# Measurement of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ Branching Ratio

Toshio Numao

*TRIUMF*

For E949 Collaboration:

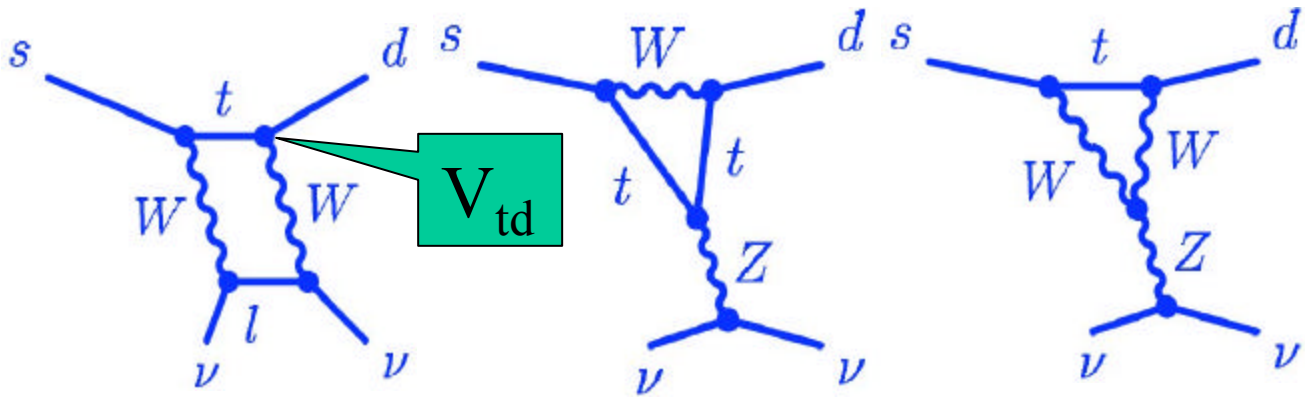
*IHEP, New Mexico ,BNL, TRIUMF, UBC*

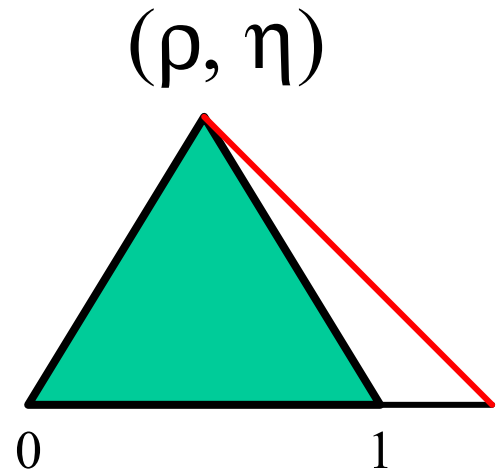
*Tsinghua,Stony Brook,FNAL,Kyoto,KEK*

*INR,Alberta,Fukui,Osaka,Defense Academy*

November 10, 2004

# $K^+ \to \pi^+ \nu \bar{\nu}$




Before isospin correction.

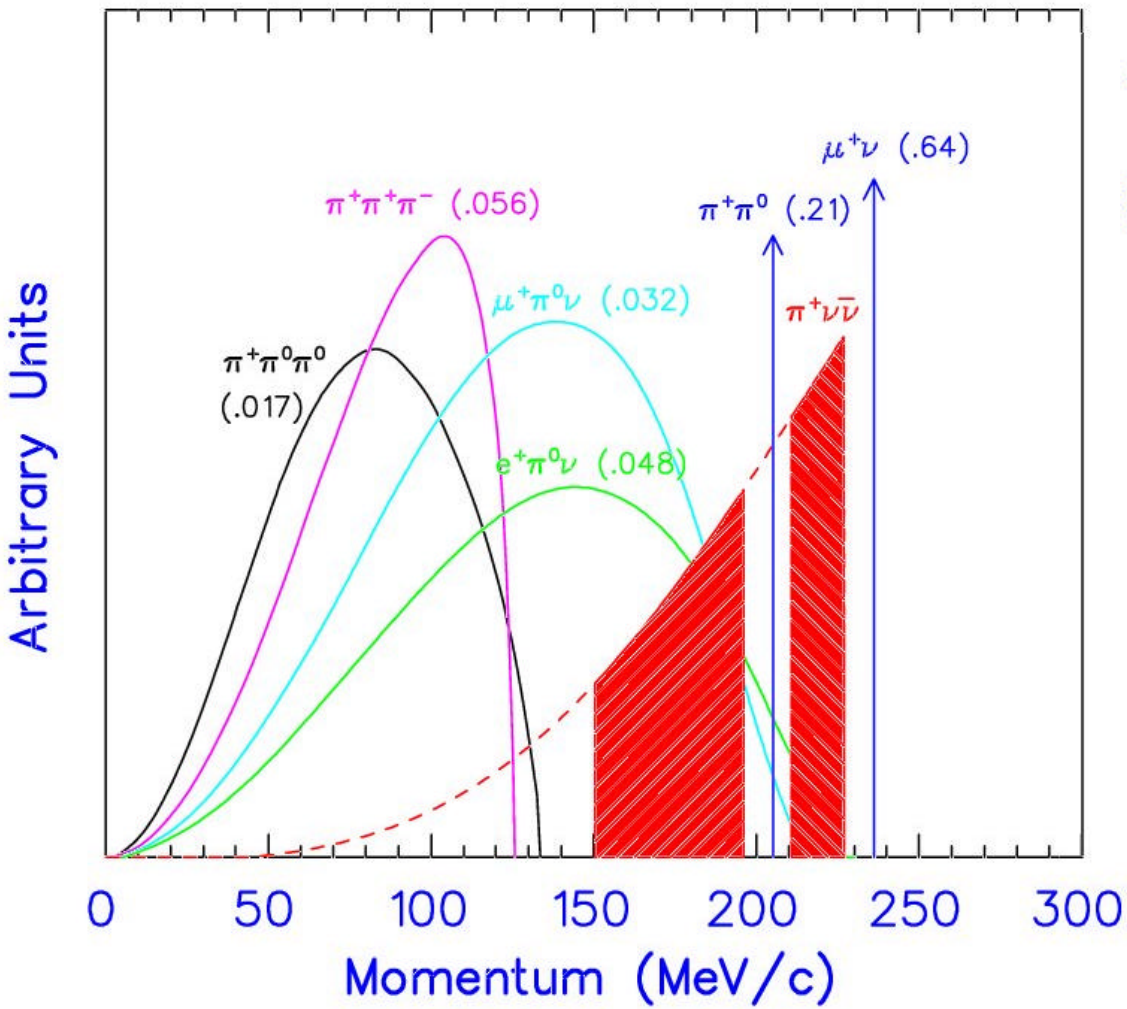
$$\frac{\mathrm{BR}(K^+ \to \pi^+ \nu \bar{\nu})}{\mathrm{BR}(K^+ \to \pi^0 e^+ \nu)} = \frac{3\alpha^2}{8\pi^2 \sin^4 \theta_W} \frac{1}{|V_{us}|^2} \left| \sum_{i=u,c,t} V_{qs}^* V_{qd} X(x_q) \right|^2$$

