BNL E949 collaboration

> 60 physicists, 15 institutes from Canada, Japan, Russia and the US.

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E949 institutes

- Japan: KEK(+Tokyo), RCNP, Fukui, Kyoto, Osaka, NDA
- US: BNL, FNAL, Stony Brook, New Mexico
- Canada: TRIUMF, Alberta, British Columbia
- Russia: IHEP, INR

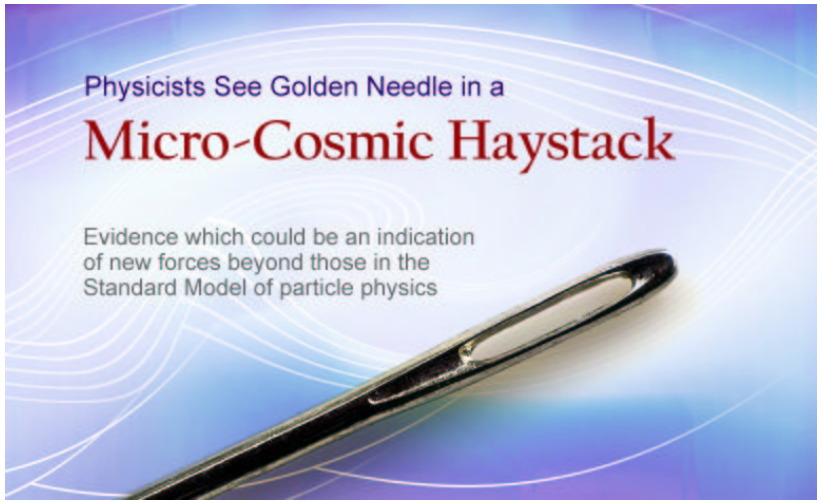
BNL-E787 (-1998)
proposed (1998), approved (1999)
construction/upgrade (-2001)
engineering run (2001)
First Physics Run (2002)

First Results from BNL-E949 on the Rare Decay $K^+ \to \pi^+ \nu\bar{\nu}$

Takeshi K. Komatsubara (KEK-IPNS)

representing the E949 collaboration

- `arXiv:hep-ex/0403036`
- JPS talk on March 28
  by T.Sekiguchi (KEK & U.Tokyo)

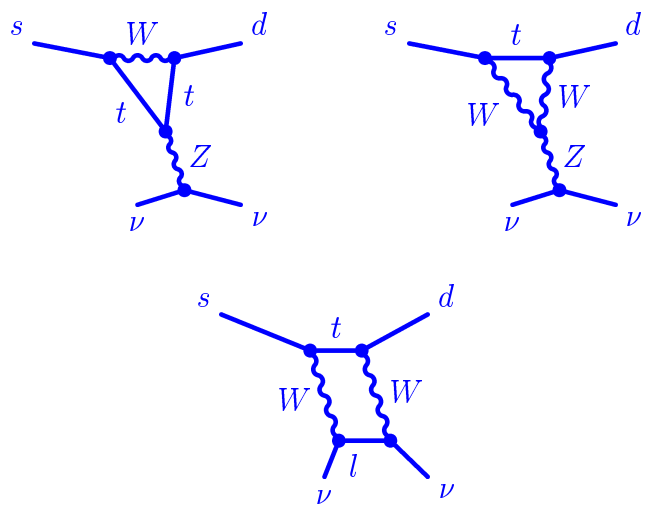


KEK Physics Seminar, April 7, 2004

Outline [in the next 49 slides, 50 minutes]

- $\mathbf{K}^+ \longrightarrow \boldsymbol{\pi}^+\boldsymbol{\nu}\bar{\boldsymbol{\nu}}$:
  physics in and beyond the Standard Model
- E949 experiment in 2002: beam and detector
- Analysis: Likelihood Ratio Technique
  Confidence Level computation in Searches with Small Statistics
- Results
- Conclusions, and Future

$\mathbf{K^+ \to \pi^+ \nu \bar{\nu}}$ decay



- Standard Model:
  $s \to d$ FCNC loop ($W^{\pm}/Z^0$)
- top-quark (174 GeV/c^2) dominant
- $\lambda_t \equiv V_{ts}^* \cdot V_{td}$

  $= -A^2\lambda^5 \cdot (1 - \rho - i\eta)$:

  best place to determine $|\lambda_t|$ (or $|V_{td}|$)
- theoretical uncertainty $\sim 7\%$

Cabibbo(1963)-Kobayashi-Maskawa(1972) matrix

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} .975 & .22 & .002-.005 \\ .22 & .974 & .038-.044 \\ .004-.014 & .037-.044 & .999 \end{pmatrix}$$

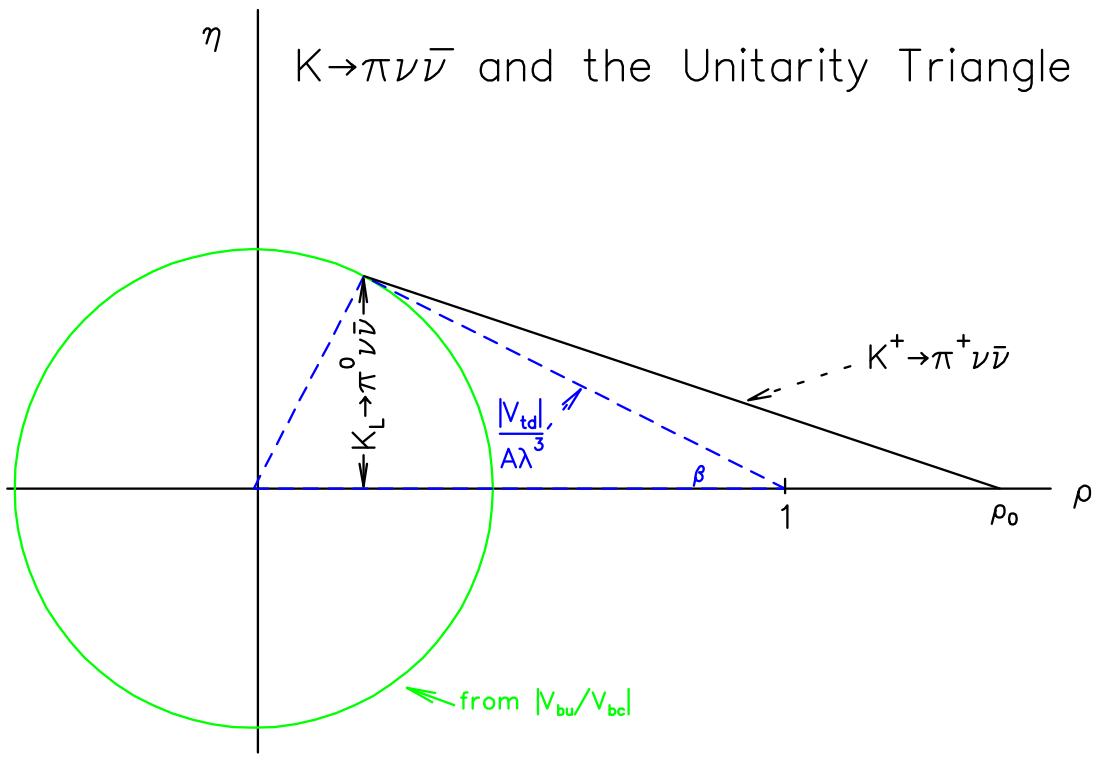
$$\simeq \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

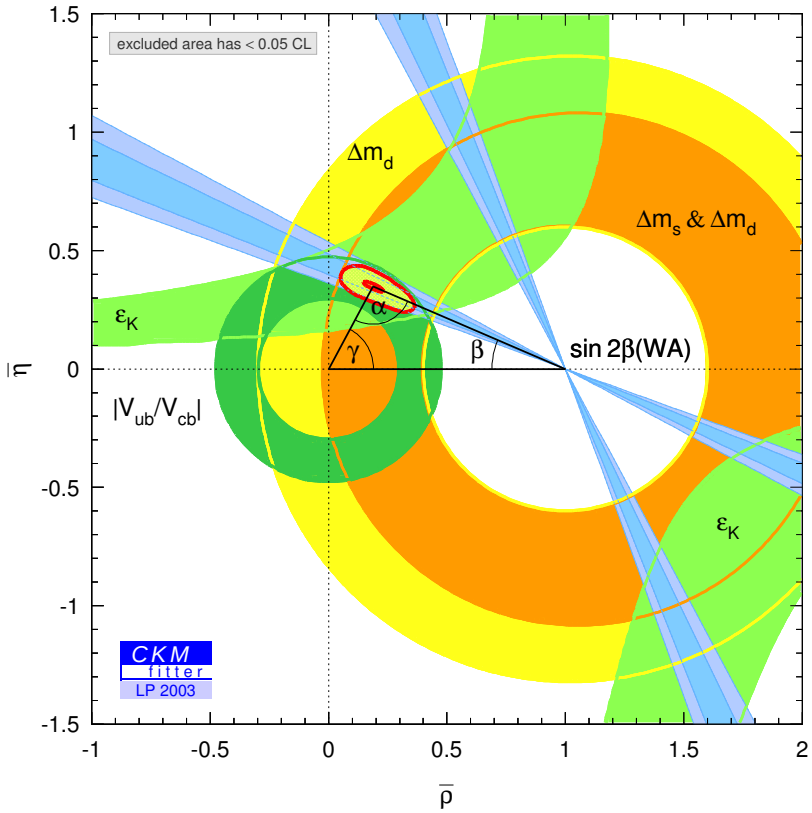
- Wolfenstein parameterization (1983) :
  $\lambda \equiv sin\theta_C = 0.22,\ A,\ \rho,\ \eta.$

- ρ and η are hard to measure,
  because they are in V_{ub} and V_{td} of $O(\lambda^3)$.
  $\rightarrow$ "rare" processes in K and B decays.

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

$$\underline{4.75 \times 10^{-11}} \quad \bullet \quad A^4 \cdot X(x_t)^2 \cdot [\ (\rho_0 - \rho)^2 \ + \ \eta^2\ ]$$

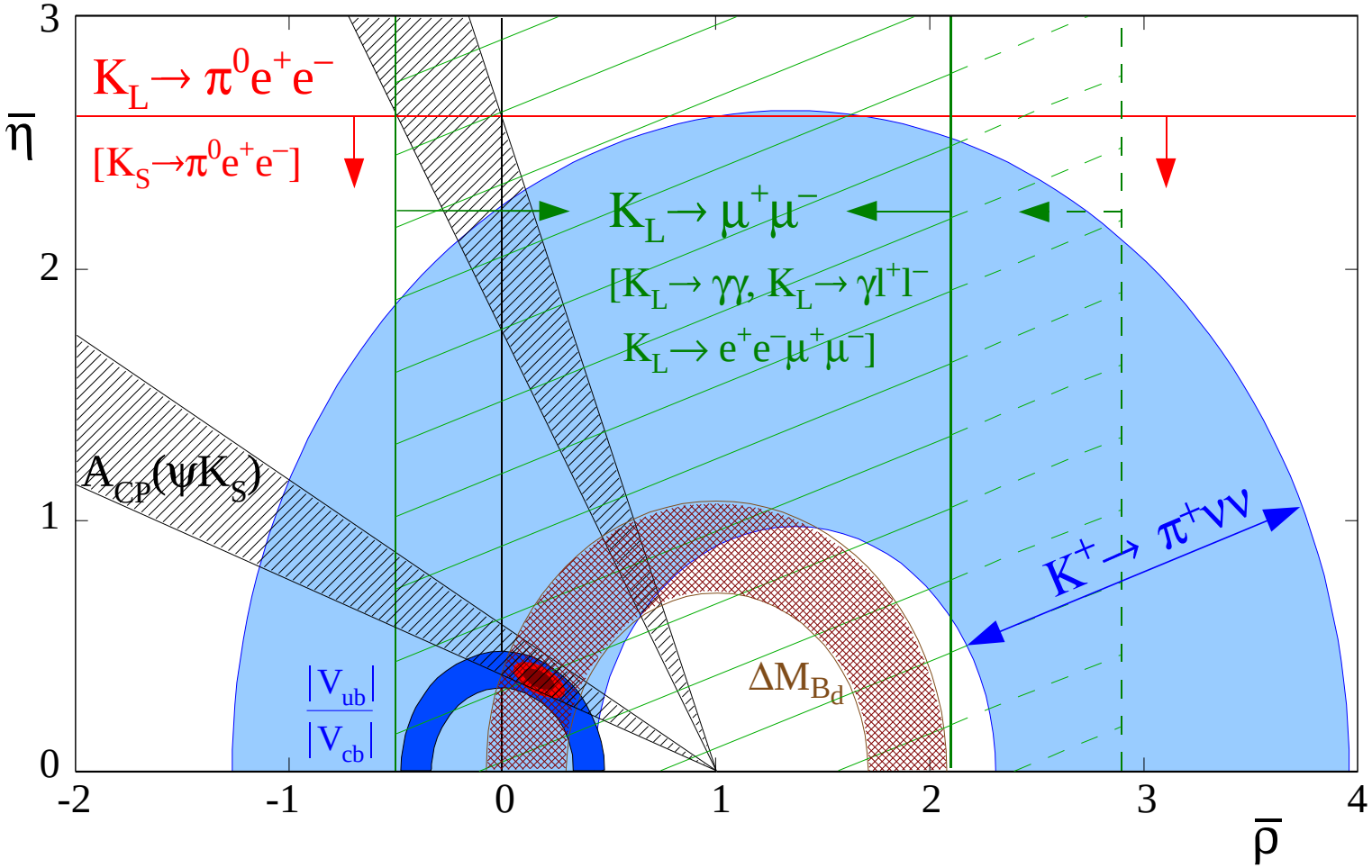




(ρ, η) constraints @LP03

	Isidori hep-ph/0307014	Buras et al hep-ph/0402112
$K^+ \to \pi^+ \nu\bar{\nu}$	$(7.7 \pm 1.1) \times 10^{-11}$	$(8.0 \pm 1.1) \times 10^{-11}$
$K_L^0 \to \pi^0 \nu\bar{\nu}$	$(2.6 \pm 0.5) \times 10^{-11}$	$(3.2 \pm 0.6) \times 10^{-11}$

$\Delta S = 1$ (ρ, η) Isidori & Unterdorfer, hep-ph/0311084



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

- Minimal Flavor Violation Buras, hep-ph/0310208

	SM	MFV
$K^+ \to \pi^+ \nu\bar{\nu}$	$(7.7 \pm 1.1) \times 10^{-11}$	19.1×10^{-11}
$K_L^0 \to \pi^0 \nu\bar{\nu}$	$(2.6 \pm 0.5) \times 10^{-11}$	9.9×10^{-11}

- $B \to \pi\pi$, $K\pi$ and New Physics

  Buras et al., PRL 92, 101804(2004), hep-ph/0402112

  S. Recksiegel, KEK Theory Seminar scheduled on April 13

	SM	NP
$K^+ \to \pi^+ \nu\bar{\nu}$	$(7.7 \pm 1.1) \times 10^{-11}$	$(7.5 \pm 2.1) \times 10^{-11}$
$K_L^0 \to \pi^0 \nu\bar{\nu}$	$(2.6 \pm 0.5) \times 10^{-11}$	$(3.1 \pm 1.0) \times 10^{-10}$

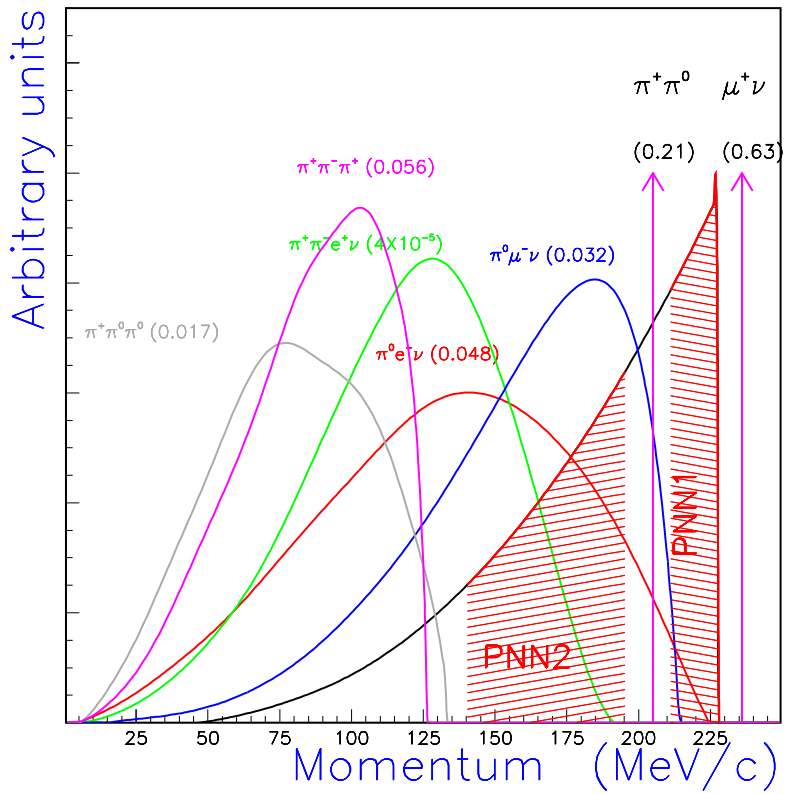
* $(sin2\Phi_1)_{B^0 \to \Phi K_S} \approx +0.9 \Leftarrow \underline{-0.96 \pm 0.50}$ by Belle

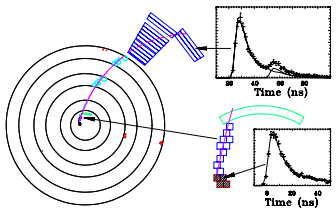
Name	**"PNN2"**	**"PNN1"**
P_π (MeV/c)	[140,195]	[211,229]
Years	1996-97	1995-98
Stopped K^+	1.7×10^{12}	5.9×10^{12}
Candidates	1	2
Background	1.22 ± 0.24	0.15 ± 0.05
$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})$	$< 22 \times 10^{-10}$	$(1.57^{+1.75}_{-0.82}) \times 10^{-10}$

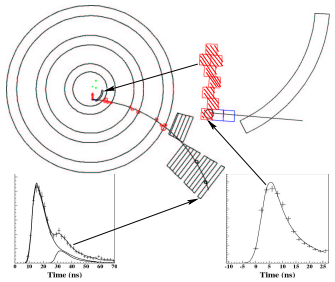
E787
$K^+ \to \pi^+\nu\bar{\nu}$
results

PNN1: PRL **88**, 041803 (2002).

