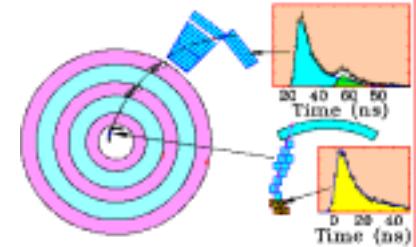


# Search for the rare kaon decay

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$  at BNL - E949



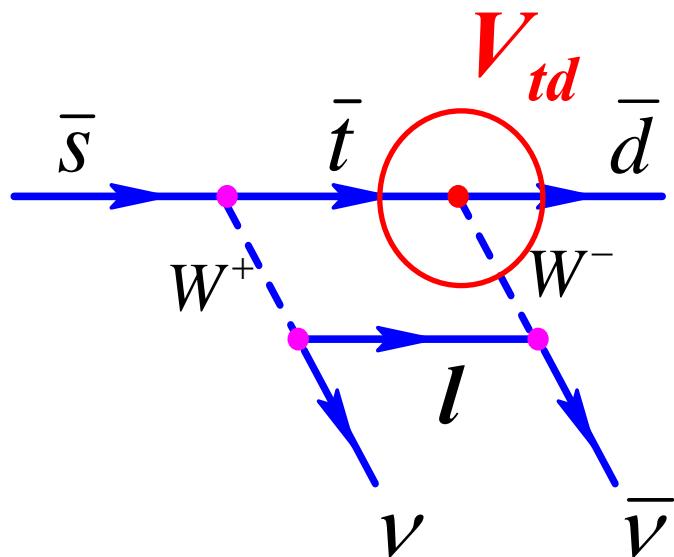
*KEK, Osaka Univ. RCNP<sup>A</sup>, Osaka Univ.<sup>B</sup>, Kyoto Univ.<sup>C</sup>, JAERI<sup>D</sup>, Fukui Univ.<sup>E</sup>, NDA<sup>F</sup>, Alberta<sup>G</sup>, UBC<sup>H</sup>, BNL<sup>I</sup>, FNAL<sup>J</sup>, IHEP<sup>K</sup>, INR<sup>L</sup>, UNM<sup>M</sup>, SUNY Stony Brook<sup>N</sup>, TRIUMF<sup>O</sup>*

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and BNL-E949 Collaboration<sup>A,B,C,D,E,F,G,H,I,J,K,L,M,N,O</sup>

# 1. Physics Motivation

The rare decay  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

(Flavor Changing Neutral Current: FCNC)



- Second order: Top quark dominant
- $V_{td}$  vertex
- Theoretical uncertainty in  $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \sim 7\%$



Good decay to measure  $|V_{td}|$  in  $K^+$  system

## **1.1 Search for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$**

**Two events were observed from BNL-E787.**

$$Br(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = 1.57_{-0.82}^{+1.75} \times 10^{-10}$$

**Observation**



$$(0.77 \pm 0.11) \times 10^{-10}$$

**SM prediction**

Mean value is twice higher,  
but consistent within error.

## *2. BNL-E949 Experiment*

BNL-E949: Successor to BNL-E787.

Aim: Collect more signal events.