Where $x_q = m_q^2 / M_W^2$

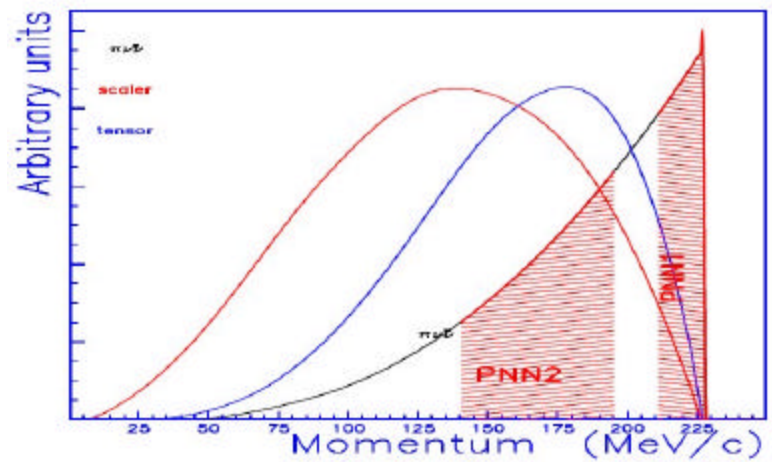
- Top contribution dominates (Charm contribution ~30 %).
- Small theoretical uncertainty ~5 %.
- Expected to be BR=**$(0.85 \pm 0.07) \times 10^{-10}$**
- Unique probe of new physics; MSSM, LHT…