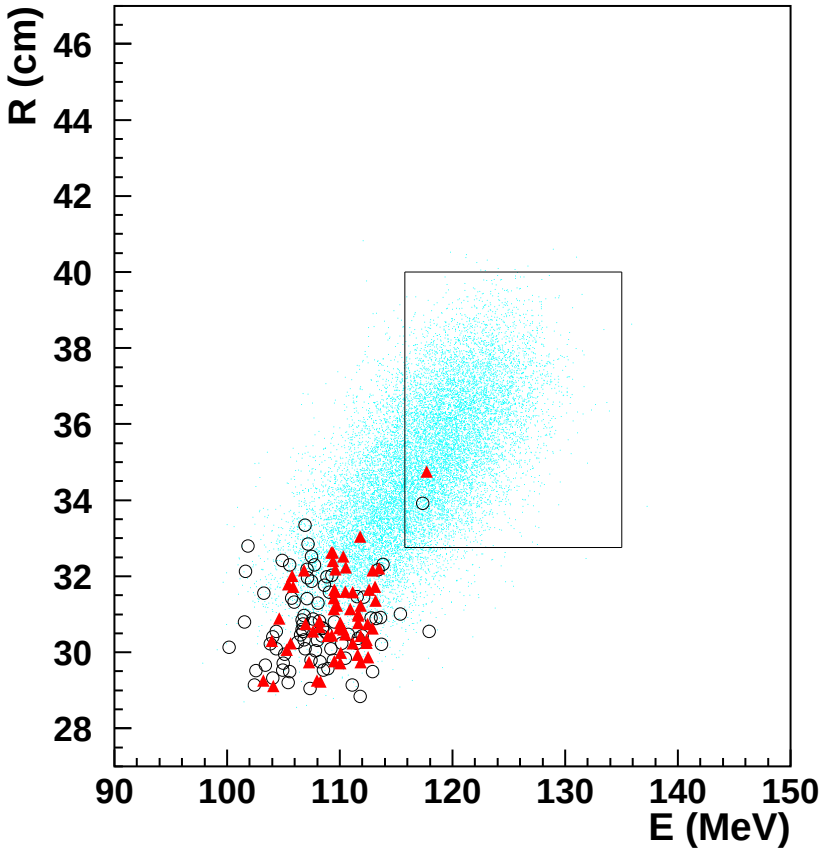
PNN2: limit at 90%CL is combined result from 1996 (PL **B537**, 211 (2002)) and 1997 (hep-ex/0403034) data.







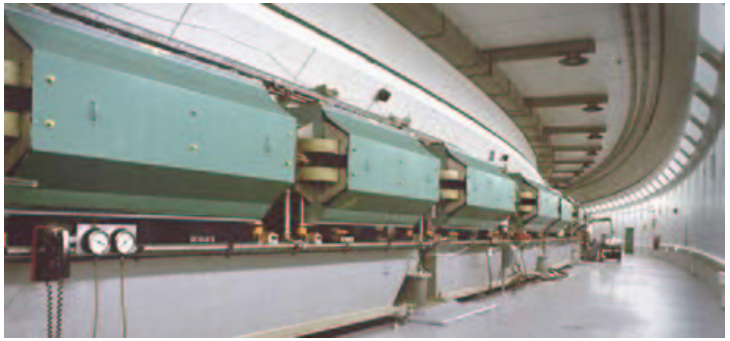
E787-PNN1: PRL **88**, 041803 (2002)



- π^+ Range vs Energy
- 95-97 / 98 / MonteCarlo

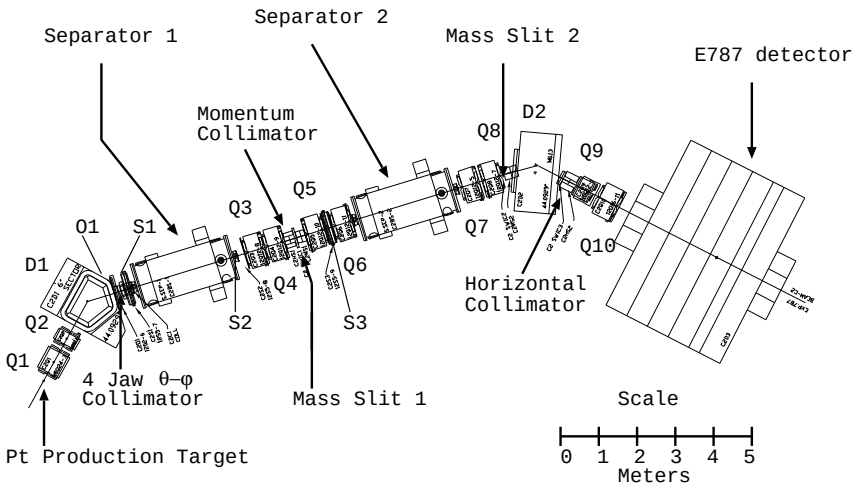
E949 experiment in 2002

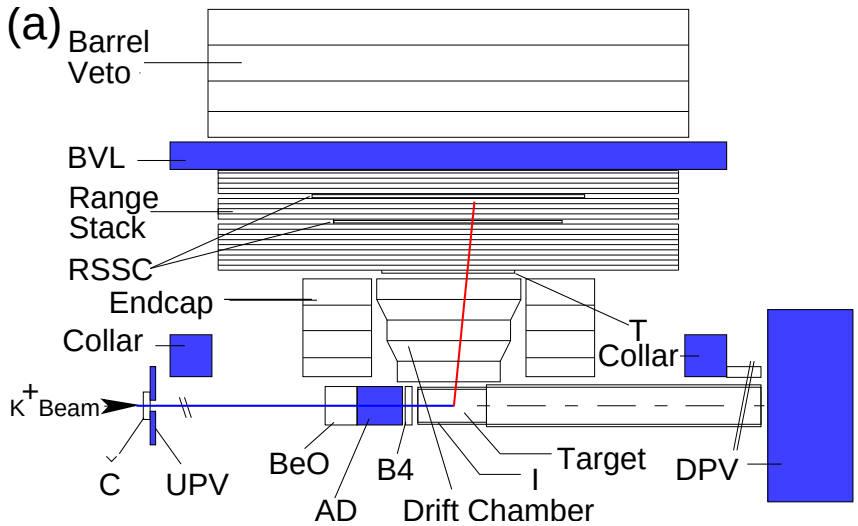
BNL-AGS: $\geq 60 \times 10^{12}$(Tera) protons per spill



		E787-'98	E949-'02
protons per spill	Tp	25-40	70
AGS energy	GeV	24	22
beam spill	sec	2.2	2.2
cycle	sec	4.2	5.4
duty factor	%	52	41

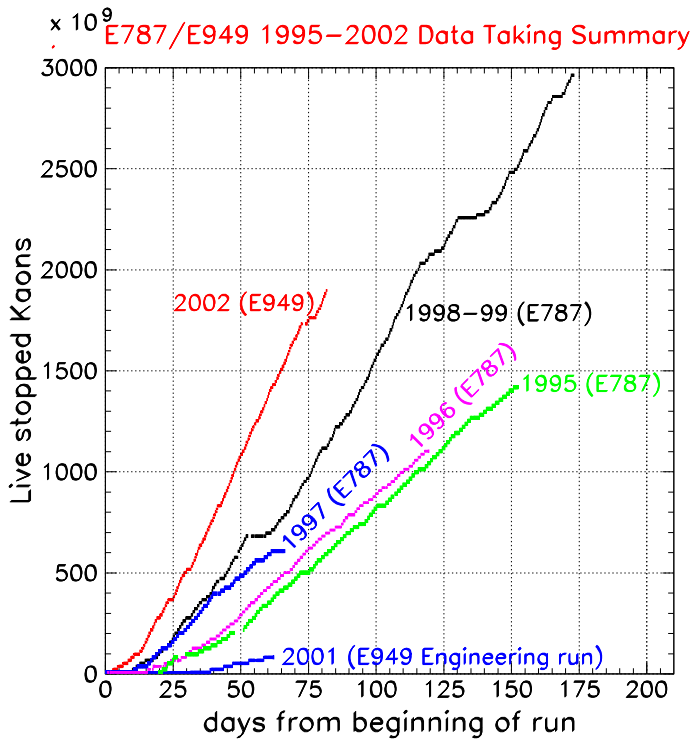
LESB3 → K^+ slowed by degrader and coming to rest





	E787-'98	E949-'02
K^+/π^+	4	3
kaon momentum MeV/c	710	710
stopping fraction %	28	28

		E787	E949-'02
N_K in the spill	M	1.8	2.5
N_K	MHz	0.8	1.2
rates in the detector			$\times 2$
N_K accumulated		5.9×10^{12}	1.8×10^{12} $\times 0.305$



# of kaons incident on the target (N_K)

- 12 weeks (March-June 2004)

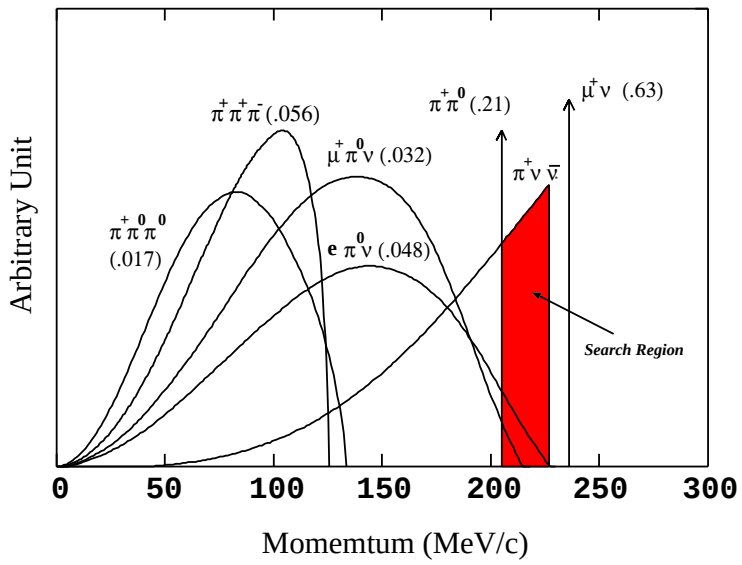
Reminder: E949-2002 beam conditions were not optimized

- a failure of the AGS power supply
- reduced operating voltage of one of the DC separators
- 12 weeks

The conditions will be improved in the next run.

		E787	E949-'02	E949 optimized
AGS energy	GeV	24	22	24
beam spill	sec	2.2	2.2	4.1
cycle	sec	4.2	5.4	6.4
duty factor	%	52	41	64
K^+/π^+		4	3	4
N_K in the spill	M	1.8	2.5	5.0
N_K	MHz	0.8	1.2	1.2
rates in the detector			$\times 2$	$\times 2$ or less
beam time	weeks		12	$\geq$60

K^+decay at rest $\rightarrow \pi^+ +$ "nothing"

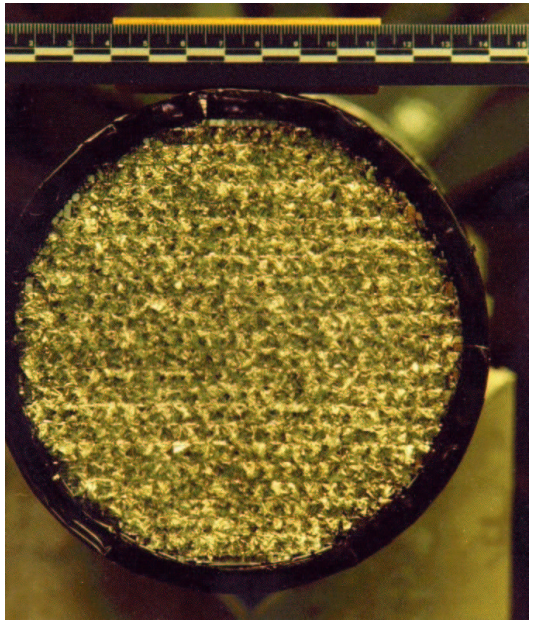


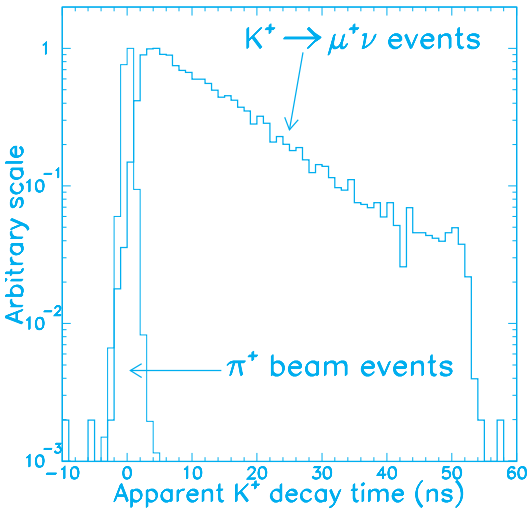
Background Rejection

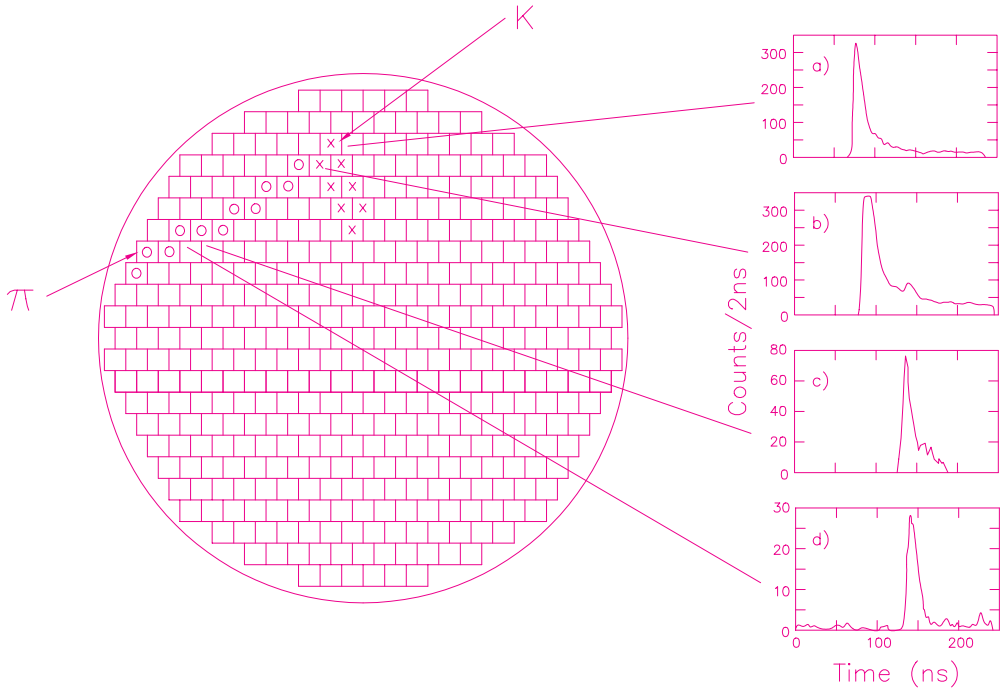
- Kinematics of π^+
  - Momentum
  - Kinetic Energy
  - "Range" in plastic scintillators
- π^+/μ^+ separation
  $\Longleftrightarrow K^+ \rightarrow \mu^+\nu$
- extra particles (γ, ..)
  $\Longleftrightarrow K^+ \rightarrow \pi^+\pi^0$

each weapon should have rejection of $\underline{10^6 \sim 10^7}$

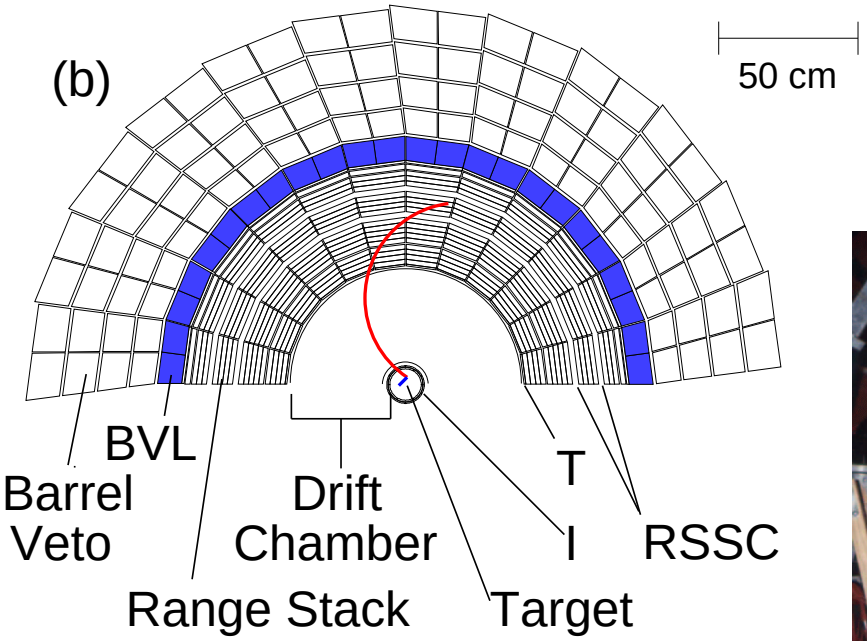
K^+ decay at rest in the Target (end-view)