### *2.1 Search Region*

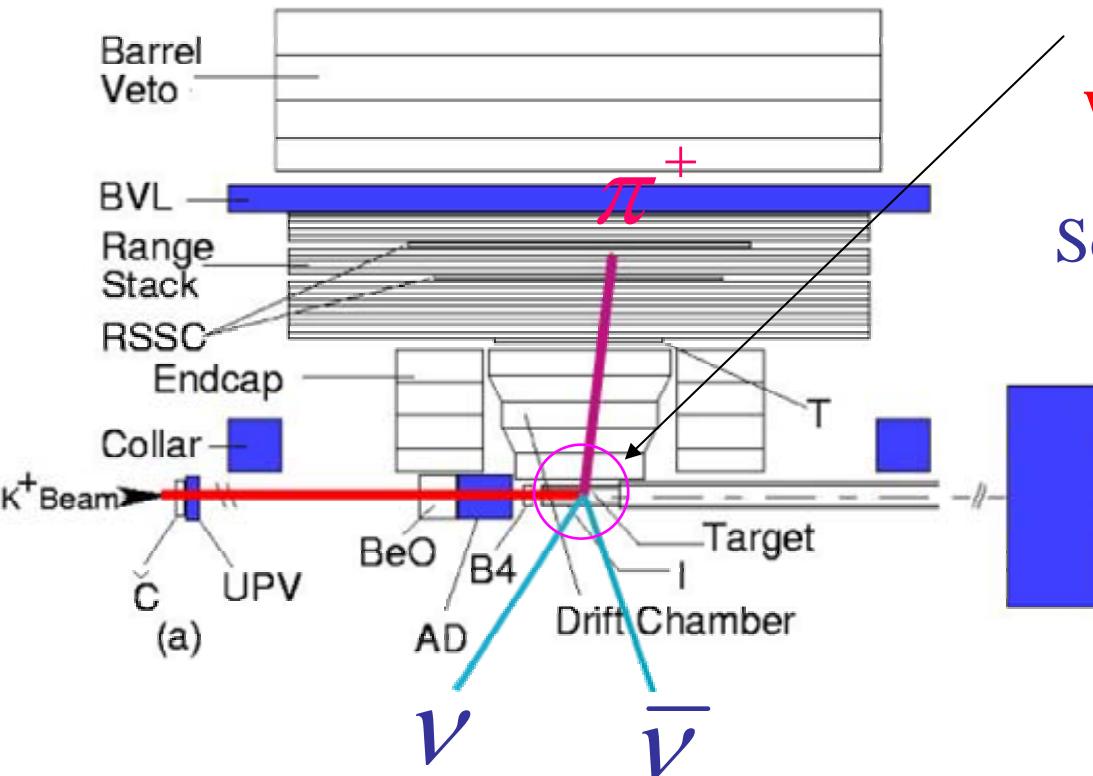
$211 \text{ MeV/c} < P < 229 \text{ MeV/c}$

Above  $K^+ \rightarrow \pi^+ \pi^0$  peak  
( $\pi^+ \nu \bar{\nu}$  region 1)

Below  $K^+ \rightarrow \pi^+ \pi^0$  peak  
( $\pi^+ \nu \bar{\nu}$  region 2)