# Momentum Spectra

## K+ Decay (Standard Model)

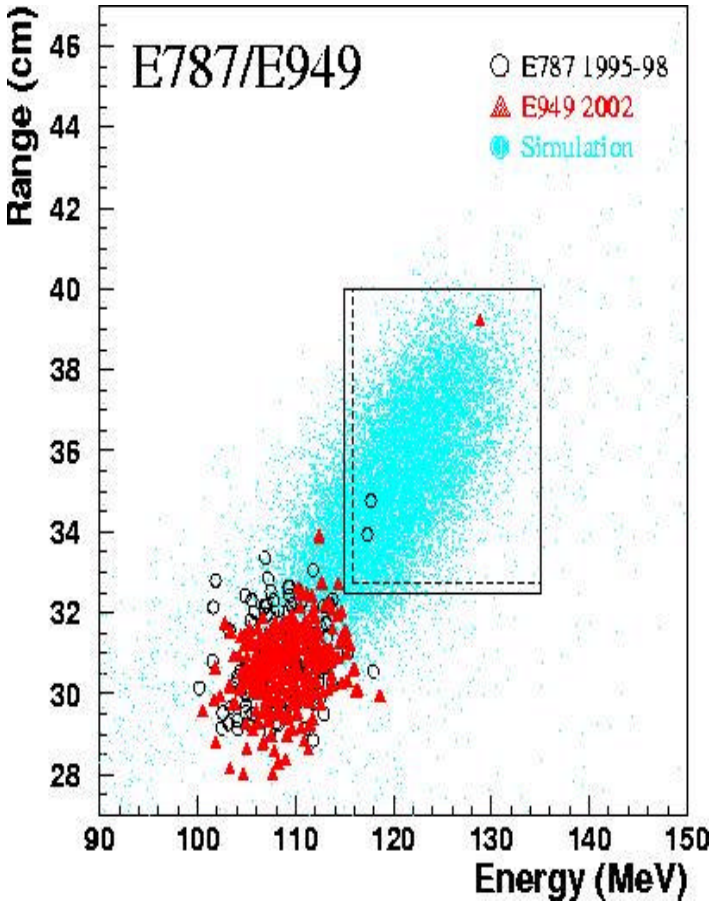



## V-A, S, T



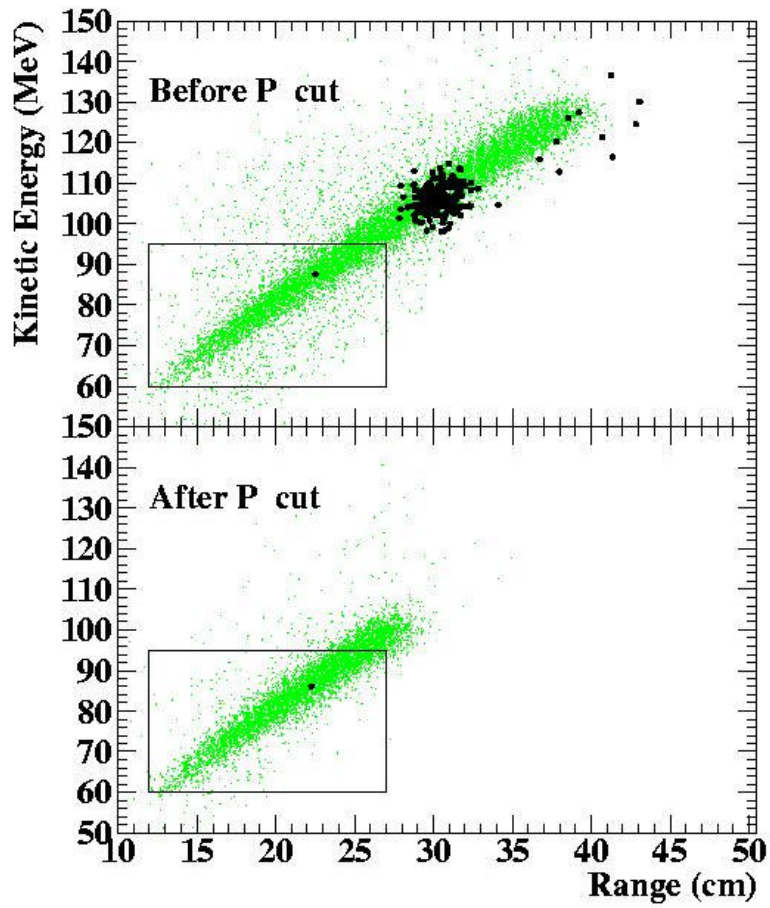
# Previous measurements

## Above Kπ2 peak




$B(K^+ \to p^+nn) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$

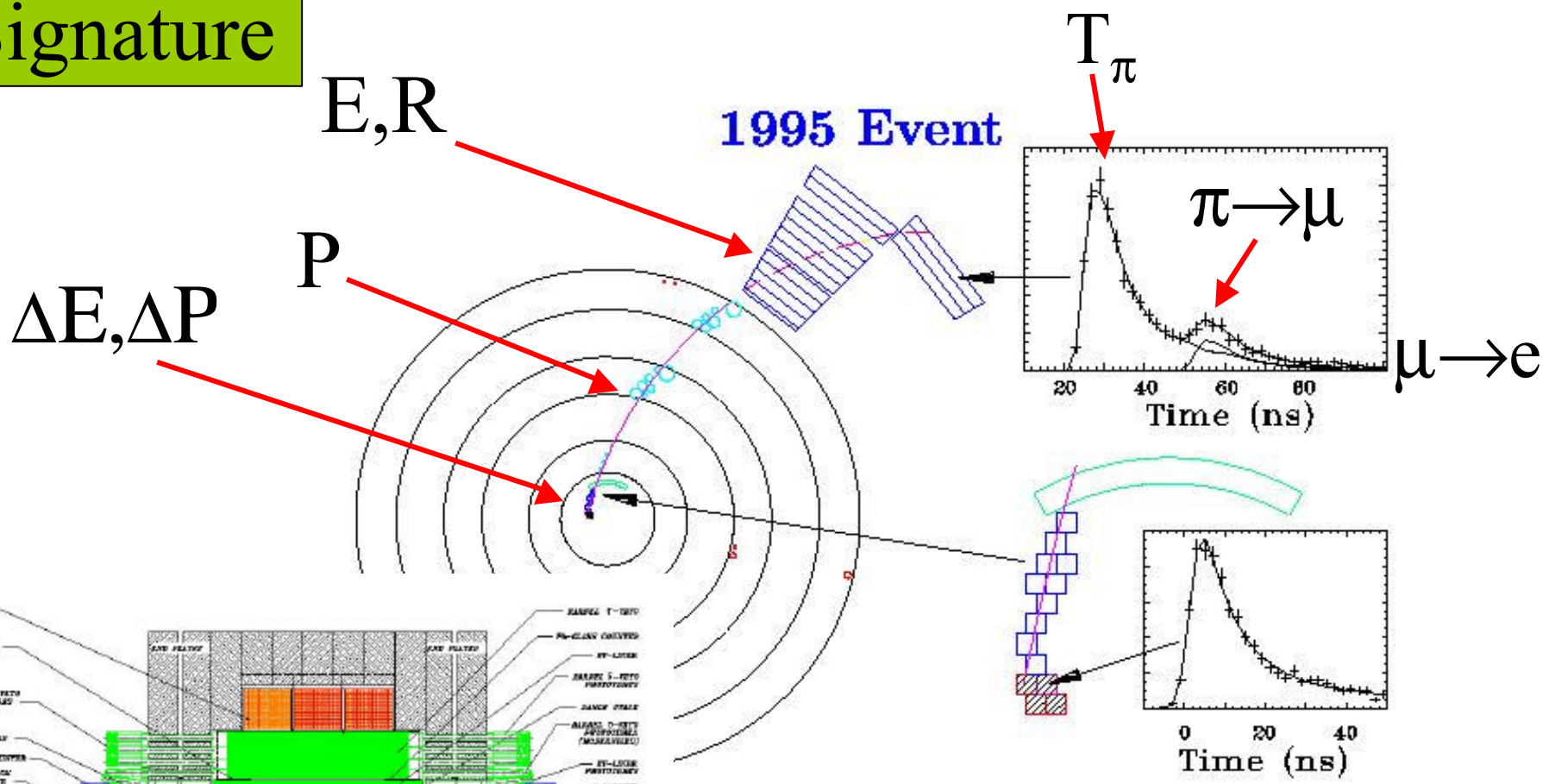
## Below Kπ2 peak

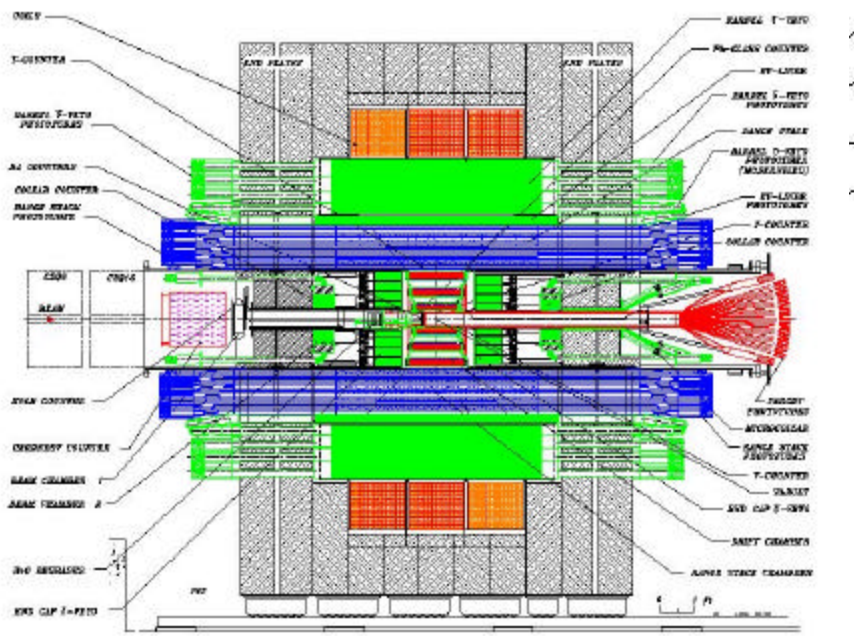



$B(K^+ \to p^+nn) < 2.2 \times 10^{-9}$

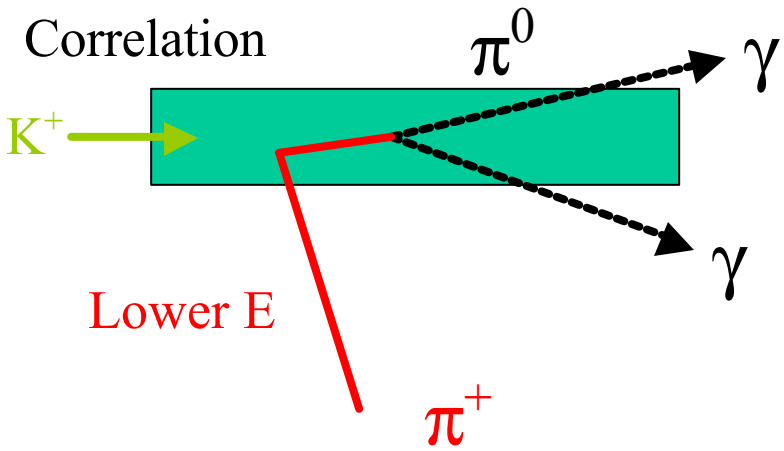
b.g.=1.22±0.24 events.