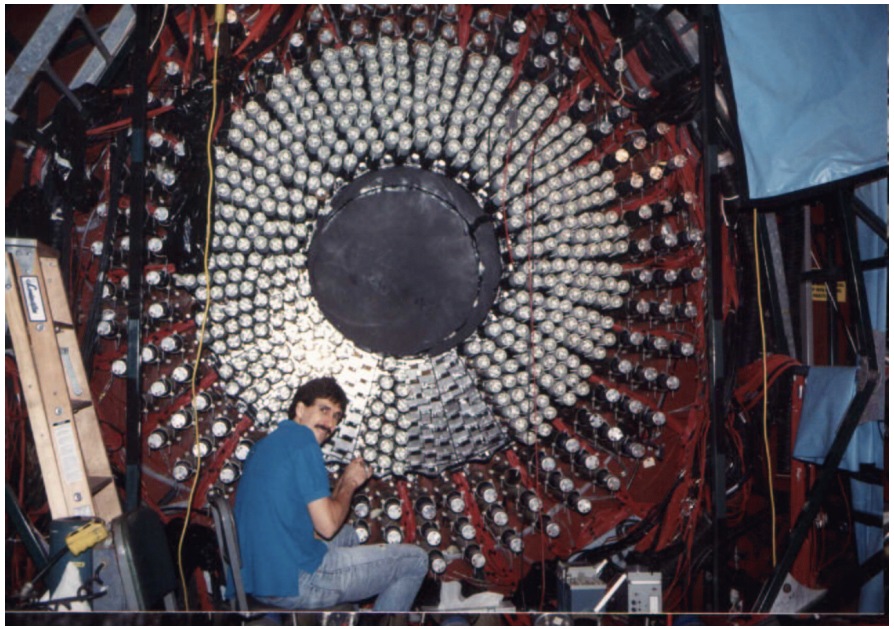




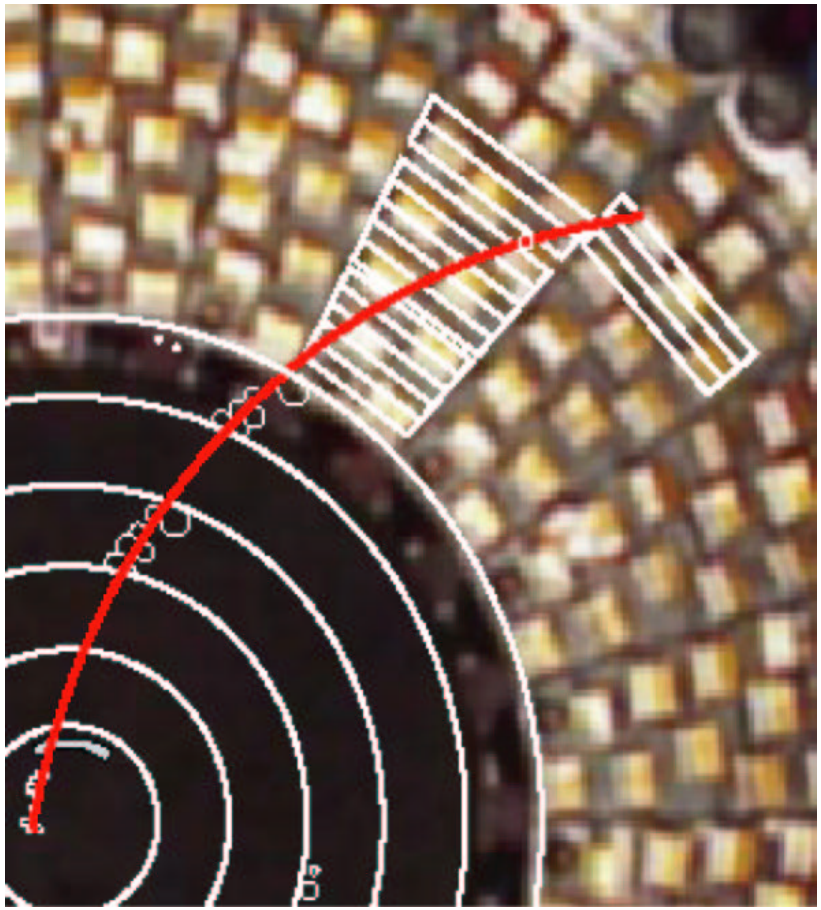


Charged track from the Target to the Range Stack

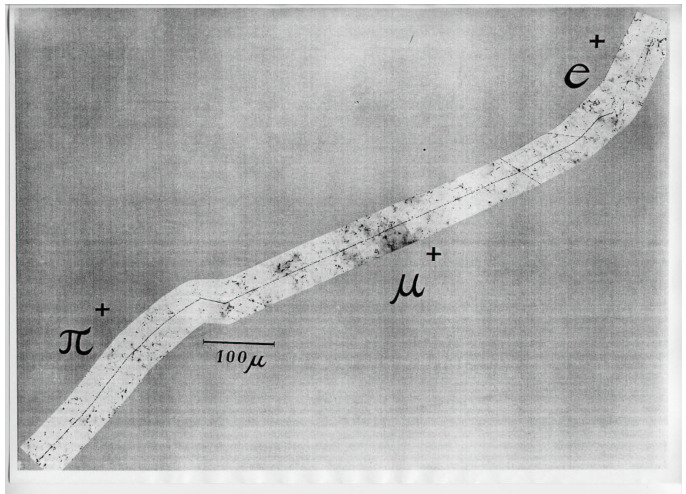




π^+ loses energy and comes to rest in the RS



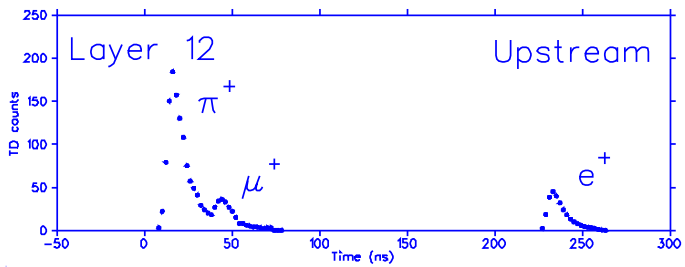
in the stopping counter ...



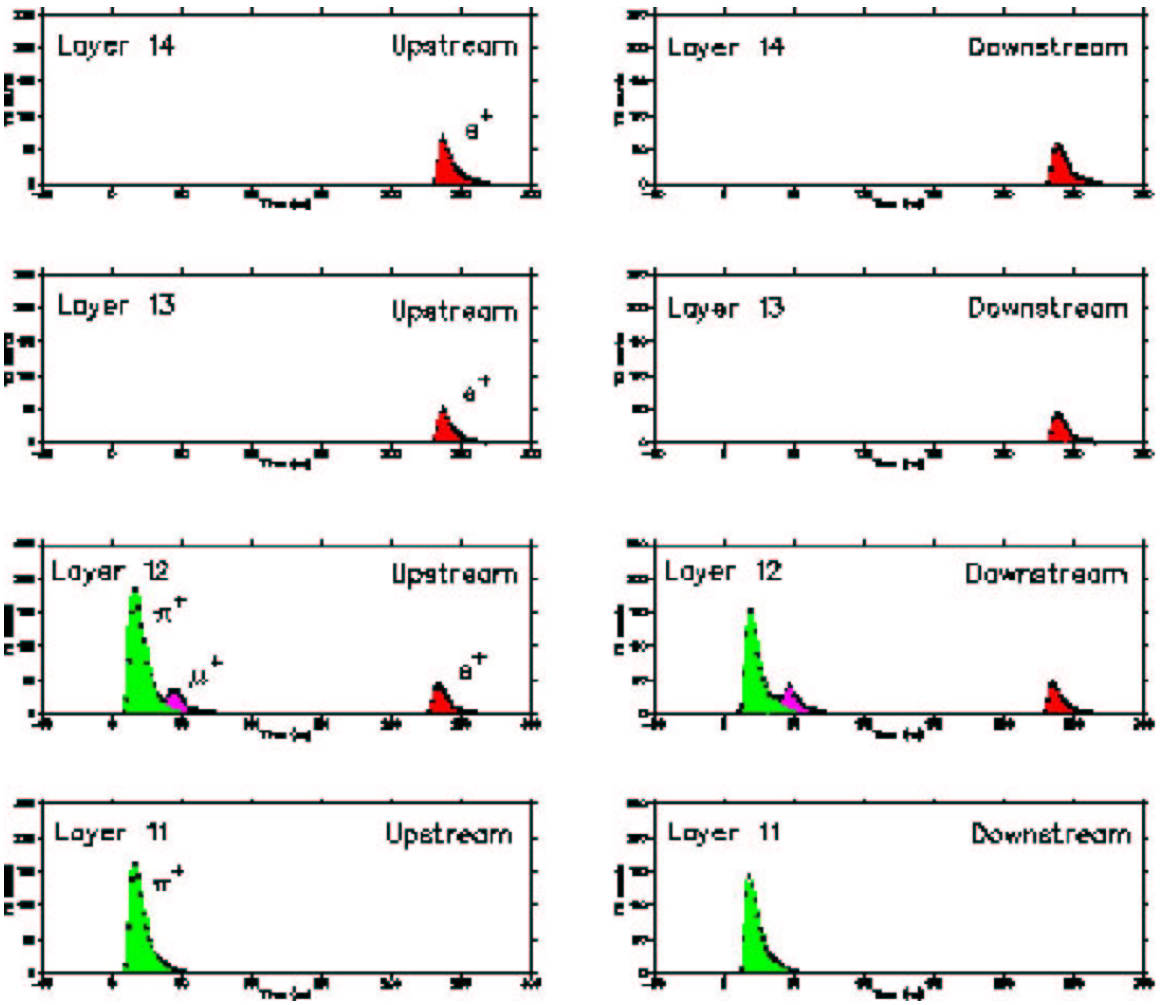
first π^+ and its decay by Japanese accelerator (1962) in Nuclear Emulsion;

to the memory of INS-Tokyo (–1997 March).

from the plastic scintillator to PMT



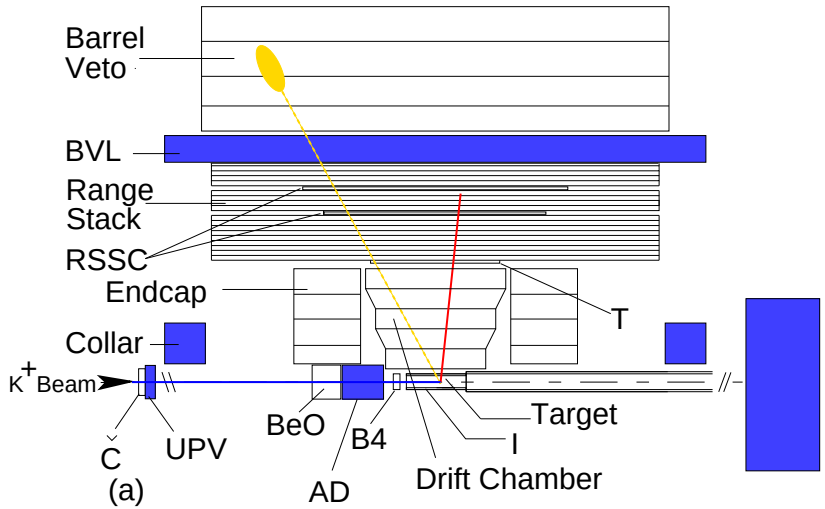
$\pi^+ \rightarrow \mu^+ \rightarrow e^+$ recorded by 500-MHz waveform digitizer



Online + Offline μ^+ rejection ($> 10^5$)

γ detection by the hermetic Calorimetry $\Rightarrow$ "Photon Veto"

with Barrel Veto, Endcap, Range Stack, Target

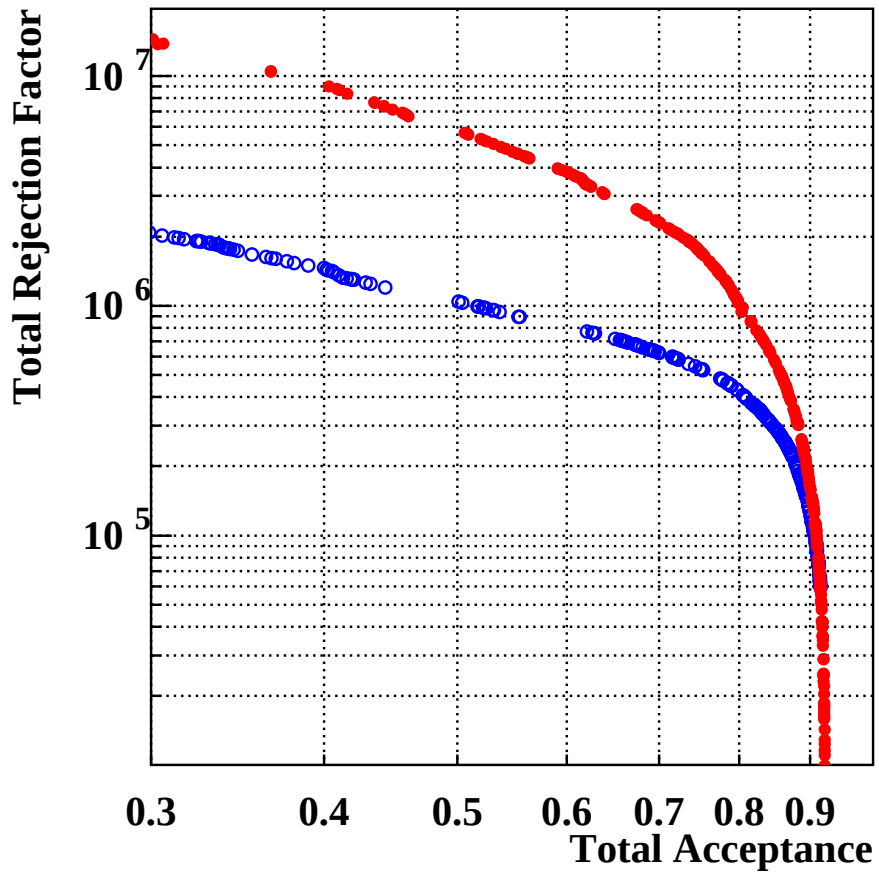


new Calorimeters:

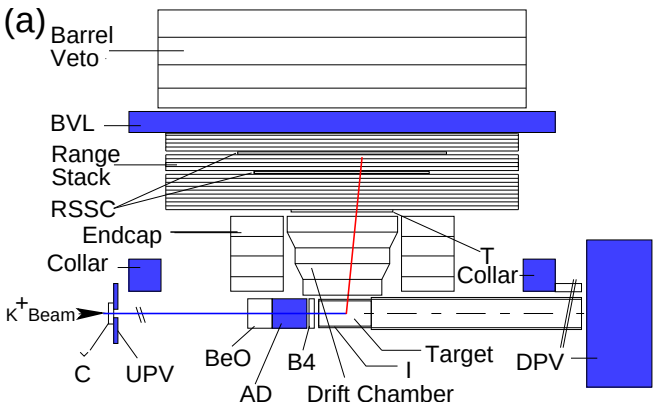
- barrel part:
  - Barrel Veto Liner (BVL)
    add 2.3 X_0
- minor openings
  along the beam direction
  - segmented Active Degrader
  - new Collar detectors
  - Upstream, Downstream PV

E949 improvements (1): "Photon Veto"

- PV cuts:
  π^0 Rejection as a function of
  $\pi^+\nu\bar{\nu}$ Acceptance
  for E949 and E787.
- $\times 2$ better rejection
  at nominal acceptance (80%)