## 2.2 E949 detector

### Stopped $K^+$ experiment



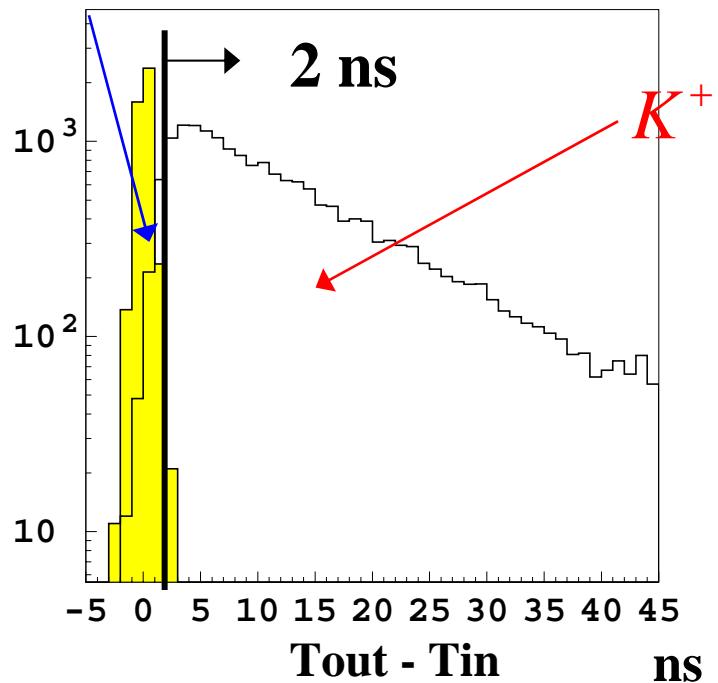
$K / \pi$  ratio in beam

$$\underline{K^+ : \pi^+ = 3:1}$$

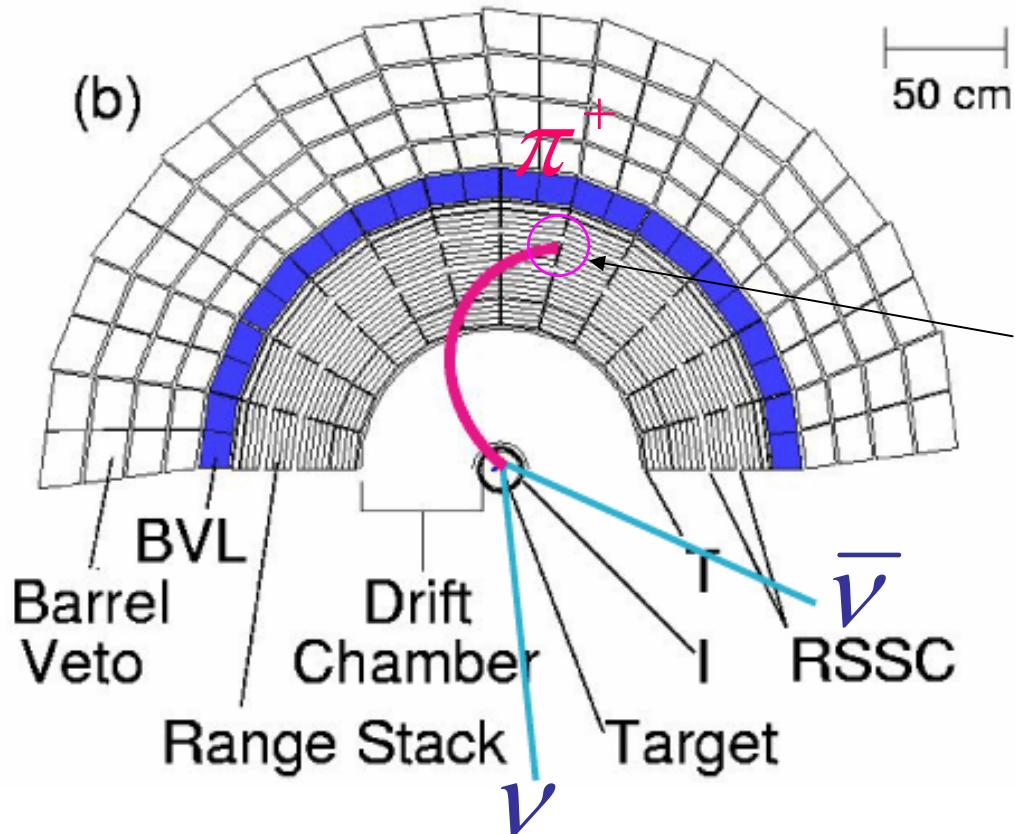
### Delayed Coincidence

Wait 2ns after  $K^+$  enters detector

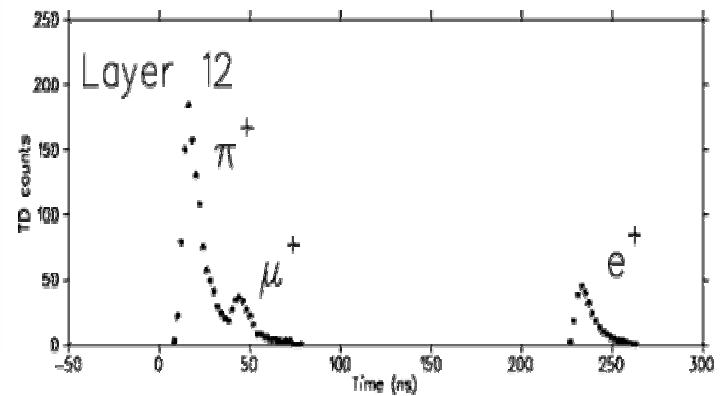
Scattered  $\pi^+$  beam



## 2.2 E949 detector

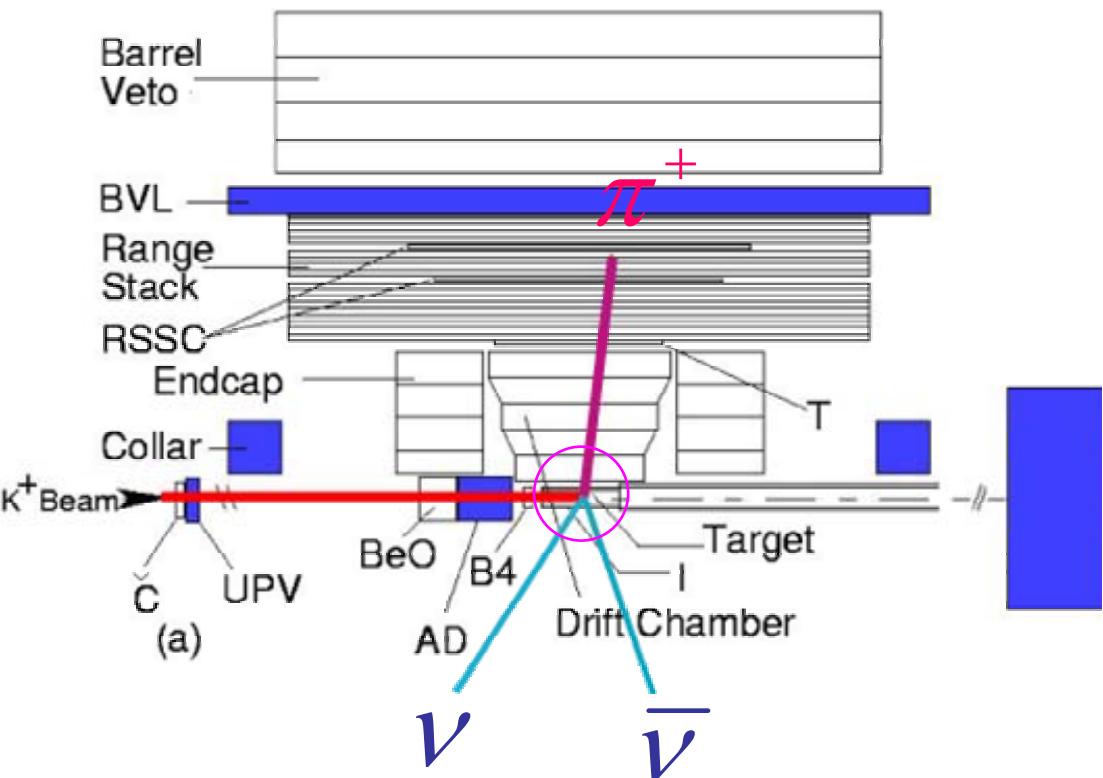


$\pi \rightarrow \mu \rightarrow e$  decay ID



Pulse analysis with Waveform Digitizer

## 2.2 E949 detector



$4\pi \gamma$  veto (Barrel + Endcap)

$\Rightarrow$  Veto  $K^+ \rightarrow \pi^+ \pi^0$  events

### Upgrades in E949 detector

- $\times 2$  higher beam intensity
- New Photon Detectors  
(Barrel:  $+ 2.3 X_0$ , Beam Hole)

• ...