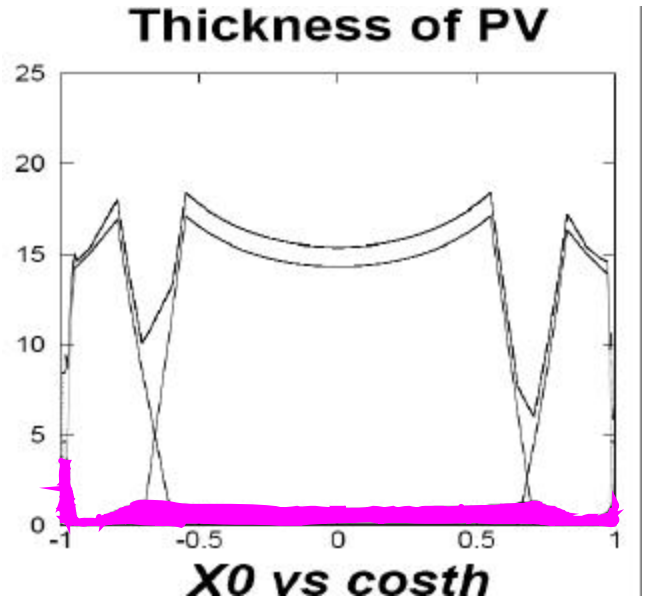
# Signature



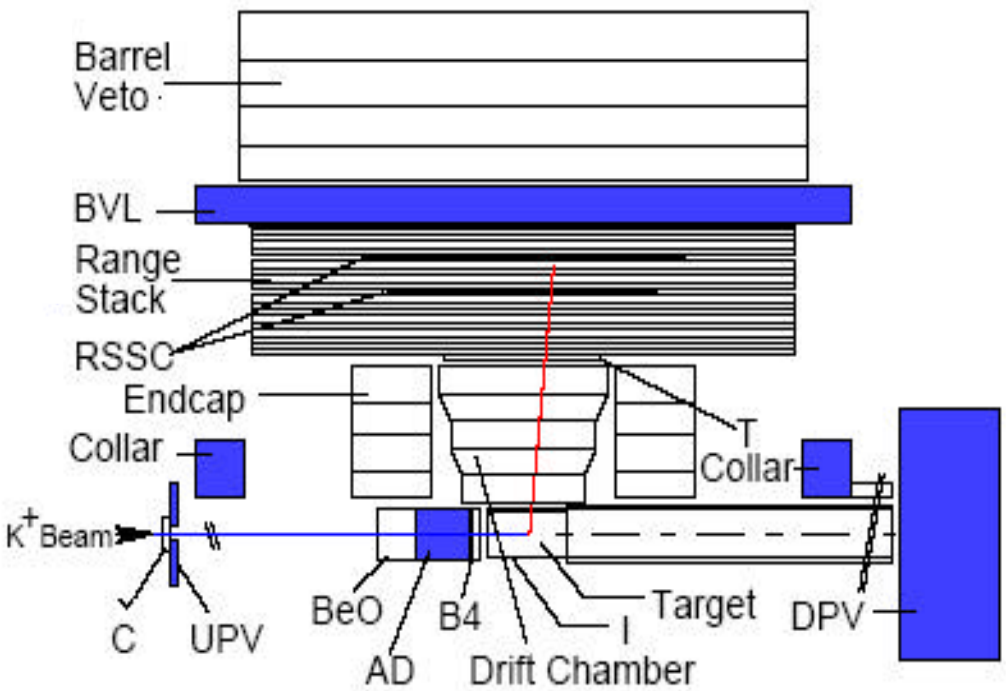



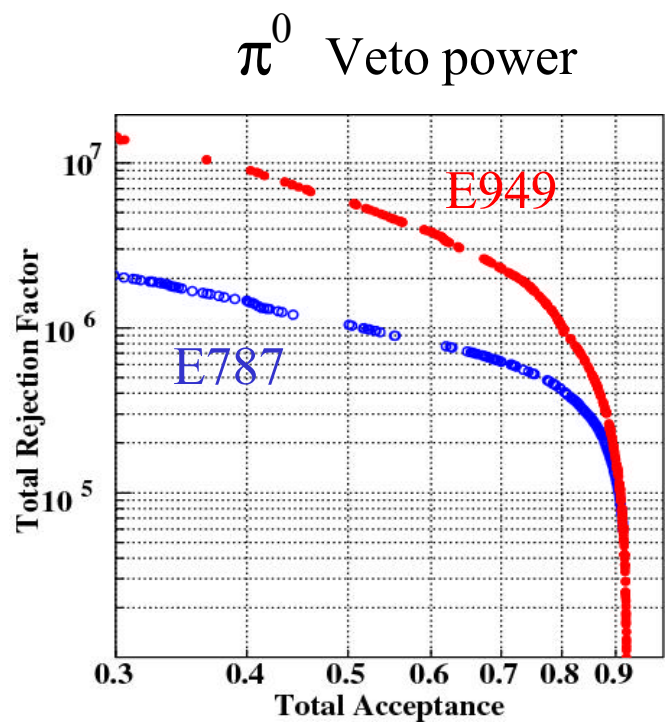
-Stopped kaon
-Delayed decay
-Single pion
-No other activity


Correlation
$\pi^0$
$\gamma$
$K^+$
$\gamma$
Lower E
$\pi^+$


Thickness of PV
25
20
15
10
5
0
-1
-0.5
0
0.5
1
X0 vs costh

E787 → E949


Barrel Veto
BVL
Range Stack
RSSC
Endcap
Collar
T
Collar
$K^+$ Beam
C
UPV
BeO
B4
AD
Drift Chamber
I
Target
DPV


$\pi^0$ Veto power
E949
E787
Total Rejection Factor
$10^7$
$10^6$
$10^5$
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Total Acceptance