E949 upgrades (2): Rate capability, Kinematics

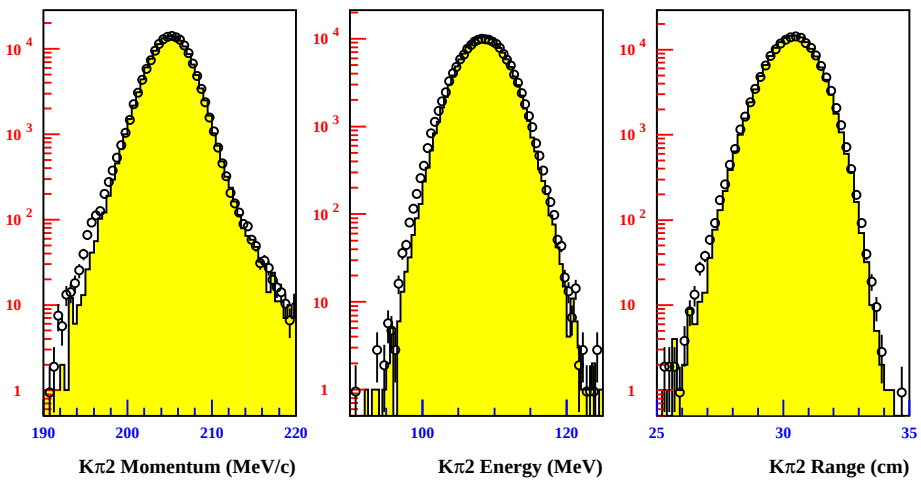


- higher segmented B4 hodoscope
- record waveforms from beam counters
- RS Layer 1-5, 19 replaced
  $\longrightarrow$ more light output
- LED flasher system $\longrightarrow$ RS monitor
- new wire-chamber electronics

π^+ kinematics from $K_{\pi 2}$:
E787(○) vs E949 (histo)

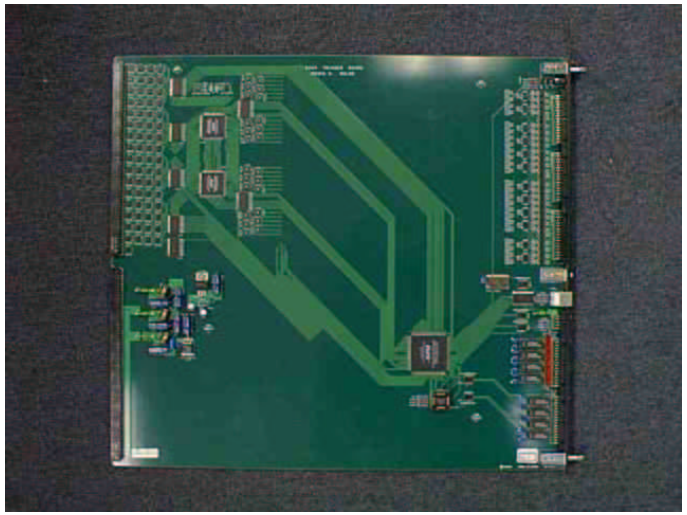
- $\sigma_P = 2.3$ MeV/c
- $\sigma_E = 3.0$ MeV
- $\sigma_R = 0.9$ cm

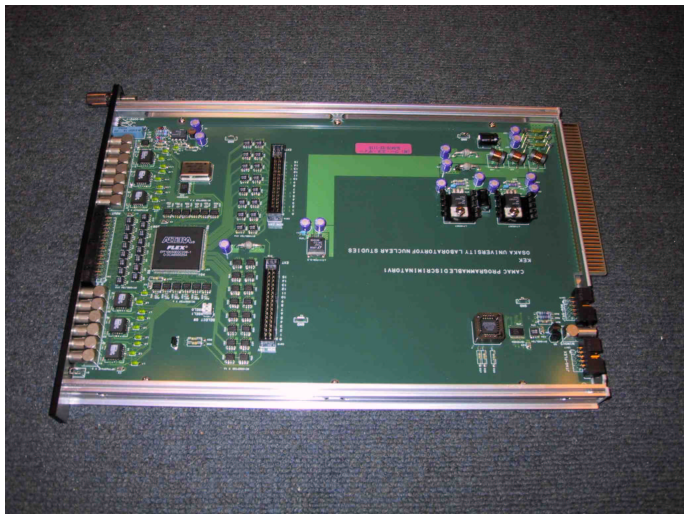
Reminder:
the rate is $\times 2$ higher in E949.

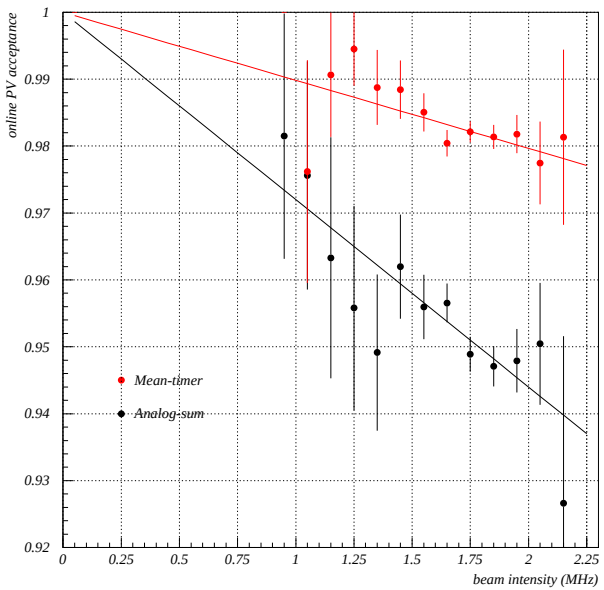


E949 upgrades (3): Trigger/DAQ

e.g. Level0 trigger board and digital Meantimer module







T.Yoshioka, M.Nomachi et al., KEK Preprint 2003-109, IEEE TNS (in press)

Analysis

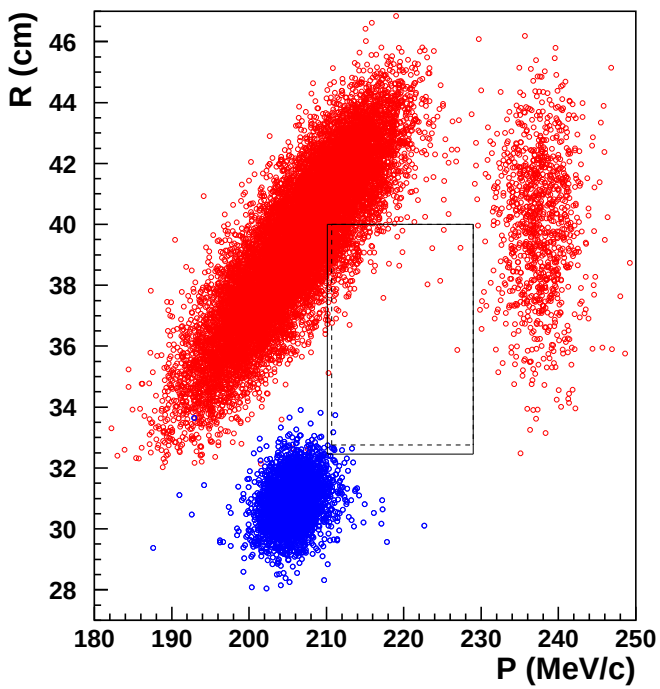
Search region ("BOX") in the multi-dimesional "cut" space

"cuts" $\equiv$ Selection Criteria

1. π^+ kinematic-region cuts:
   - Momentum above $K_{\pi 2}$: 211<P<229 MeV/c
   - Range(R), Kinetic Energy (E)
   - Range-Momentum relation
2. Event Identification ("Rejection" cuts)
   - Photon Veto
   - $\pi^+ \to \mu^+ \to e^+$ decay chain
3. Beam cuts: K^+ decay at rest, no extra beam particles, ..
4. "Pathology" cuts
   - failures in the reconstuction of pattern/energy/timing
   - ...

characterizing the background sources

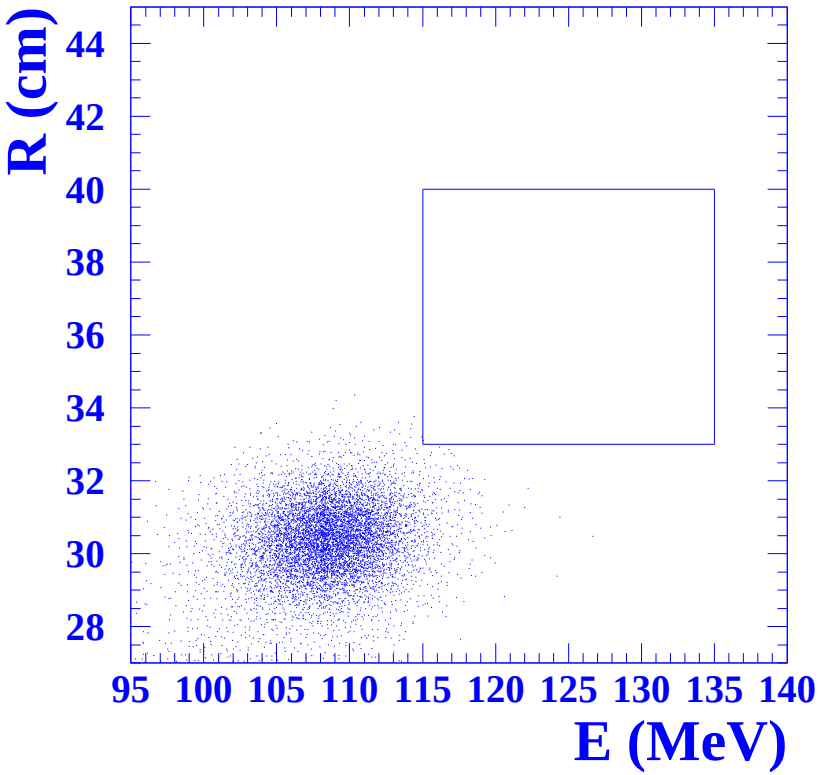
- $K_{\pi 2}$: $K^+ \to \pi^+\pi^0$
  - proximity (P,E,R) to $K_{\pi 2}$ peak: `Kp2-K`
  - Photon veto
    timing-windows/energy-thresholds: `PV`
- $K_{\mu 2}$: $K^+ \to \mu^+\nu$ but R is small
  due to interactions in the RS
  - proximity (P) to $K_{\mu 2}$ tail: `Km2t-K`
  - $\pi^+ \to \mu^+ \to e^+$ properties
    via Neural Network func: `TD`
- $K_{\mu m}$: multi-body decays
  ($K^+ \to \mu^+\nu\gamma$,$K^+ \to \mu^+\pi^0\nu$, ..)
  - proximity (R,P) to the $K_{\mu\ 2}$ band: `Km2b-K`
  - `TD`

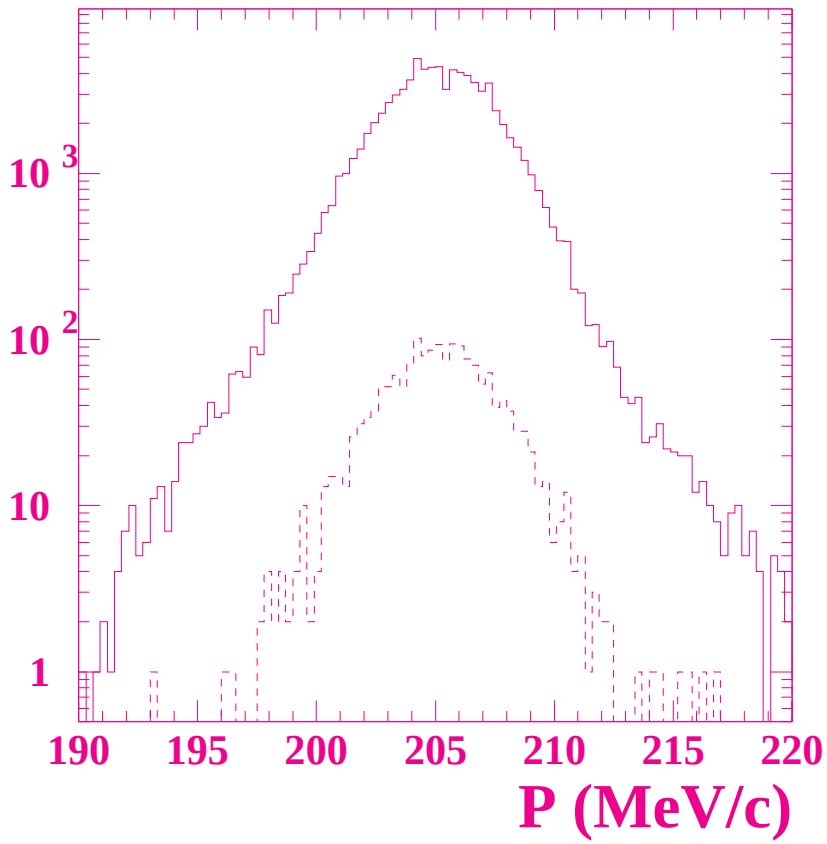


Background studies: our policy and philosophy

- To avoid bias due to small statistics,
  - 1/3 of sample: for study
  - 2/3 of sample: (keep untouched)
- **invert** at least one of the cuts to:
  - enhance the backgrounds collected by the trigger
  - prevent candidate events from being examined ("Blind Analysis" even at the event selection)
- Cuts were **frozen** with the 1/3 sample.
- Then measure the background levels in the search region with the remaining (independent) 2/3 sample.

Example: $K^+ \to \pi^+\pi^0$ background study with "two cuts"





Normalization for `Kp2`:

- select events with photons,
- measure proximity of (P,E,R) to $K_{\pi 2}$ peak

Rejection for `PV`:

- select events whose (P,R,E) are in $K_{\pi 2}$ peak,
- measure rejection by Photon Veto

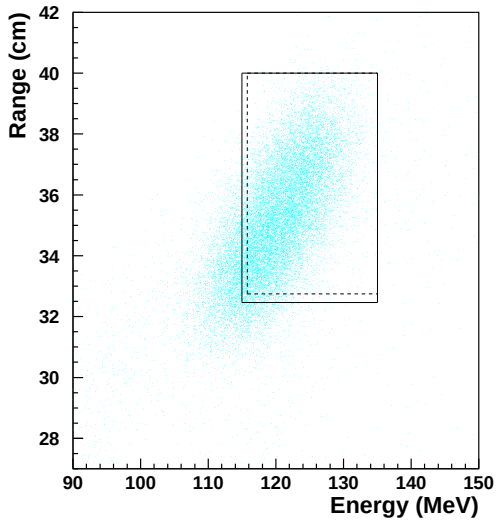
Background levels in the Search region

- $K_{\pi 2}$ background level got larger (see the next slide).

Source	E787	E949-'02
$K_{\pi 2}$	0.032	0.216 ± 0.023
Muon	0.064	
$K_{\mu 2}$		0.044 ± 0.005
$K_{\mu m}$		0.024 ± 0.010
Beam (single+double)	0.024	0.009 ± 0.003
K^+ charge exchange	0.026	0.005 ± 0.001
Total background	0.14 ± 0.05	0.298 ± 0.026

Acceptance and Sensitivity in the Search region

- In E949, we loosened
  - Kp2-K: lower edge of (P,E,R) to seek better acceptance
  - PV and TD (improved in E949) to keep acceptance in $\times 2$ higher rates.



		E787	E949-'02
N_K		5.9×10^{12}	1.8×10^{12} $\times 0.305$
Total background	events	0.14 ± 0.05	0.30 ± 0.03
Total acceptance	%	0.20 ± 0.02	0.22 ± 0.02 $\times 1.1$
Single Event Sensitivity		0.83×10^{-10}	2.6×10^{-10} $\times 0.336$

We are ready to open the "BOX"

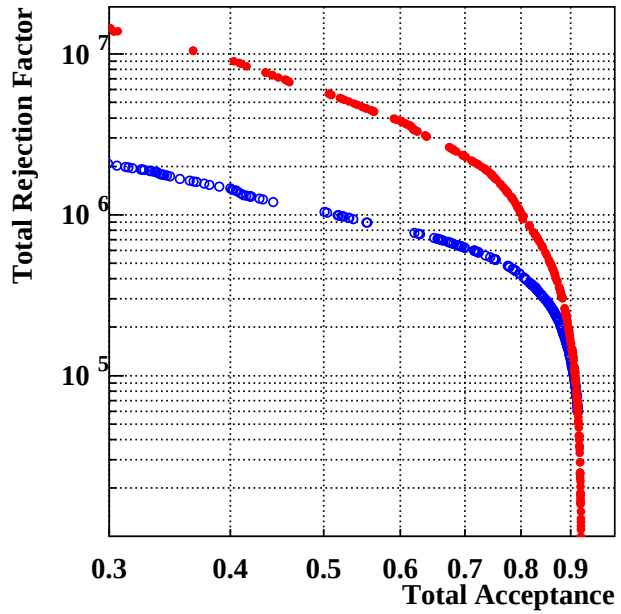
if we would perform
a simple "counting" experiment

(# of candidate events vs. background level)

Isn't the total background (0.30 ± 0.3) a little bit high ?
Did you get into a background-limited situation ??