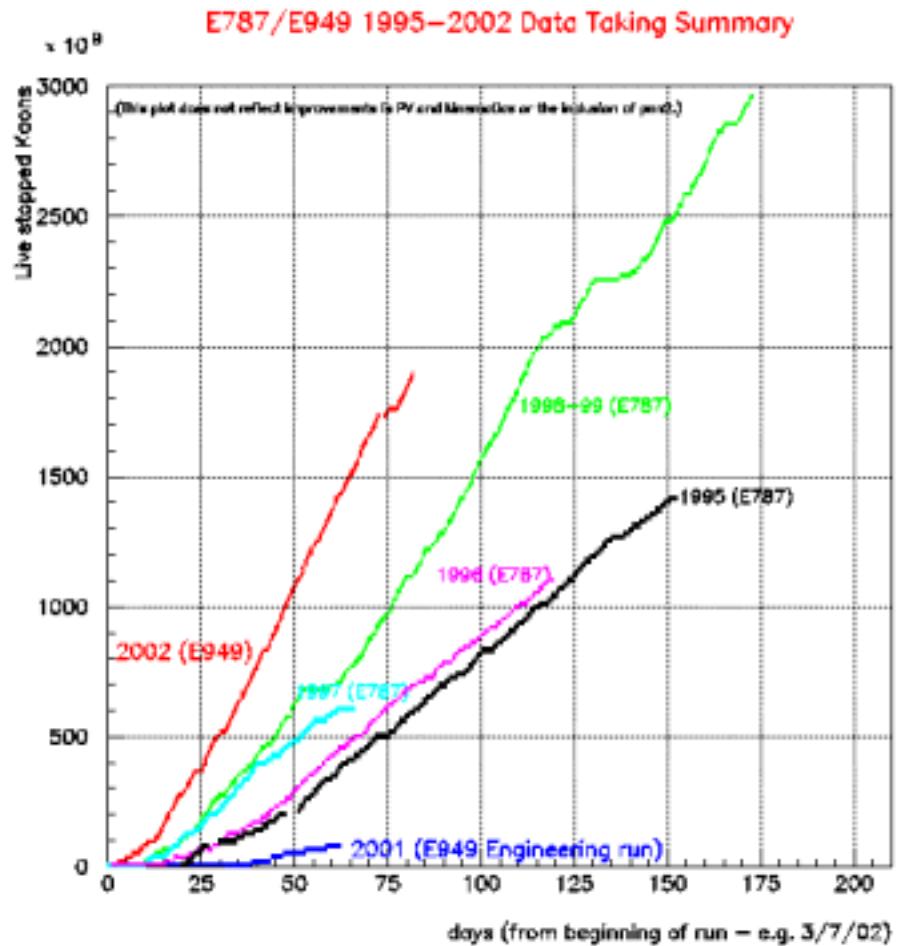
## 2.4 Data Taking

Physics run: 2002, February ~ June

~12 weeks

$$N_K = 1.8 \times 10^{12}$$

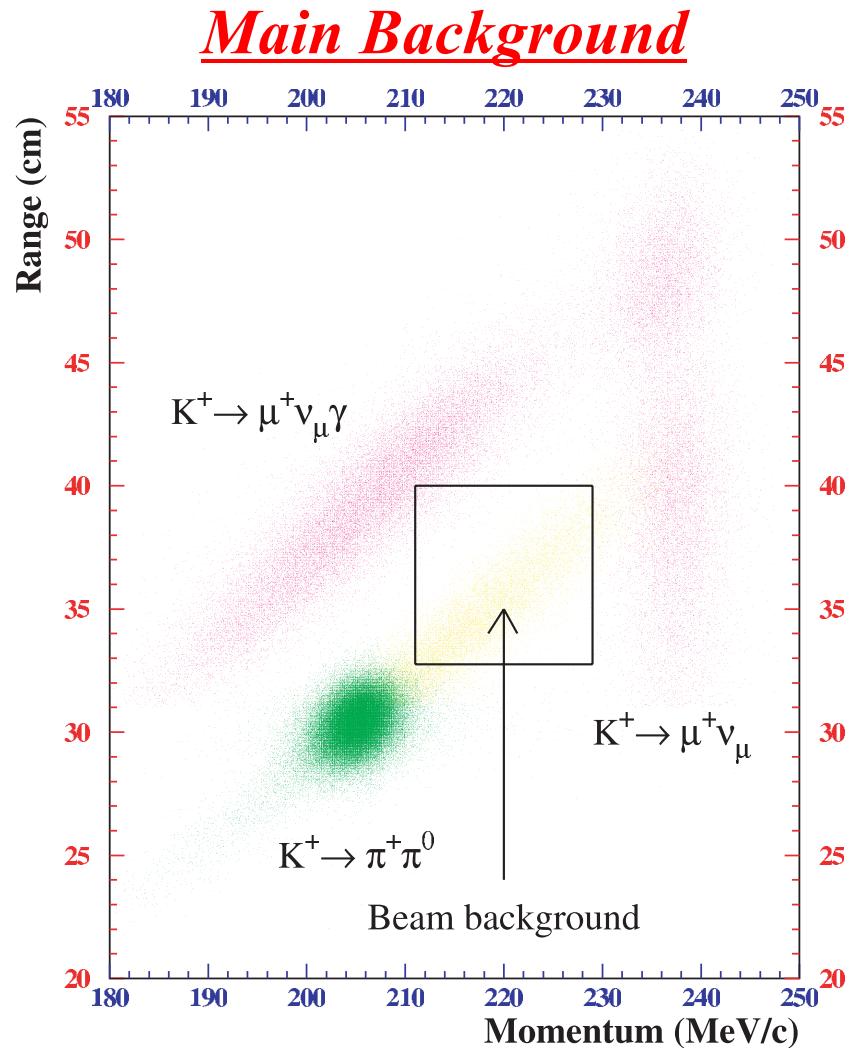
~1/3 of E787 data  
( E787 :  $5.9 \times 10^{12}$  )



