bar{\nu}$ @ stopped-kaon experiments

- The stopped-kaon experiment (E787) is currently the best method to observe $K^+ \to \pi^+ \nu\bar{\nu}$.
- The new BNL-E949 experiment is rising; this experiment is very important to know:
  - is BR($K^+ \to \pi^+ \nu\bar{\nu}$) really consistent with SM ?
  - is it possible to measure $K^+ \to \pi^+ \nu\bar{\nu}$ below $K_{\pi 2}$?



- Speak up for better duty-cycle, and start designing K1.1 beamline for stopped-kaon experiments at JHF (and studying many R&D issues for pnnJHF).