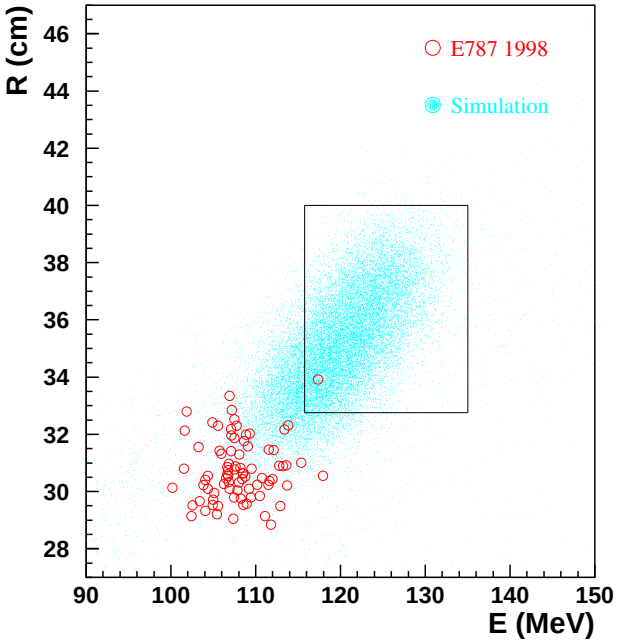
Rare Kaon-decay searches (sensitivity $\leq 10^{-10}$)

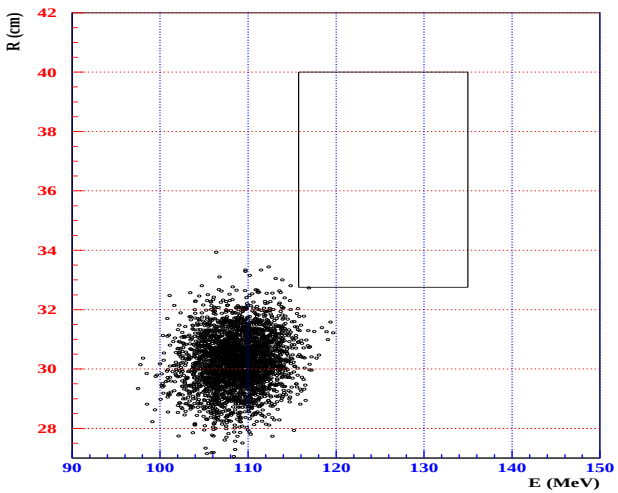
- Bgd levels ($<$ 1 event),
  expected # of events (0 or 1 or 2 ...):
  both in <u>small statistics</u>
  - a dedicated experiment
    to a specific decay mode
    with a special-purpose detector
  - not easy to increase the acceptance



- We understand the behavior of background sources
  (where they appear in the "cut" space).

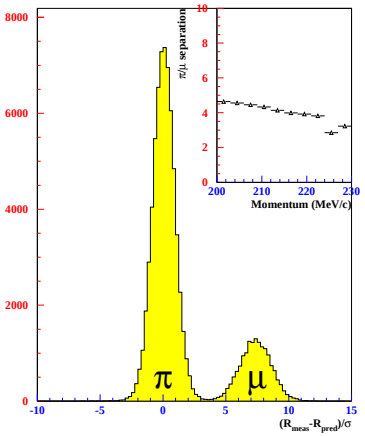
$K_{\pi 2}$ kinematic Bgd shape (plots from E787-98)

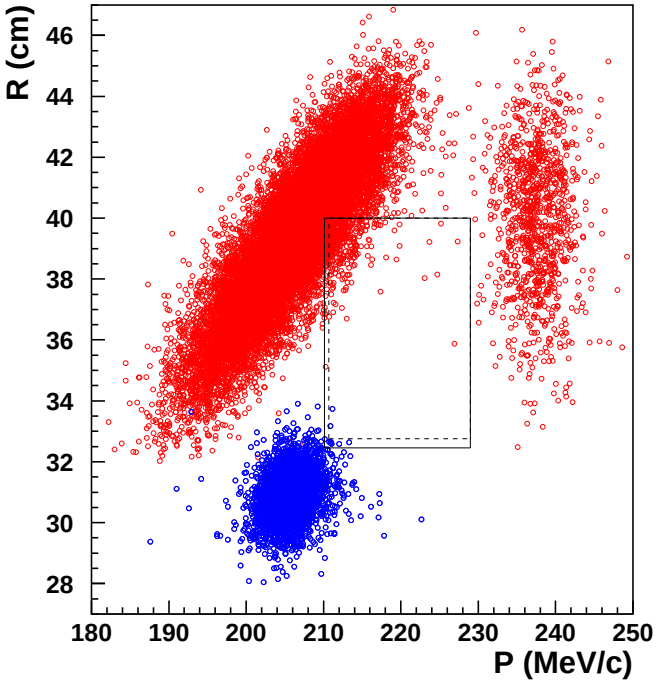


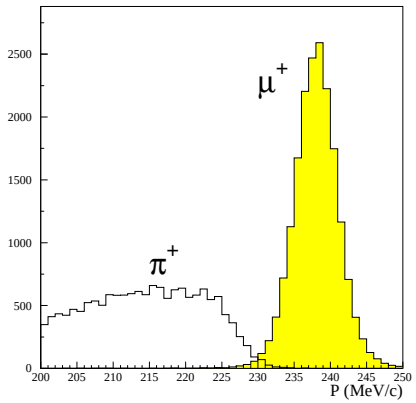


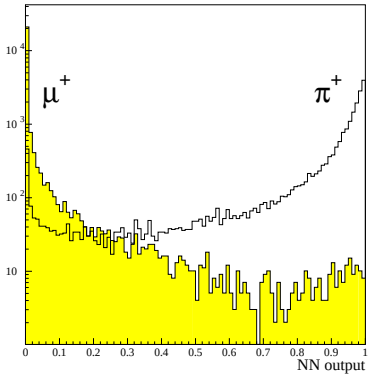
- sub-divide inside and just-outside the "BOX" into many small "cells"
  - proximity of (P,E,R) to the $K_{\pi 2}$ peak:
    $(P,E,R) \geq (P_B,E_B,R_B) \pm \underline{n \times 5\% \times (\sigma_P,\sigma_E,\sigma_R)}$
- evaluate Acceptance A_i and Background level b_i for each cell (labeled by $\boxed{i}$)

Muon Bgd shape: $K_{\mu m}$(band) and $K_{\mu 2}$(tail)









TD cut using Neural Network

- for each cell (labeled by i),
  - Acceptance A_i and BR (as a free parameter)

    $\Longrightarrow$ expected Signal $\boxed{S_i(BR)} \equiv BR \bullet \mathrm{N}_K \bullet A_i$
  - Background level $\boxed{b_i}$
- after opening the BOX, count:
  - # of observed candidates in each bin $\boxed{d_i}$
- Assume both $S_i(BR)$ and b_i are small

  $\longrightarrow$ use of Poisson statistics

  for "likelihood ratio" (signal-like outcomes vs. background-like ones)

$$X_i(BR) \equiv \frac{\exp^{-(S_i+b_i)}(S_i+b_i)^{d_i}}{d_i!} \Big/ \frac{\exp^{-b_i}(b_i)^{d_i}}{d_i!} = \exp^{-S_i}(1+\frac{S_i}{b_i})^{d_i}$$

Likelihood estimator: $X(BR) = \prod_{i=1}^{n} X_i$

T. Junk, NIM A434(1999), 435

$$X(BR) = \prod_{i=1}^{n} \frac{\exp^{-(S_i+b_i)}(S_i+b_i)^{d_i}}{d_i!} \Big/ \frac{\exp^{-b_i}(b_i)^{d_i}}{d_i!} = \prod_{i=1}^{n} \exp^{-S_i}(1+\frac{S_i}{b_i})^{d_i}$$

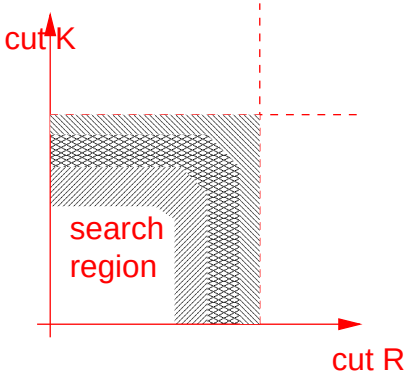
1. provide Junk's computer-program with
   - a set of ($\boxed{S_i(BR)}$, $\boxed{b_i}$, $\boxed{d_i}$) based on an BR assumption
2. the program calculates the C.L. of the BR assumption from modified Frequentist's approach
   - $\boxed{f_i} \equiv S_i/b_i$: Signal-to-Background function
   - $\boxed{W_i} \equiv S_i/(S_i+b_i)$: effective "weight" or each to the BR
3. loop over possible BR's and get limits on BR with the C.L. you want.
4. BR which gives the maximum value of $X(BR)$: the central value

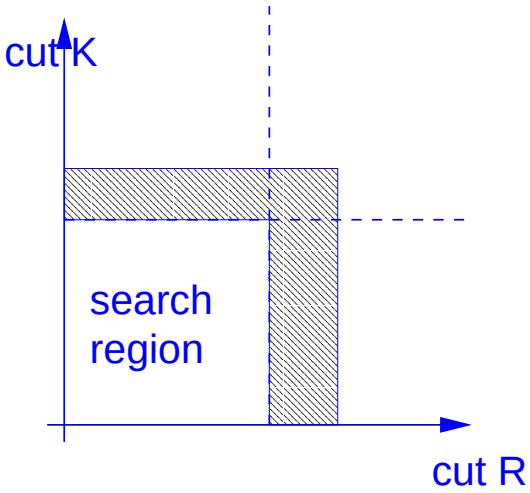
We are ready to open the "BOX".

We are not background-limited;

we perform
Likelihood analysis
to the candidate events
in the Search region.

Final check: "just-outside" the BOX region

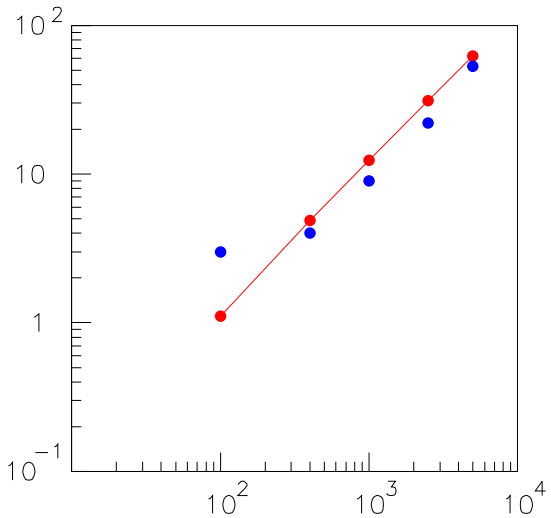




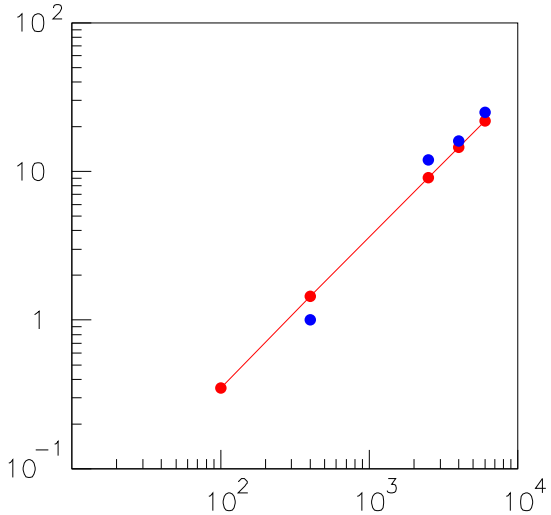
- Background levels b_i inside the BOX were evaluated, assuming that the kinematic-region cuts (cutK) and Rejection cuts (cutR) are independent.
- Let us confirm the assumption with the regions near the BOX: loosen, simultaneously,
  - cutK to reduce rejection by $\times N$
  - cutR to reduce rejection by $\times M$

  and we should observe $N \times M$ times more background events in the region.

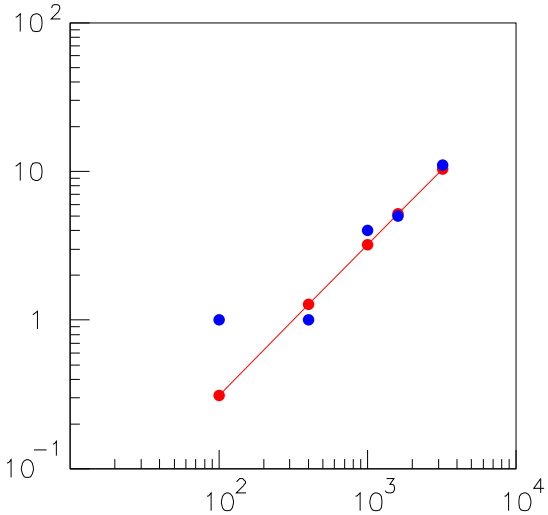
	PV×KIN	10×10	20×20	20×50	50×50	50×100
$K_{\pi 2}$	Observed	3	4	9	22	53
	Predicted	1.1	4.9	12.4	31.1	62.4
	TD×KIN	10×10	20×20	50×50	80×50	120×50
$K_{\mu 2}$	Observed	0	1	12	16	25
	Predicted	0.35	1.4	9.1	14.5	21.8
	TD×KIN	10×10	20×20	50×20	80×20	80×40
$K_{\mu m}$	Observed	1	1	4	5	11
	Predicted	0.31	1.3	3.2	5.2	10.4