**Run Summary**
(Below the $K_{\pi 2}$ peak)

1996: $1.1 \times 10^{12}$ stopped $K^+$

1997: $0.6 \times 10^{12}$ stopped $K^+$

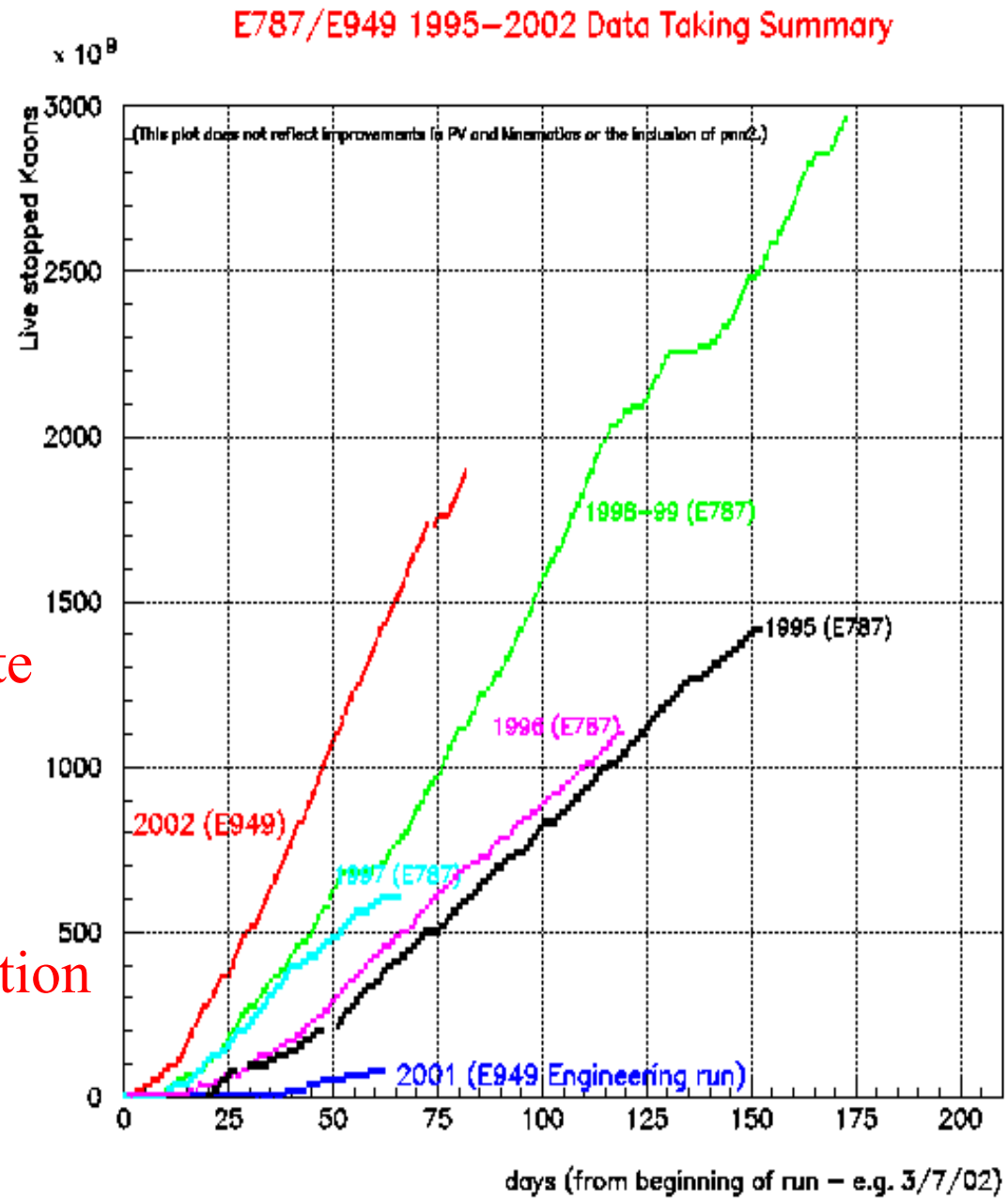
2002: $1.7 \times 10^{12}$ stopped $K^+$