### 3. *Background Study*

#### Analysis Strategy

- Blind Analysis
- Real data
- Likelihood Analysis



### 3.2 Likelihood Analysis

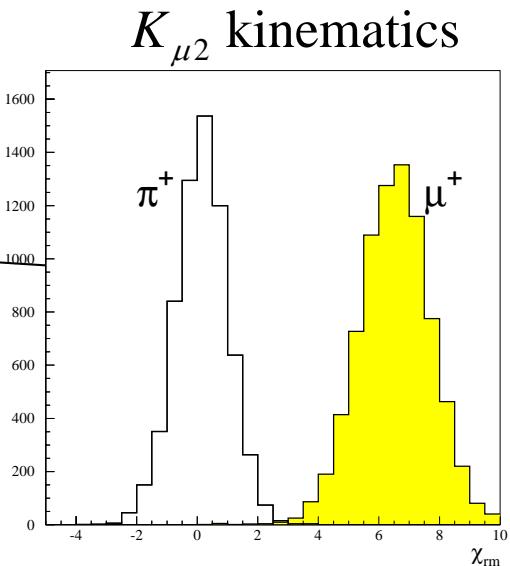
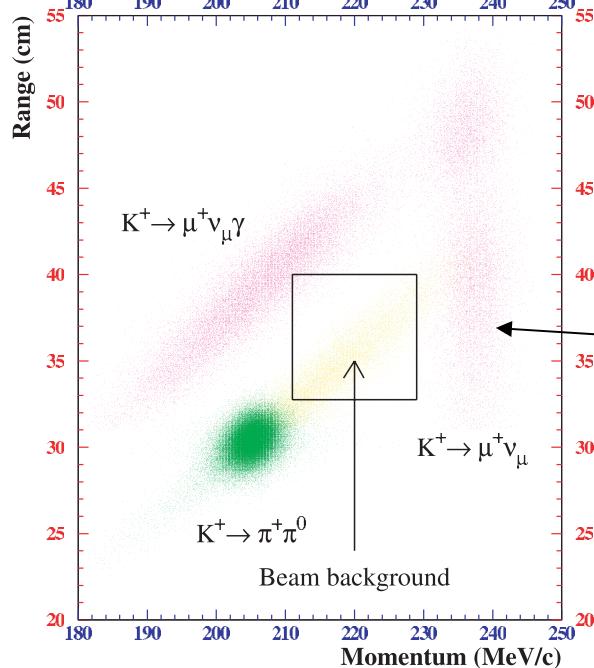
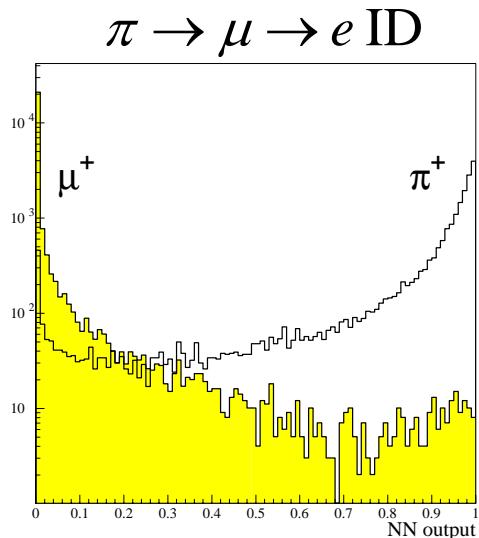
T. Junk method: [NIM A434, 435 (1999)]

**Calculate confidence level (C.L.) with a small statistic (Poisson stat.).**

$$X = \prod_{i=1}^n X_i, \quad X_i = \frac{(S_i + b_i)^{d_i} \cdot e^{-(S_i + b_i)}}{d_i!} \quad \left/ \frac{b_i^{d_i} \cdot e^{-b_i}}{d_i!} \right. = \left(1 + \frac{S_i}{b_i}\right)^{d_i} \cdot e^{-S_i}$$

$S_i = B.R. \cdot N_K \cdot A_i$  (B.R.:Branching ratio,  $N_K$  :# of  $K^+$ ,  $A_i$  :Acceptance.)

*Predefined Background Functions:*



### 3.3 Background and Sensitivity

#### Background summary

Background	Events
$K^+ \rightarrow \pi^+ \pi^0 (K_{\pi 2})$	$0.216 \pm 0.023$
$K^+ \rightarrow \mu^+ \nu_\mu (K_{\mu 2})$	$0.068 \pm 0.011$
Beam	$0.014 \pm 0.003$
Total	$0.298 \pm 0.026$

#### Sensitivity

Total Acceptance ( $10^{-2}$ )	$0.22 \pm 0.03$
$N_K (10^{12})$	1.8
Sensitivity ( $10^{-10}$ )	$2.6 \pm 0.3$