$K_{\pi 2}$: PV × KIN



$K_{\mu 2}$: TD × KIN



$K_{\mu m}$: TD × KIN

Results

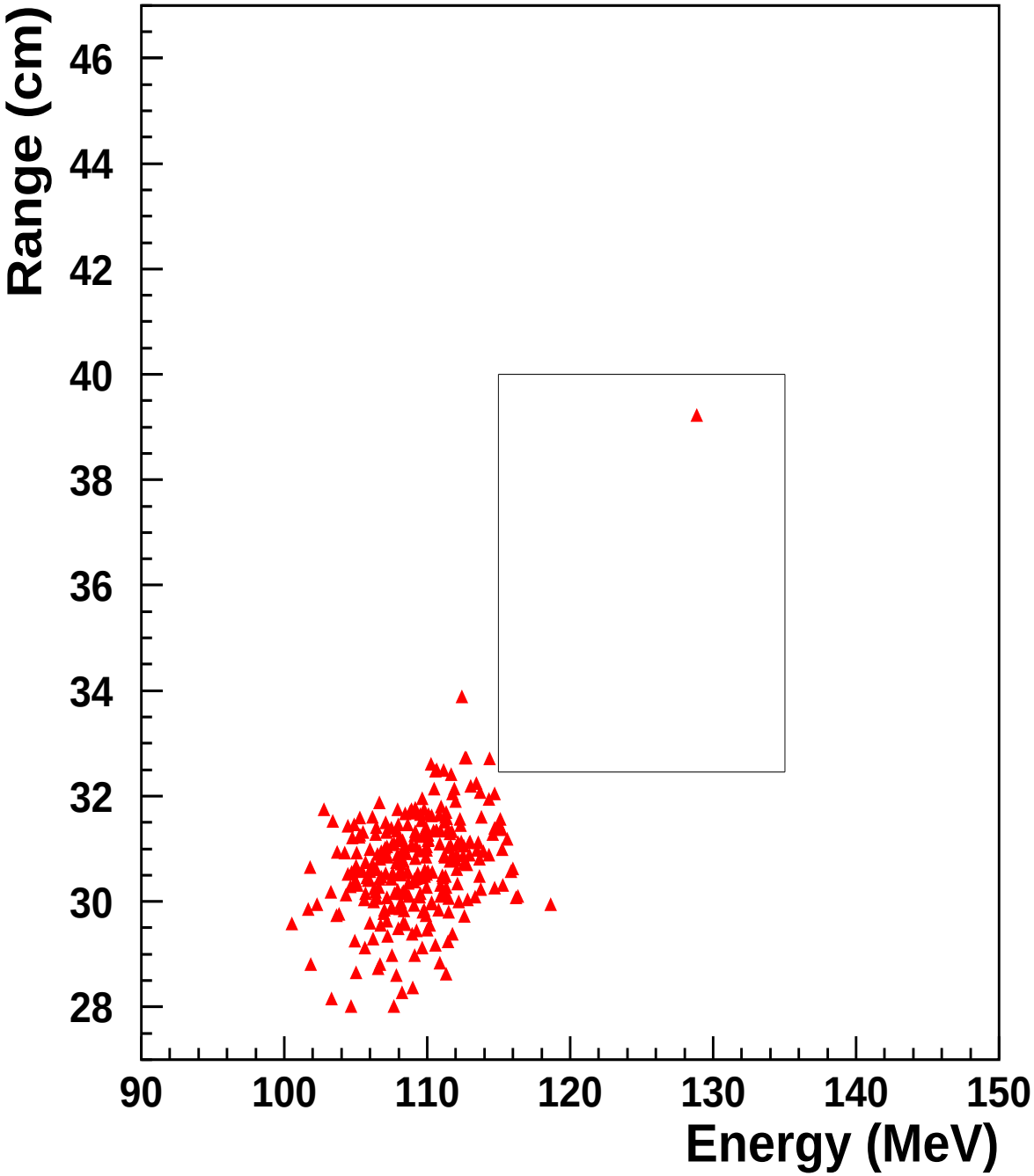
Opening the box

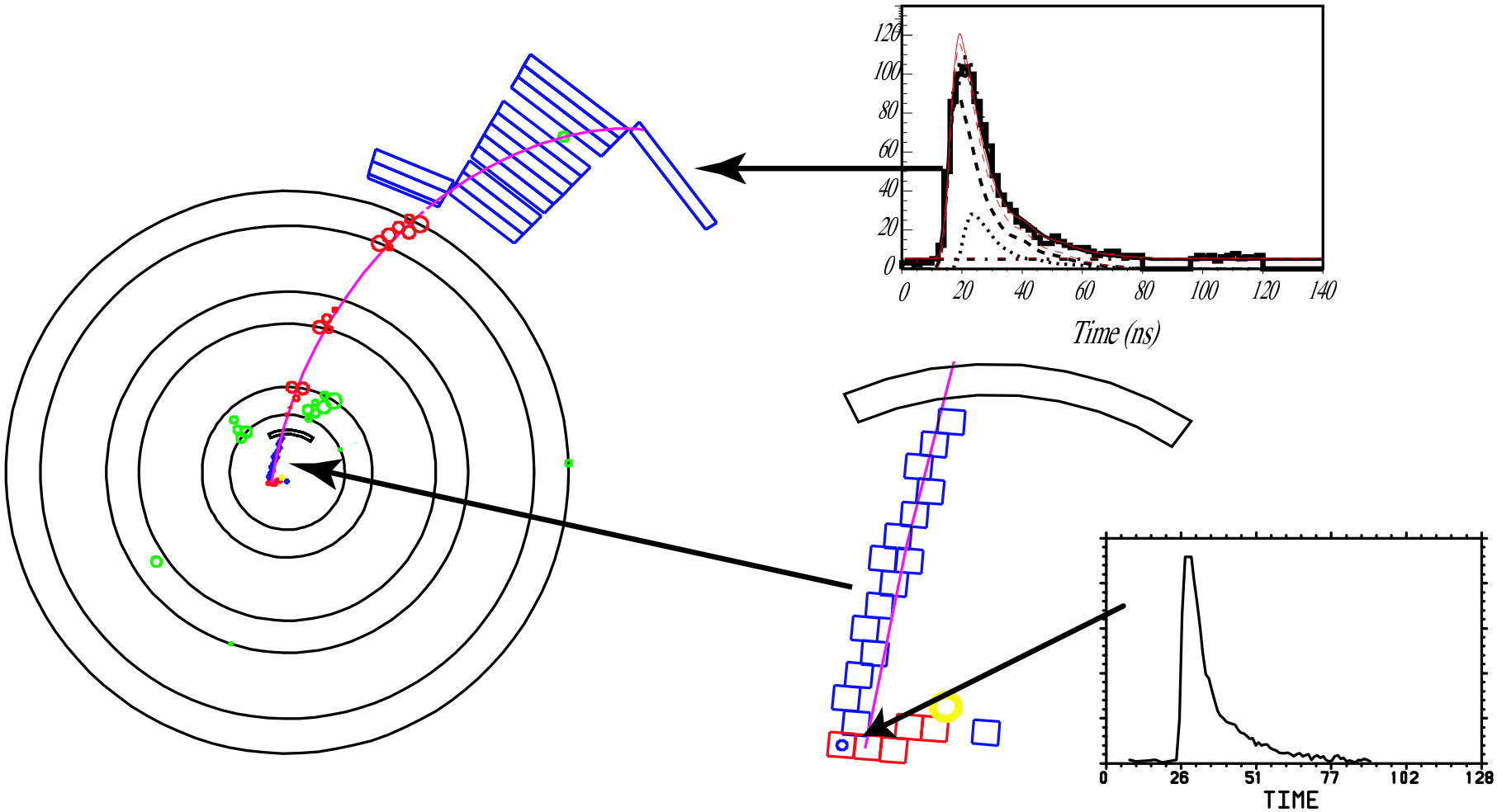
Range (cm) *vs* Energy (MeV)
for E949 data
after all other cuts imposed.

Solid line: Search region.

Single candidate found.

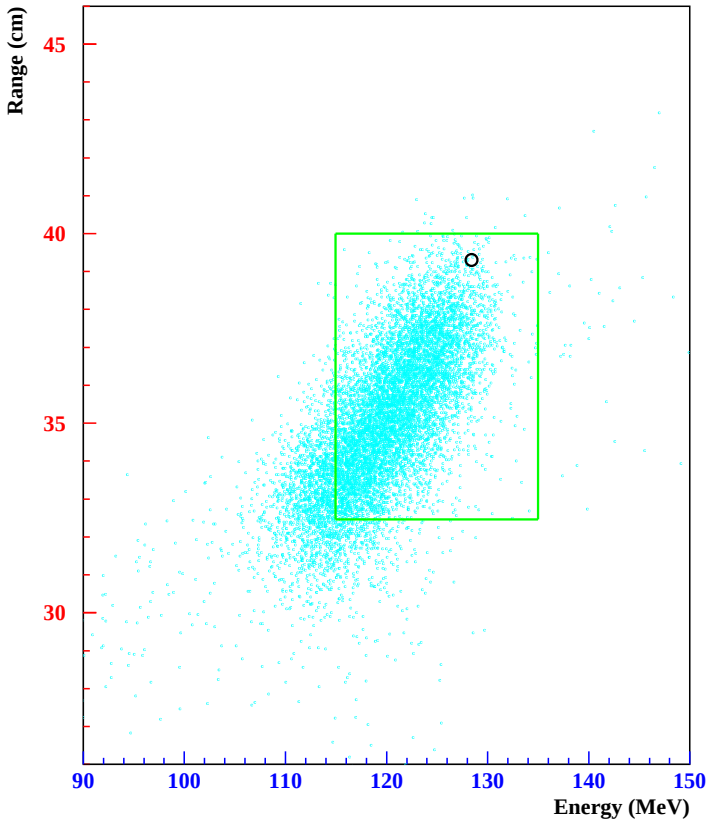
Cluster near 110 MeV:
unvetoed $K^+ \to \pi^+\pi^0$.



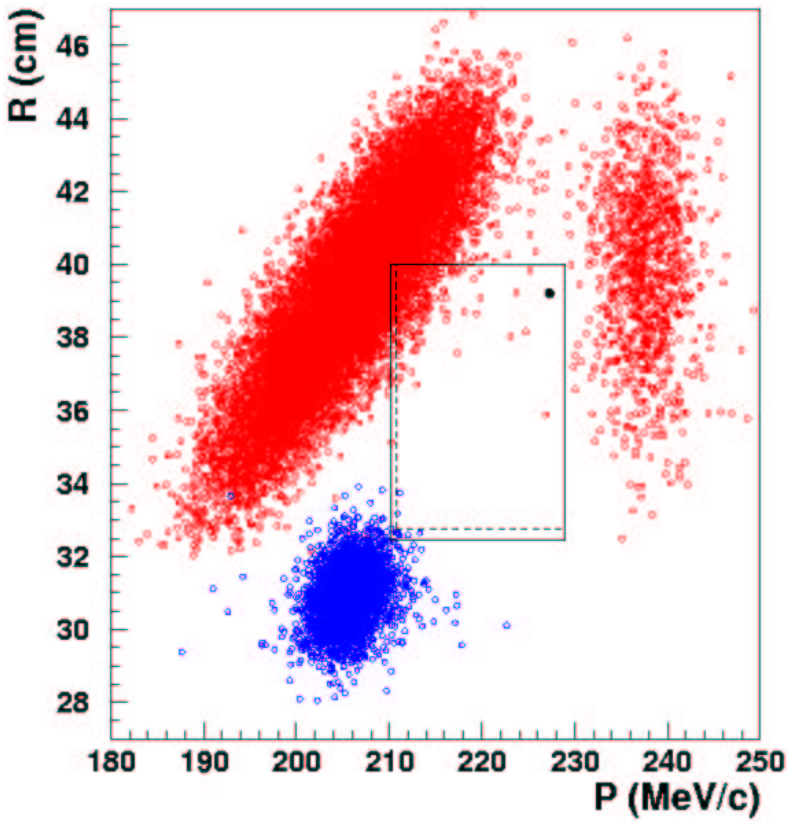

120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Time (ns)
0
26
51
77
102
128
TIME

quantities of the 3 events		1995	1998	2002
named as:		E787A	E787C	E949A
P	(MeV/c)	218.2	214.0	227.3
R	(cm)	34.7	33.9	39.2
E	(MeV)	117.7	117.4	128.9
Photon		○	○	○
$K^+ \to \pi^+$ decay time	(ns)	23.9	4.2	4.3
$\pi^+ \to \mu^+$ decay time	(ns)	26.9	16.5	6.2
$\mu^+ \to e^+$ decay time	(ns)	3253.	5333.	1370.
Beam		○	○	○

Signal S_i



Background b_i



$$S_i(BR) = 2.8 \times 10^{-5}$$

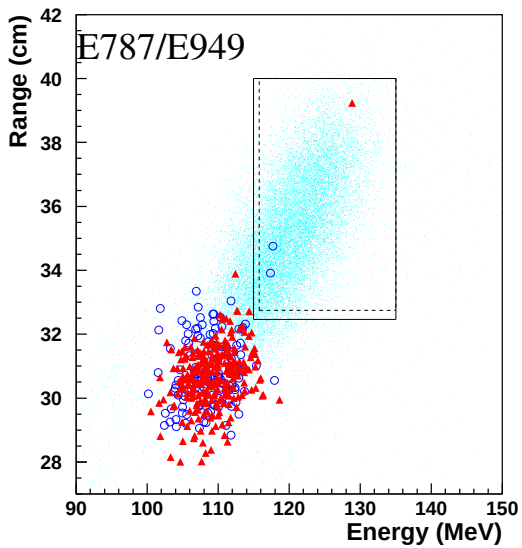
$$b_i \;=\; 5.7 \times 10^{-5} \text{ events}$$

with B.R.$_{SM}$=7.7×10^{-11}

B.R. with T. Junk method

E949 alone: $(0.96 \ +4.09 \ -0.47) \times 10^{-10}$

$\Rightarrow$ combine E787 and E949 data



	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
Candidate with $S_i(BR)/b_i$	1995A	1998C	2002A

$$\mathbf{B.R.(K^+ \to \pi^+ \nu\bar{\nu}) = 1.47^{+1.30}_{-0.89} \times 10^{-10}\ (68\%CL\ interval)}$$

	E787		E949
Candidate	1995A	1998C	2002A
S_i/b_i	50	7	0.9
W_i	0.98	0.88	0.48
Background Prob.	0.006	0.02	0.07

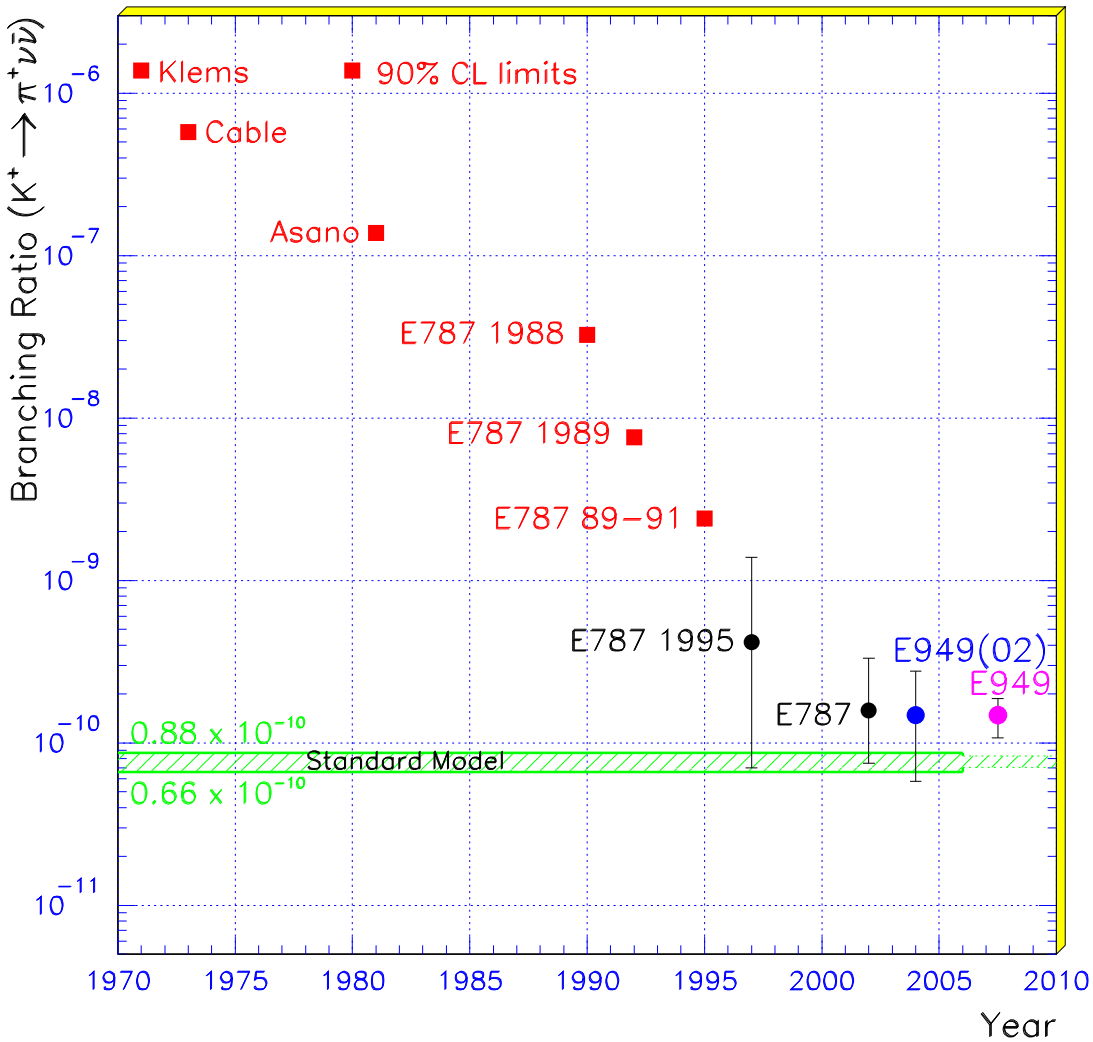
- B.R.($\mathbf{K^+ \to \pi^+ \nu\bar{\nu}}$) $> \mathbf{0.42 \times 10^{-10}}$ at 90%CL:

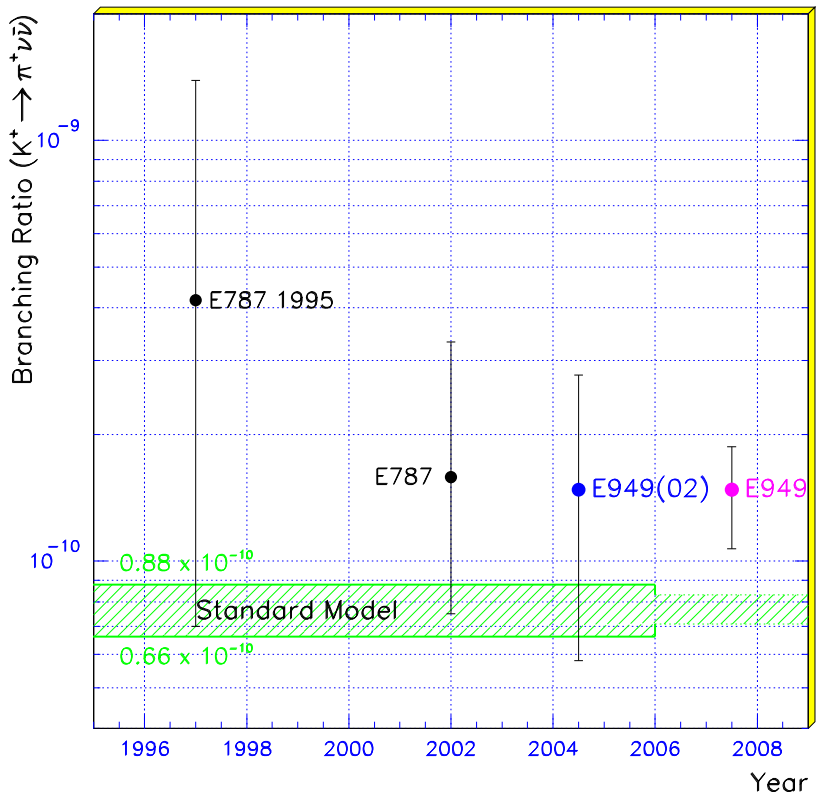
  the probability [a] that background alone gave rise to the three candidates or more: 0.001 ("$\mathbf{3\sigma}$" above the background).

- B.R.($\mathbf{K^+ \to \pi^+ \nu\bar{\nu}}$) $< \mathbf{3.22 \times 10^{-10}}$ at 90%CL:
  $\Rightarrow$ Upper limit on B.R.($\boldsymbol{K_L^0 \to \pi^0 \nu\bar{\nu}}$) by Grossman-Nir(1997): $\mathbf{1.4 \times 10^{-9}}$

- B.R.($\mathbf{K^+ \to \pi^+ \nu\bar{\nu}}$) in the SM: $\mathbf{(0.77 \pm 0.11) \times 10^{-10}}$

[a] I am a Frequentist, not a Bayesian.