-Higher K+ instantaneous rate

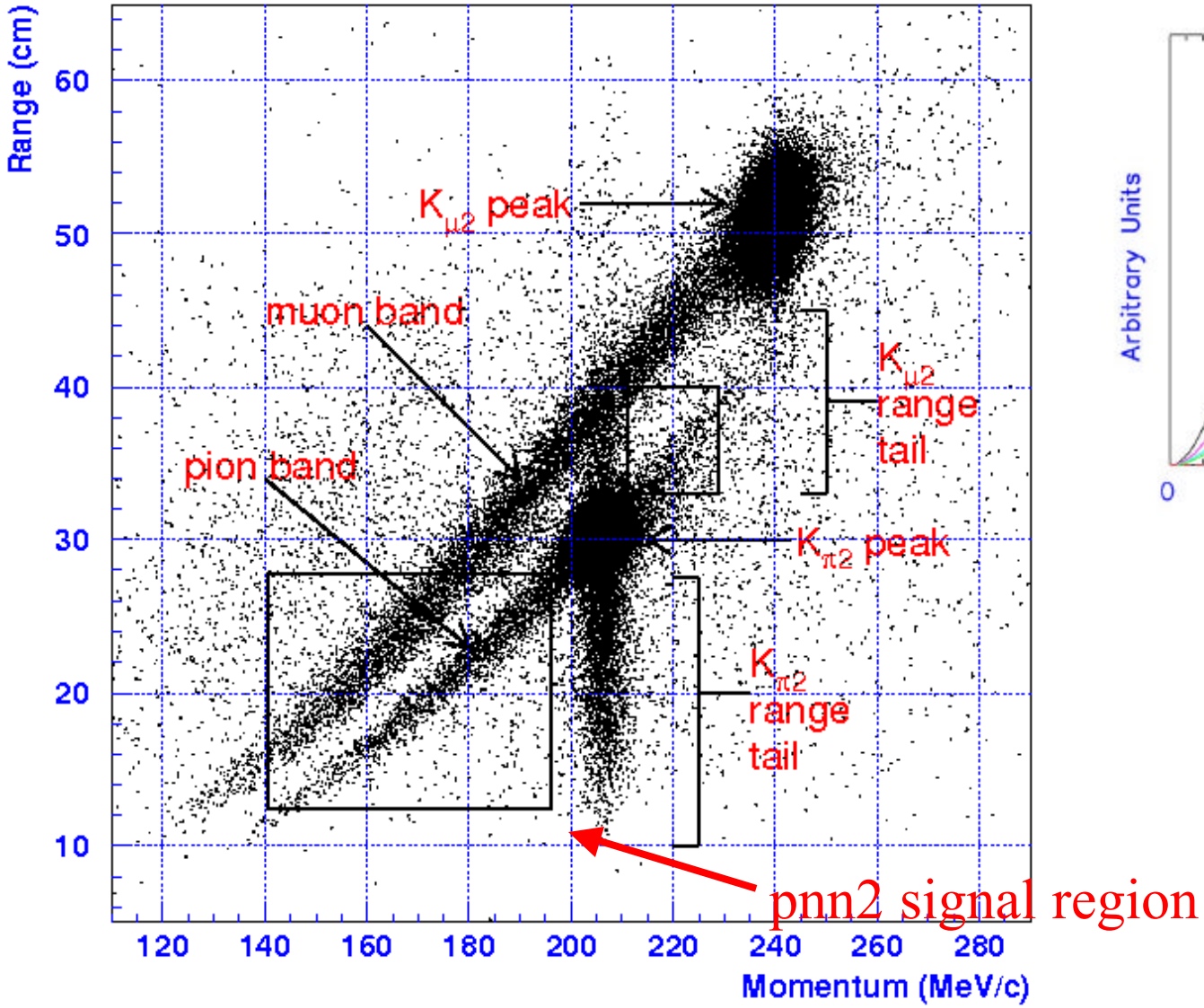
-Improved Photon veto

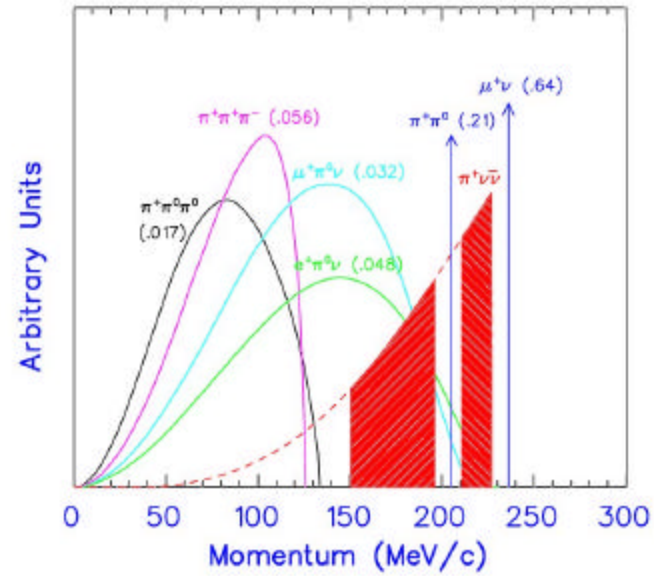
-Many detector upgrades

-Same or better P,E,R resolution



# Before any cuts



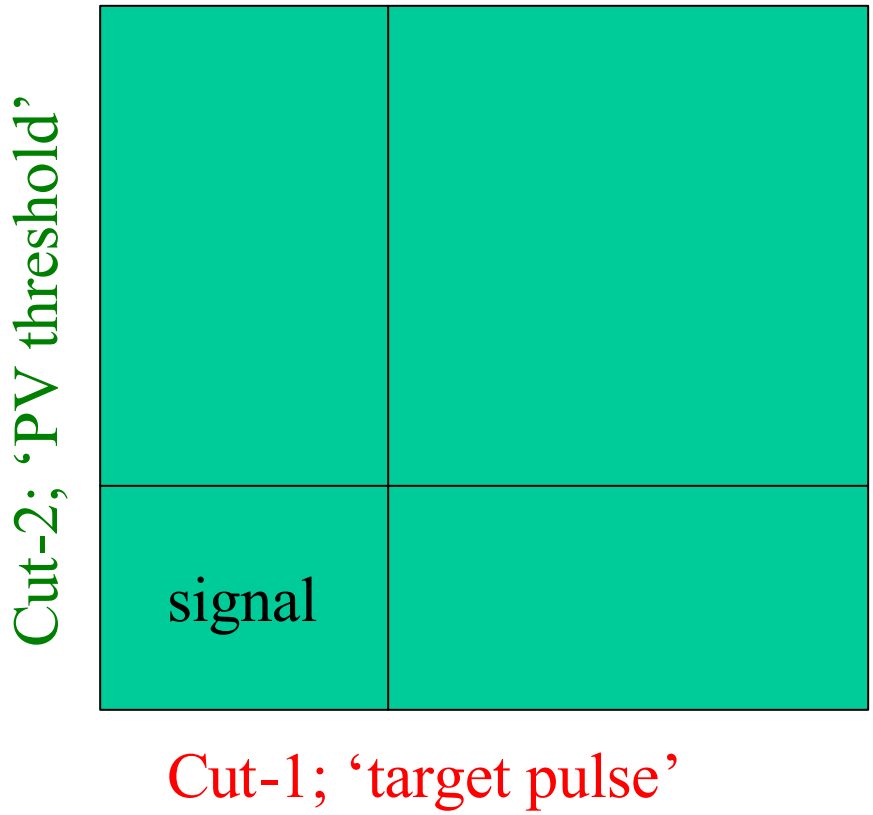




- Kinematics
- $\pi \rightarrow \mu$
- Extra particle
- Photon veto
- Kink

# Analysis strategy

To avoid a human bias:

- Mask the signal region.
- First, develop the cuts and estimate the background (1/3 data).
- Use data as much as possible in the background estimates.
- Bifurcated BG analysis (2/3) data.
- Study the correlation.
- Open the "box".