**Ready to open the BOX !**

## 4. Opening the BOX

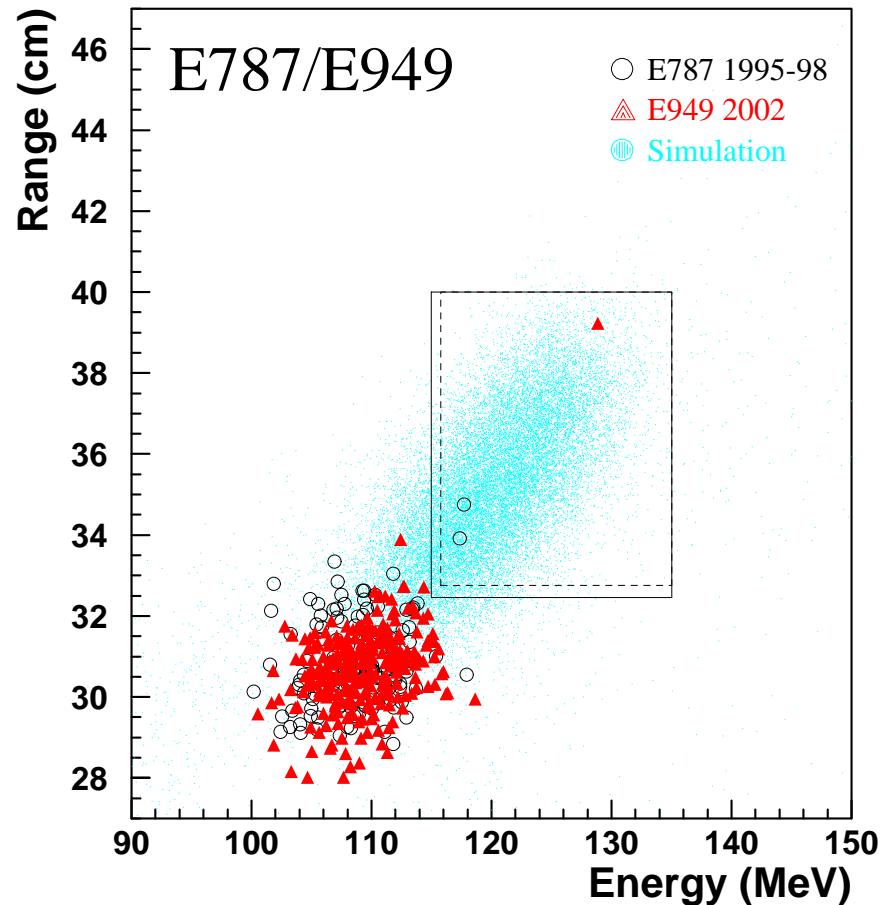
An event is observed near upper kinematic limit.

- E=128.9 MeV
- P=227.3 MeV/c
- R=39.2 cm
- $\pi^+$  decay time = 6.2 ns

**Other variables are fine.**

**S/N ratio for this event**

$$S_i/b_i = 0.9$$



## *4.1 Branching Ratio Calculation*

Combine E787 and E949 data

	E787	E949
$N_K$	$5.9 \times 10^{12}$	$1.8 \times 10^{12}$
<b>Candidate</b>	<b>1995A, 1998C</b>	<b>2002A</b>
$S_i/b_i$	<b>50, 7</b>	<b>0.9</b>
$W_i (= S_i/(S_i + b_i))$	<b>0.98, 0.88</b>	<b>0.48</b>
<b>Background Prob.</b>	<b>0.006, 0.02</b>	<b>0.07</b>

$$Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = 1.47_{-0.89}^{+1.30} \times 10^{-10} \quad (68\% \text{ C.L.})$$



$$(0.77 \pm 0.11) \times 10^{-10} \quad (\text{SM prediction})$$

## 5. Summary

- BNL - E949 is the experiment to measure  $K^+ \rightarrow \pi^+ \nu\bar{\nu}$  and to determine  $|V_{td}|$  element in CKM matrix,
- $N_K = 1.8 \times 10^{12}$  of  $K^+$  has been collected,
- Likelihood Analysis was used to calculate  $Br(K^+ \rightarrow \pi^+ \nu\bar{\nu})$ ,
- $Br(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = 1.47_{-0.89}^{+1.30} \times 10^{-10}$  is obtained with combined E787 and E949 data.

# *Backup Slides*

# *Momentum Spectrum of some $K^+$ decay modes*