Narrowing of "SM prediction" assumes measurement of B_s mixing (at Tevatron, LHC, ..) consistent with prediction.

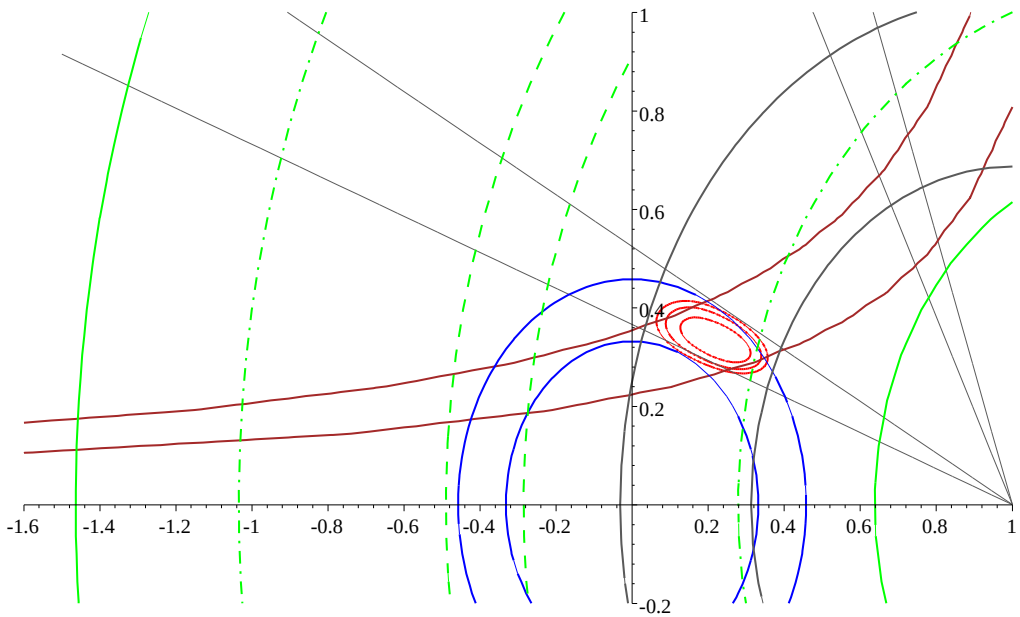
E949(02) = combined E787& E949.

E949 projection with full running period.

Impact of $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$ on Unitarity Triangle

by courtesy of G. Isidori

central value [dashed], 68% interval [dot-dash], 90% interval [solid]
(including theoretical uncertainties)



- $0.0055 \;<\; |V_{td}| \;<\; 0.0271$
- $\lambda_t \;\equiv\; V_{ts}^* \cdot V_{td} \;=\; A^2\lambda^5 \cdot (1 - \rho - i\eta)$: $\quad 0.24 \times 10^{-3} \;<\; |\lambda_t| \;<\; 1.08 \times 10^{-3}$

Conclusions

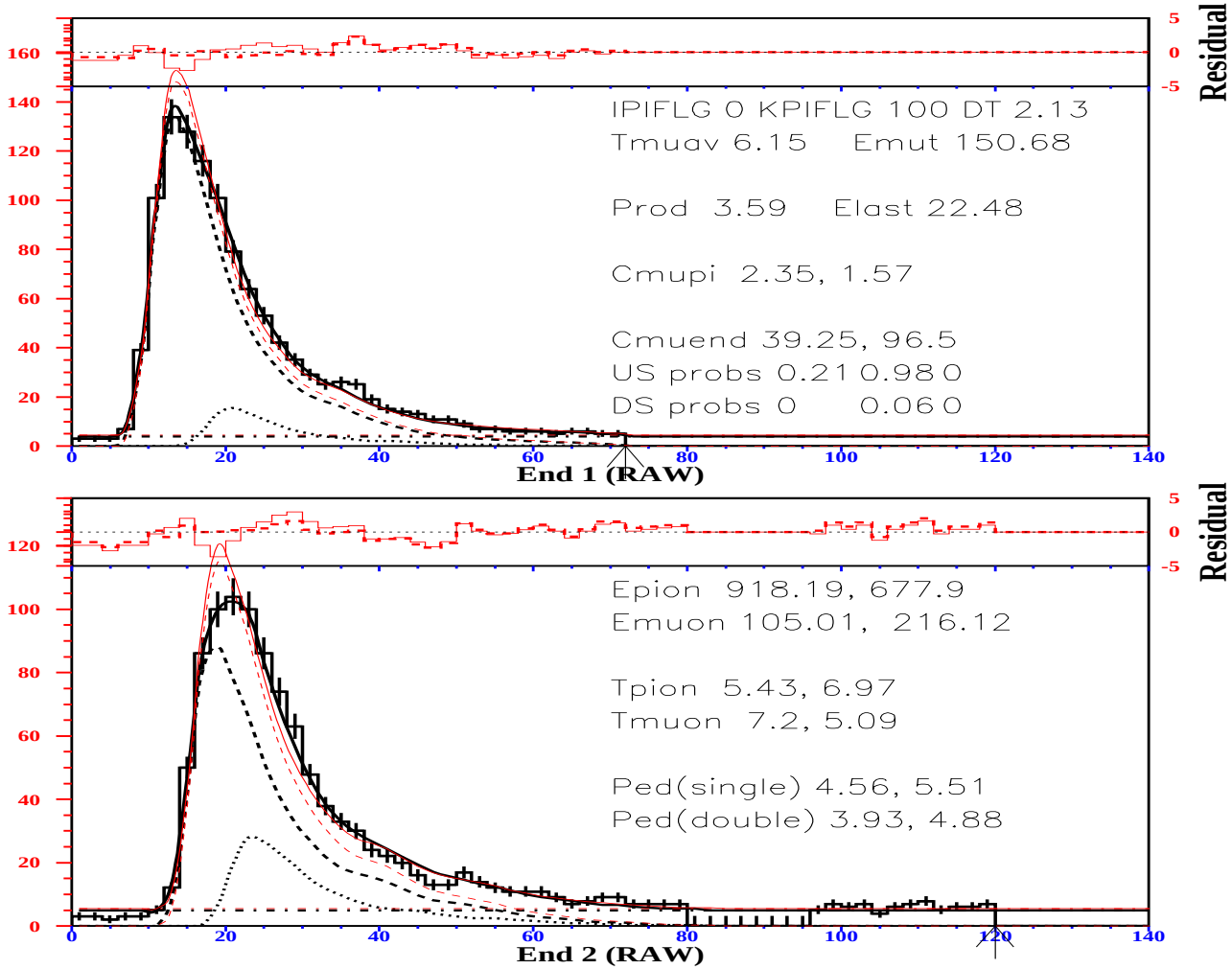
- We succeeded in upgrading E787 to create E949.
- We have proceeded to the stage of Likelihood analysis for studying rare decays
- First Results from E949 on $\mathbf{K^+ \longrightarrow \pi^+ \nu \bar{\nu}}$:
  - an additional candidate event
  - B.R.($\mathbf{K^+ \longrightarrow \pi^+ \nu \bar{\nu}}$) $= \mathbf{1.47^{+1.30}_{-0.89} \times 10^{-10}}$ for the combined data of E787 and E949
  - constraints on Unitarity Triangle (or violation ?? if the central value is correct)

Future

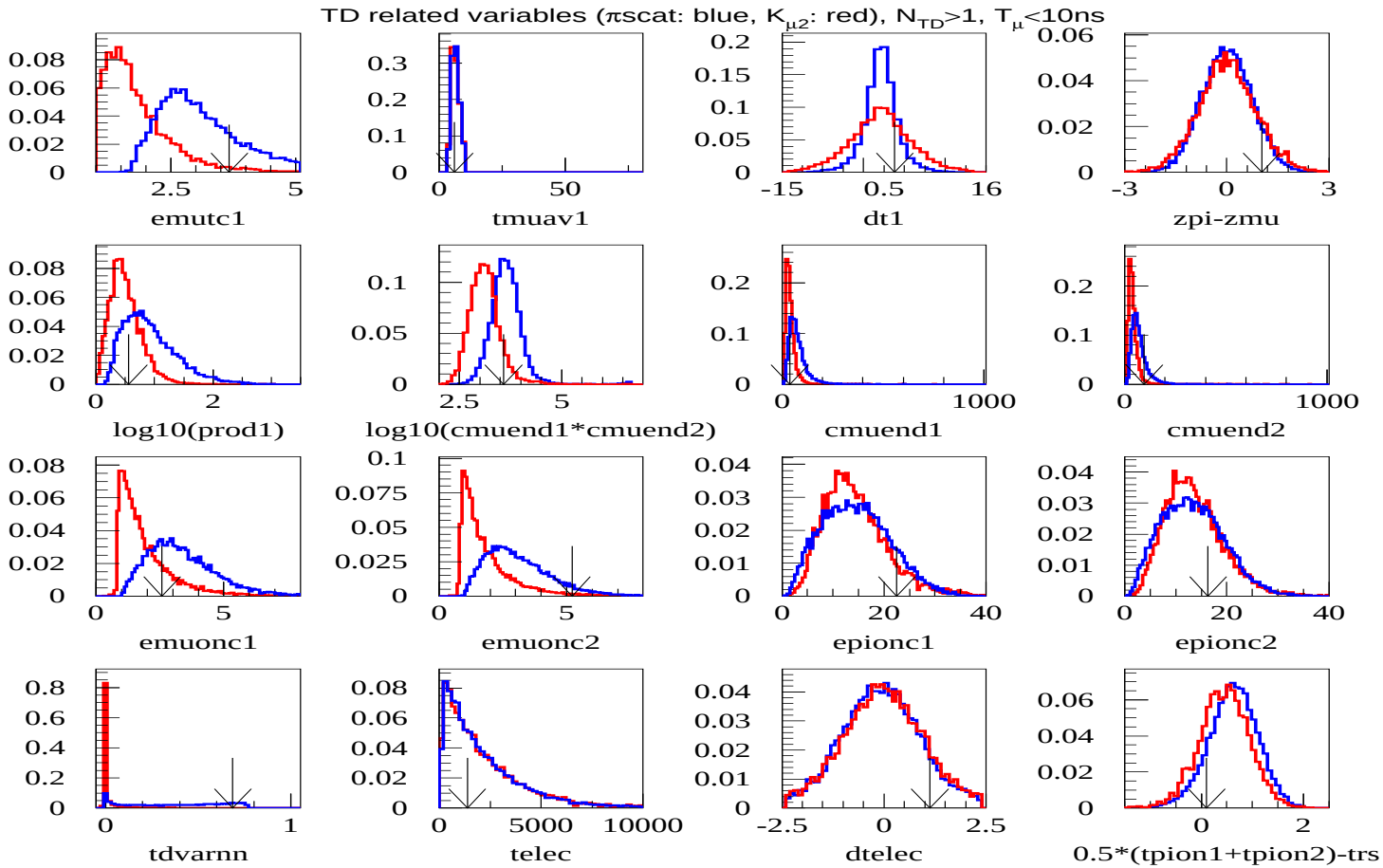
- Proton operations at AGS (by US-DOE) halted for FY2003.
  $\longrightarrow$ no new E949 data since then
- Analyses for other K^+ decay modes
  (including $\mathrm{K}^+ \to \pi^+ \nu \bar{\nu}$ for $P_{\pi^+} < 195$ MeV$/c$)
  are in progress.
- A proposal to continue running E949 has been submitted
  to the National Science Foundation of the US.
- We need more statistics; the show must go on !
  - K^+ decay at rest @ J-PARC
  - K^+ decay in flight @ FNAL, CERN

backup slides

Pulse fitting in stopping counter



Compare TD properties of candidate with π^+ and μ^+ samples



Quantities related to pion particle identification from TD variables. Events with similar background rejection and fitted muon time < 10 ns are selected. The pion signal (blue) and the muon background (red) are shown in the same plots. The arrows indicate the positions of the candidate event.

B.R. and its Confidence limits from T. Junk method

E949 alone:

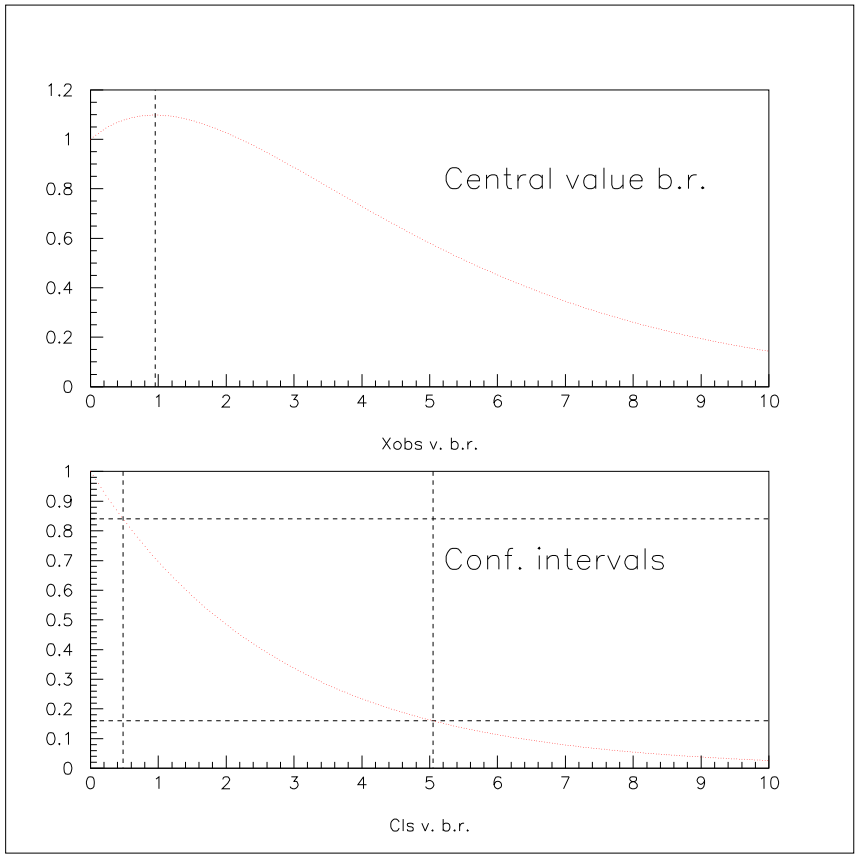
2002A event

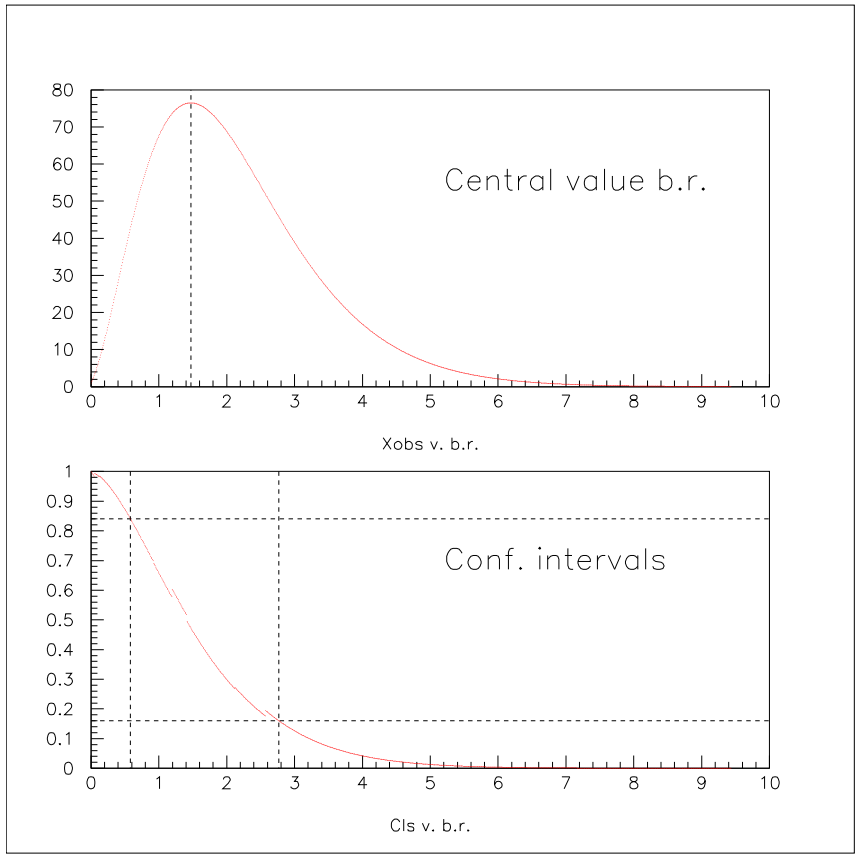
- $(0.96^{+4.09}_{-0.47}) \times 10^{-10}$
- $1 - CL_b$: 0.074 ("1.5σ")

combine E787 and E949:

1995A, 1998C and 2002A events

- $(1.47^{+1.30}_{-0.89}) \times 10^{-10}$
- $1 - CL_b$: 0.001 ("3σ")





$$\frac{\dfrac{(\ 0.98\ +\ 0.88\ )}{1}\ +\ 0.48}{\dfrac{(\ 0.98\ +\ 0.88\ )}{1}\ +\ 0.305\ \times\ 1.10} = 0.94$$