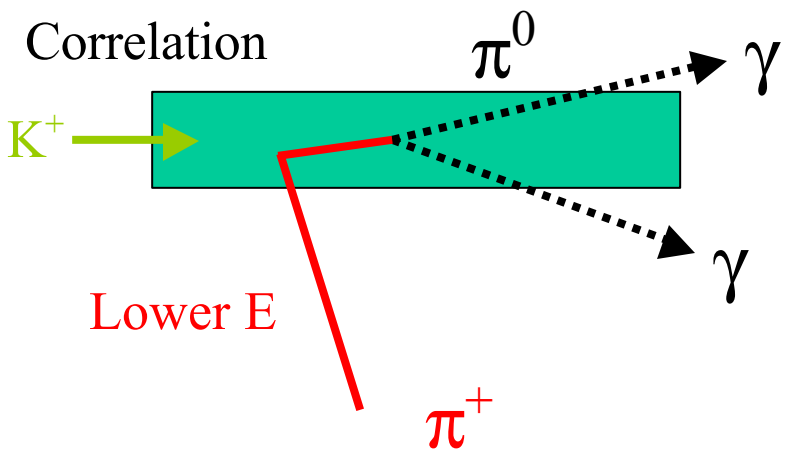


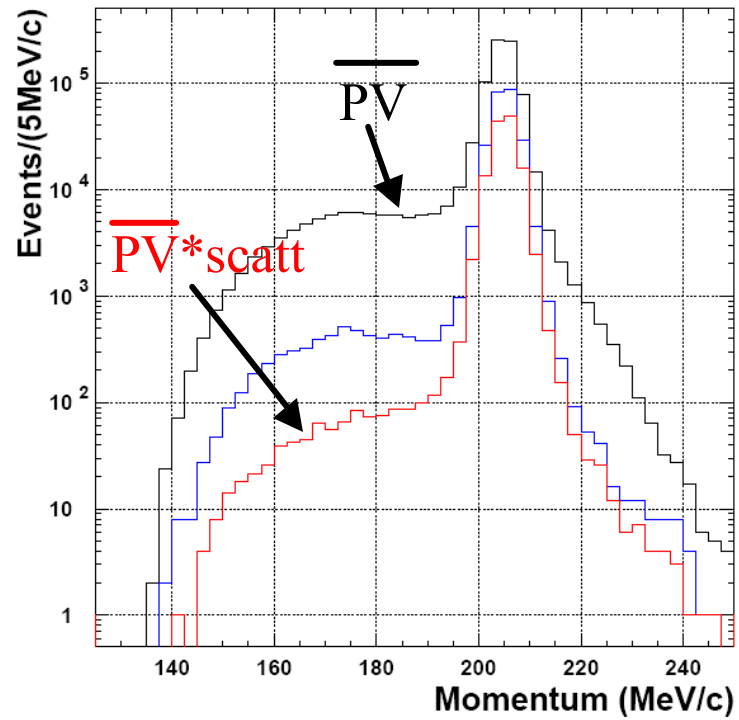

$K_{p2}$ : 1=target scatt. 2=photon veto

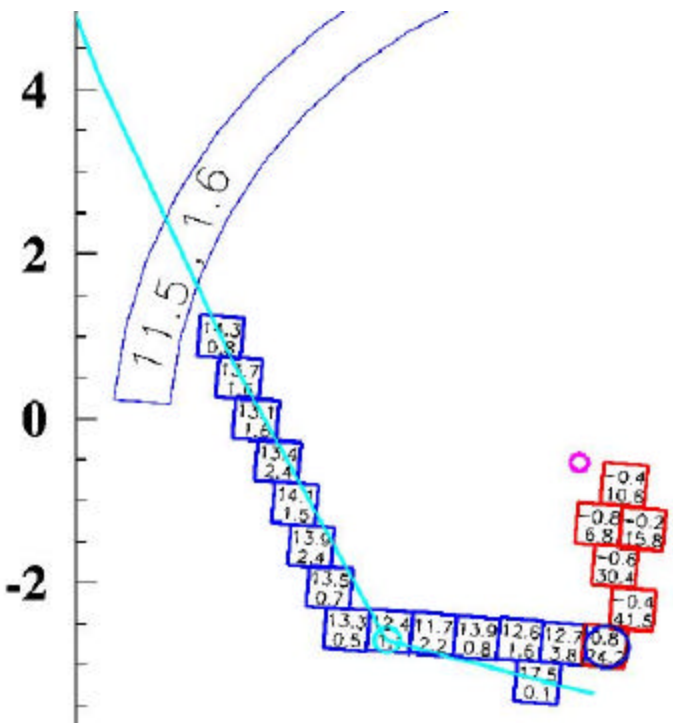
$K_{e4}$ : 1=$T_\pi$ + Te 2=MC

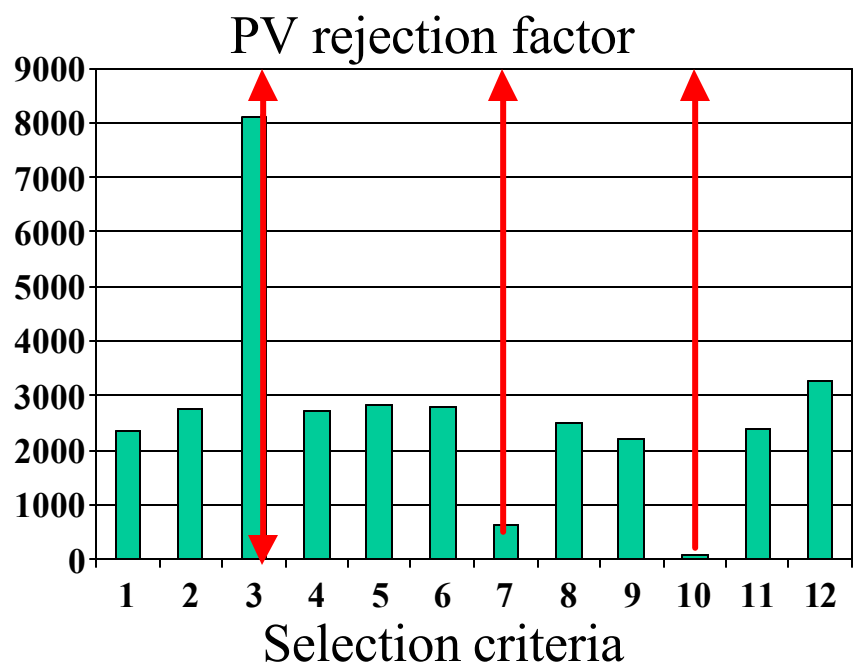
$K_{m2}$ : 1=kinematics 2=$\pi \rightarrow \mu \rightarrow e$