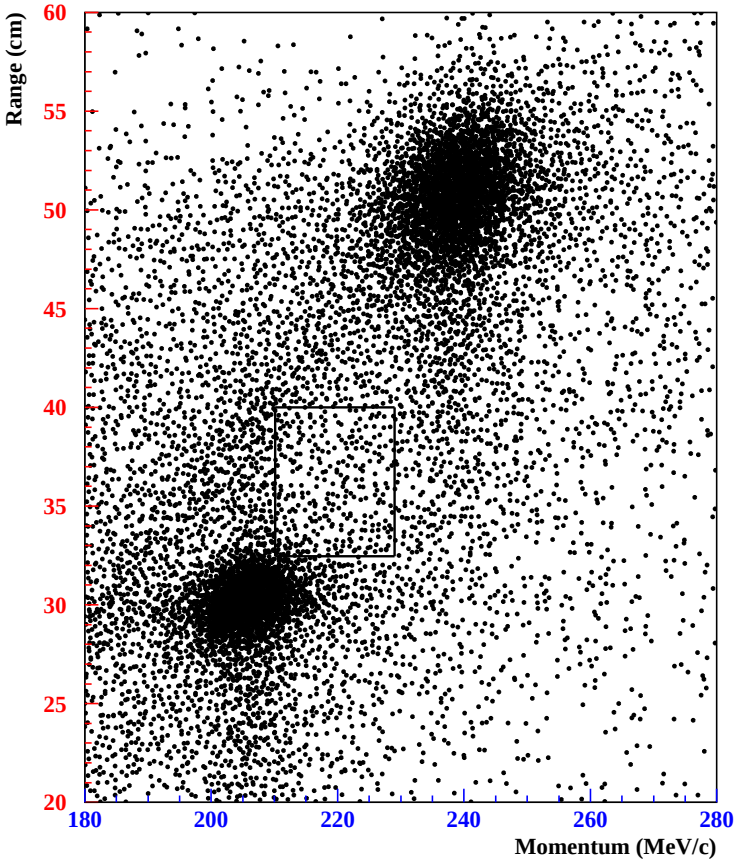
Time in spill	1.27s
Kaon energy in target	79.7 MeV
Kaon time in target (t_K)	0.6 ns
z of kaon decay vertex	8.9 cm
(x, y) of kaon decay vertex	(-2.8, -1.6) cm
π^+ energy in target	20.8 MeV
π^+ range in target	7.6 cm
π^+ time in target (t_π)	4.9 ns
π^+ time in IC (`ictime`)	3.8 ns
dip angle cosine of π^+ track	-0.24
azimuthan angle of π^+ track	1.42 π
Total momentum of π^+ track	227.3 MeV/c
Total range of π^+ track	39.2 cm
Total kinetic energy of π^+ track	128.9 MeV
RS stopping counter	Sector-3 / Layer-14
π^+ decay time	6.2 ns
μ^+ energy	3.7 MeV
μ^+ decay time	1370.53 ns
Range-momentum relation	0.63

Acceptance

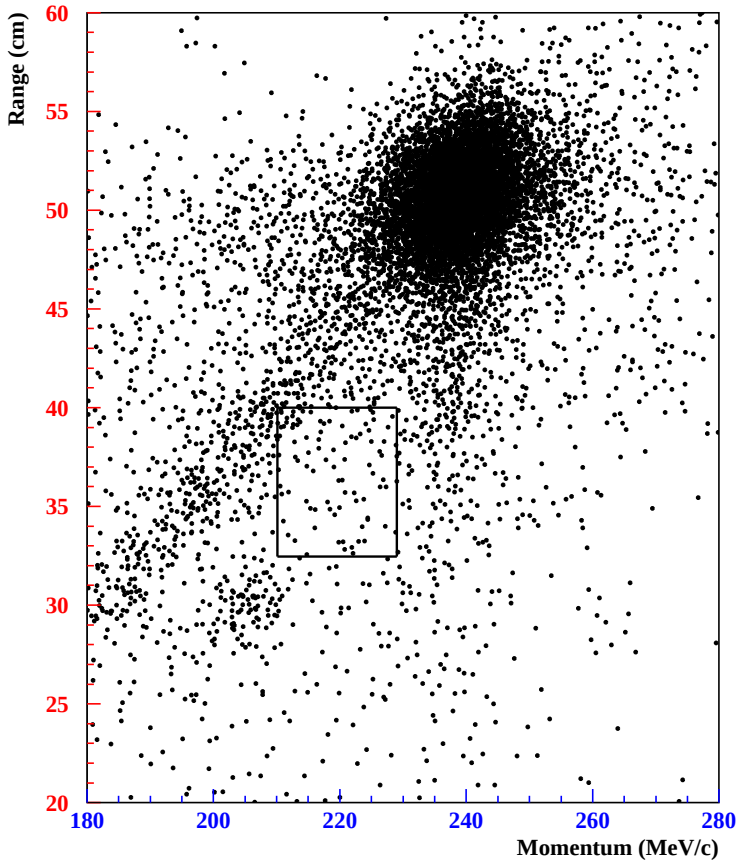
Acceptance factors	method	E787 95-97	98	E949 02
K^+ stop efficiency	BR($K_{\mu 2}$)	0.704	0.702	0.774
K^+ decay after 2 ns	$K_{\mu 2}$	0.850	0.851	0.846
$K^+ \to \pi^+ \nu \bar{\nu}$ phase space	M.C.	0.155	0.136	0.160
Solid angle acceptance	M.C.	0.407	0.409	0.414
π^+ stop efficiency	M.C.	0.513	0.527	0.544
Reconstruction efficiency	$K_{\mu 2}$	0.959	0.969	0.996
Other kinematic constraints	π_{scat},$K_{\pi 2}$,$K_{\mu 2}$	0.665	0.554	0.501
$\pi - \mu - e$ decay acceptance	π_{scat}	0.306	0.392	0.365
Beam and target analysis	$K_{\mu 2}$	0.699	0.706	0.648
Accidental loss	$K_{\mu 2}$	0.785	0.751	0.820
Total acceptance		0.21%	0.196%	0.22%

Online data reduction(1)

- K^+ decay at rest,
  CT to the RS acceptance region

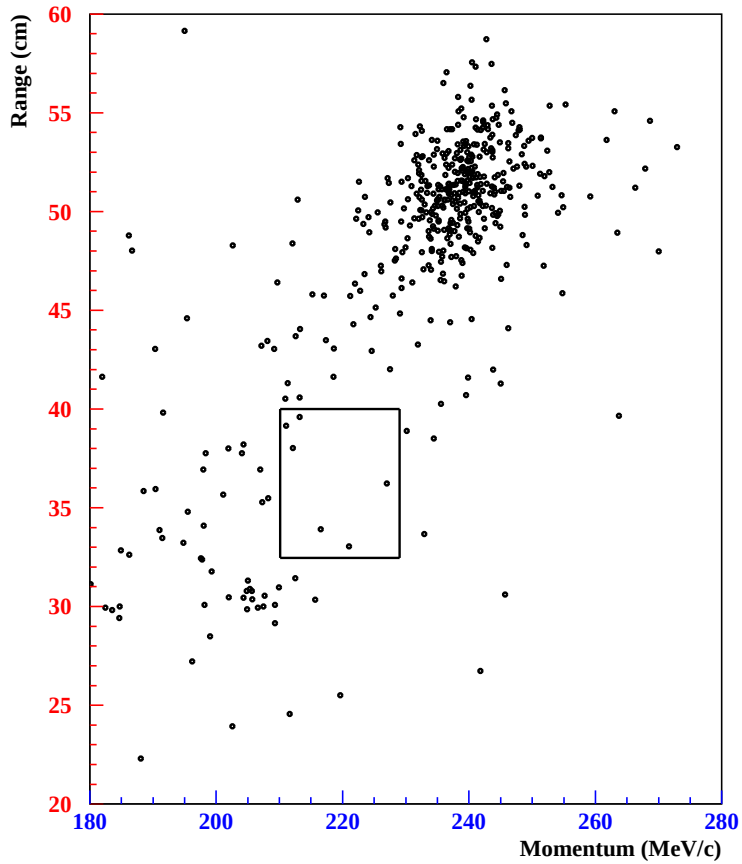


- Photon Veto
  BV, BVL, EC, RS

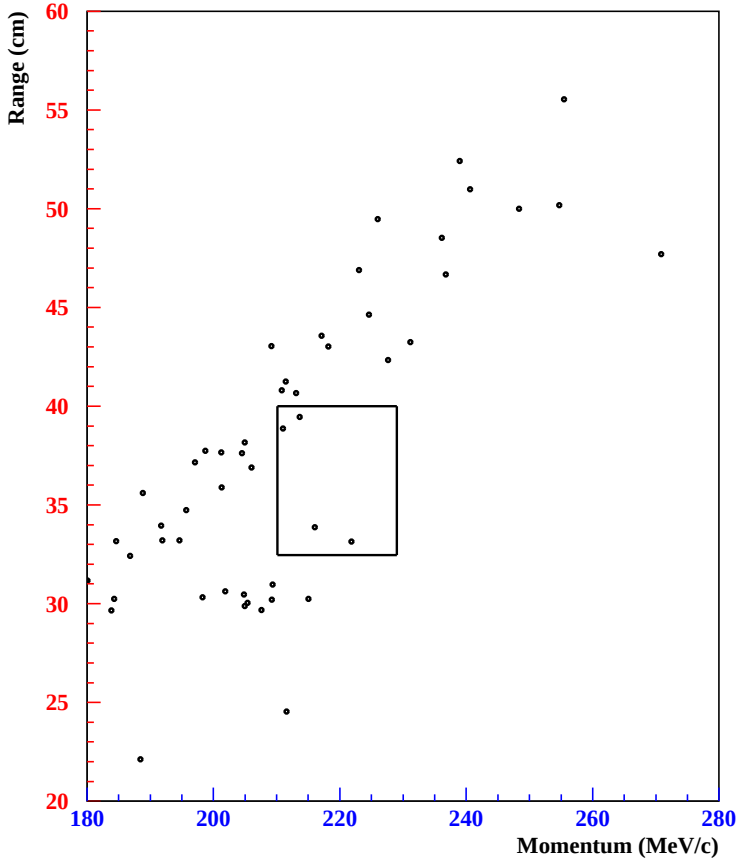


Online data reduction(2)

- π^+ comes to rest in the RS,
  $\rightarrow \mu^+$ (waveform analysis)

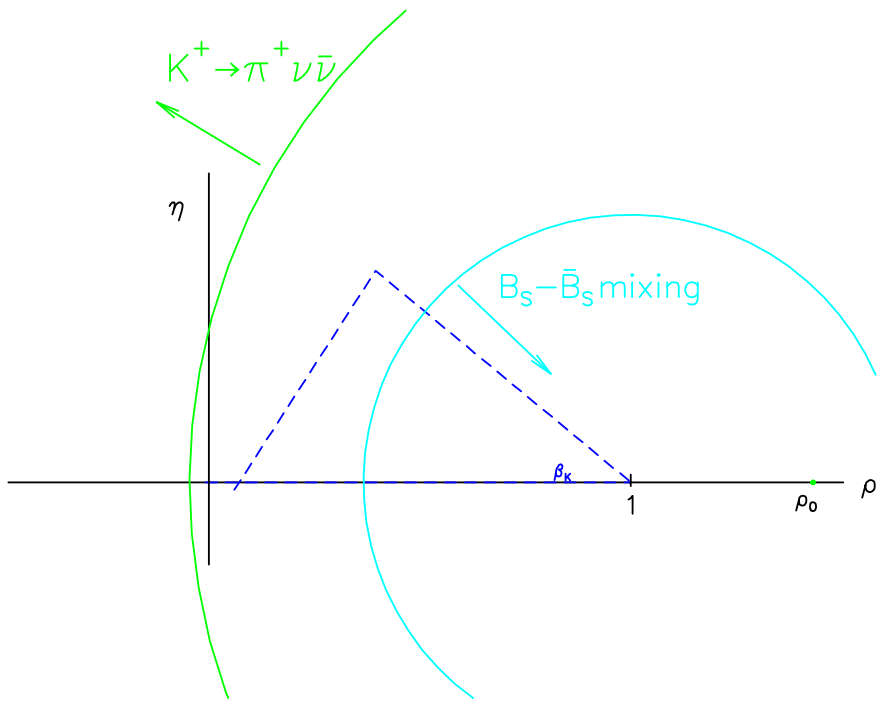


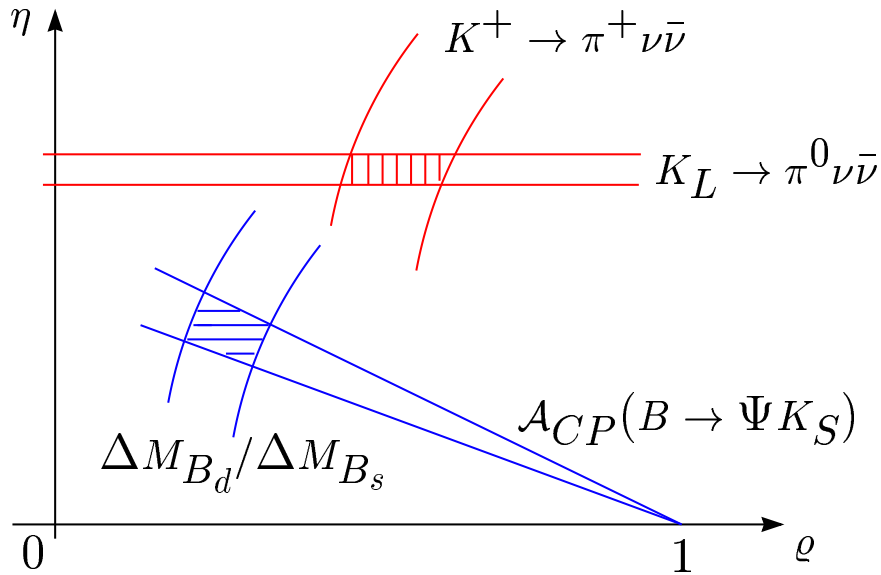
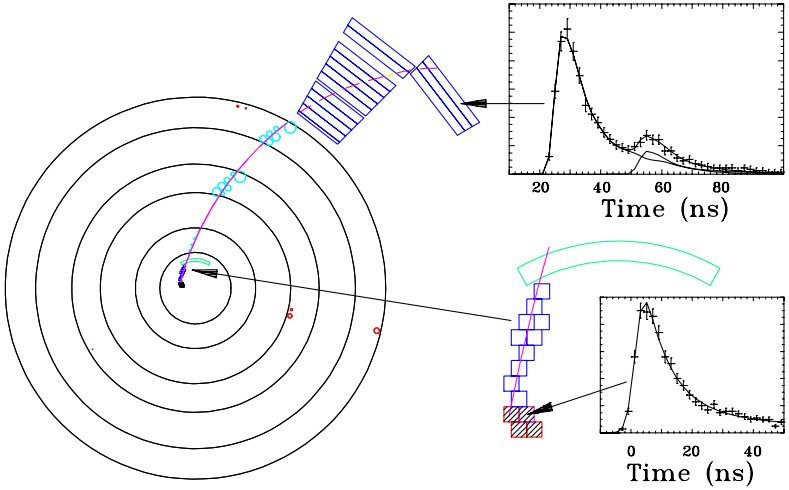
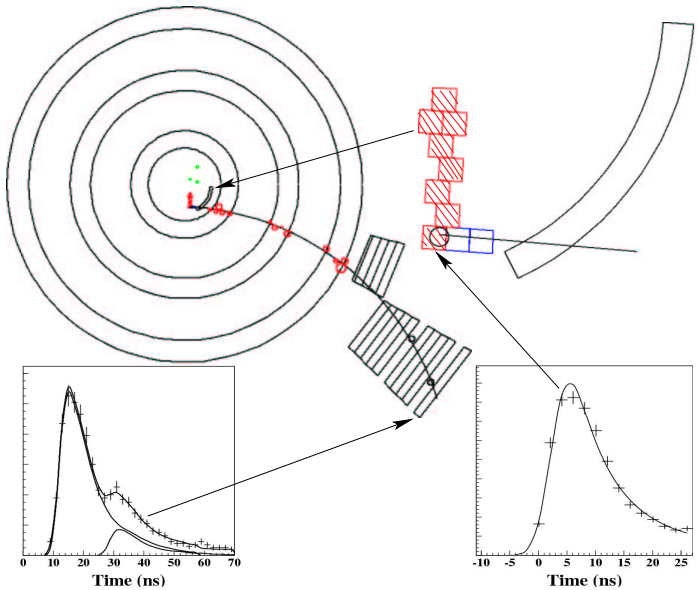
- refined Range cut
  with TG/RS hit information



Reminder: these plots (for illustration) were made from a very small part of the sample.

flagship


$K^+ \to \pi^+ \nu\bar{\nu}$
η
$B_s - \bar{B}_s$ mixing
β_K
1
ρ_0
ρ


η
$K^+ \to \pi^+ \nu\bar{\nu}$
$K_L \to \pi^0 \nu\bar{\nu}$
$\mathcal{A}_{CP}(B \to \Psi K_S)$
$\Delta M_{B_d}/\Delta M_{B_s}$
0
1
ϱ

two $K^+ \to \pi^+ \nu\bar{\nu}$ events in E787