# $K^+ \rightarrow \pi^+ \pi^0$ background



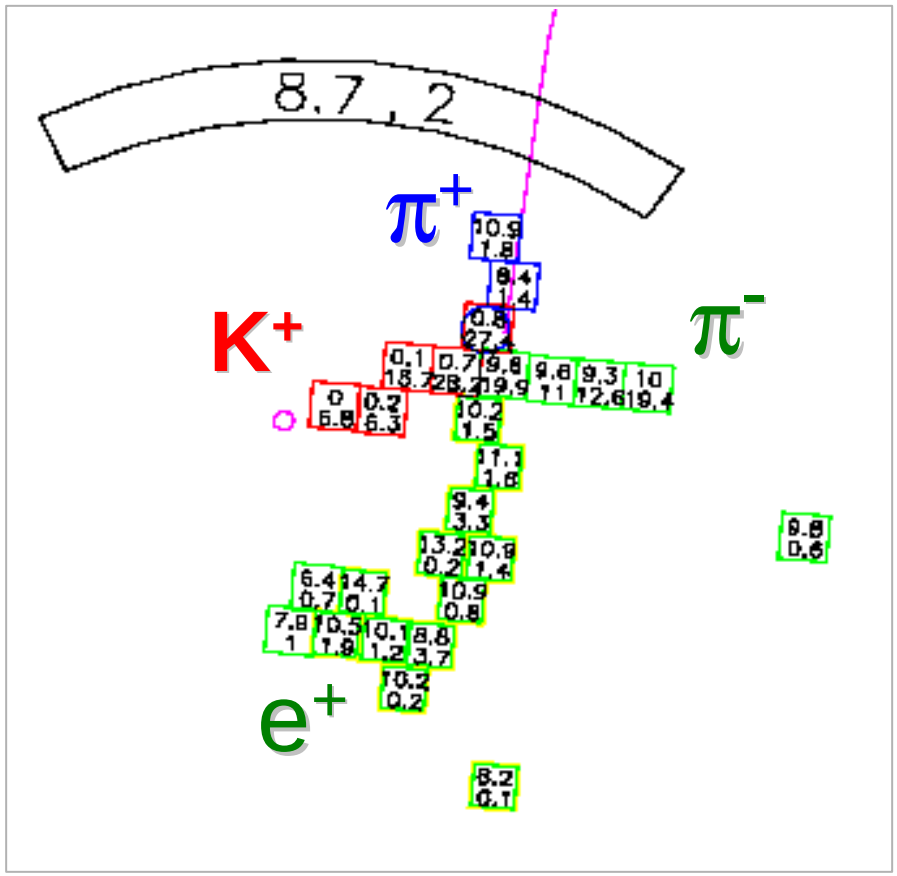



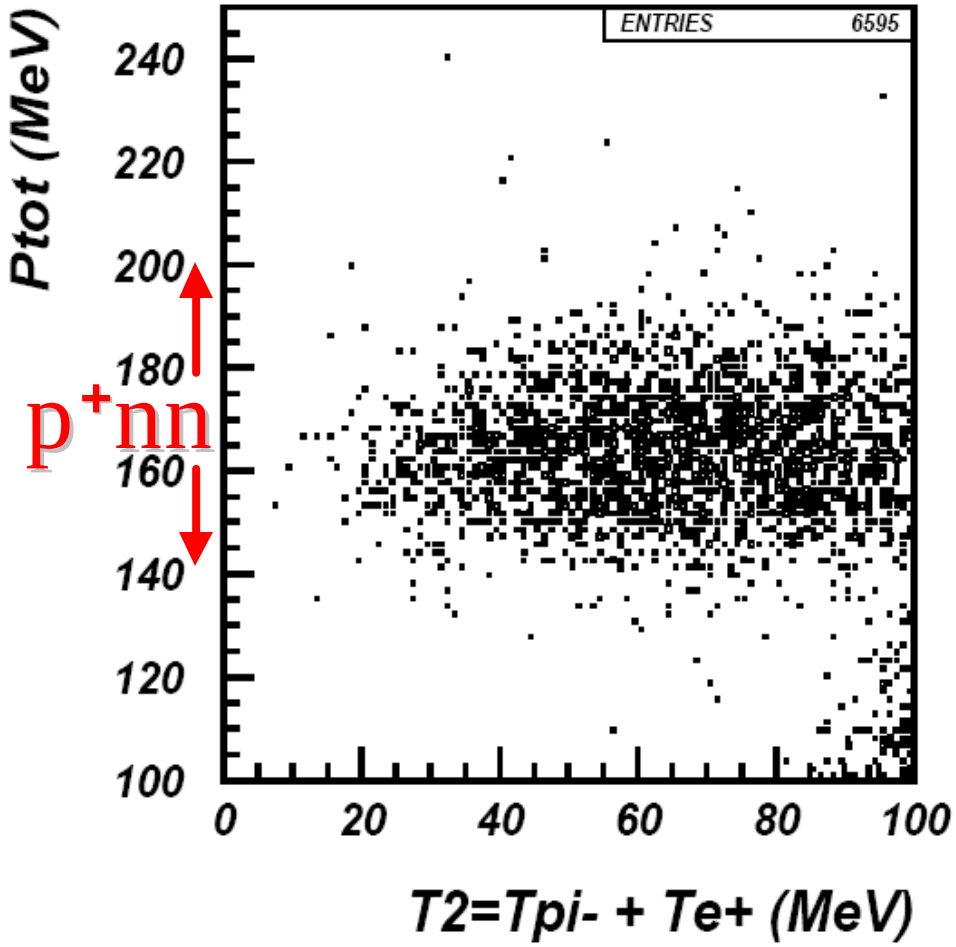



# $K^+ \rightarrow \pi^+\pi^-e^+\nu$ (Ke4) background

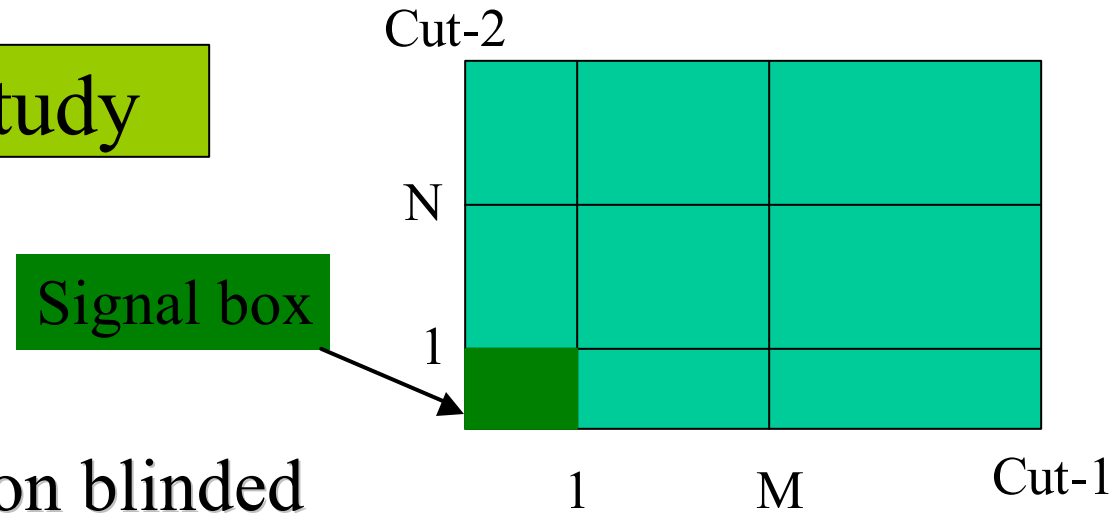
Ke4 candidate (data)




Ke4 MC event



# Correlation study




- Keep signal region blinded
- Relax photon veto or ccd (target) pulse cut
- Check the predicted events and observed events in the extended region.

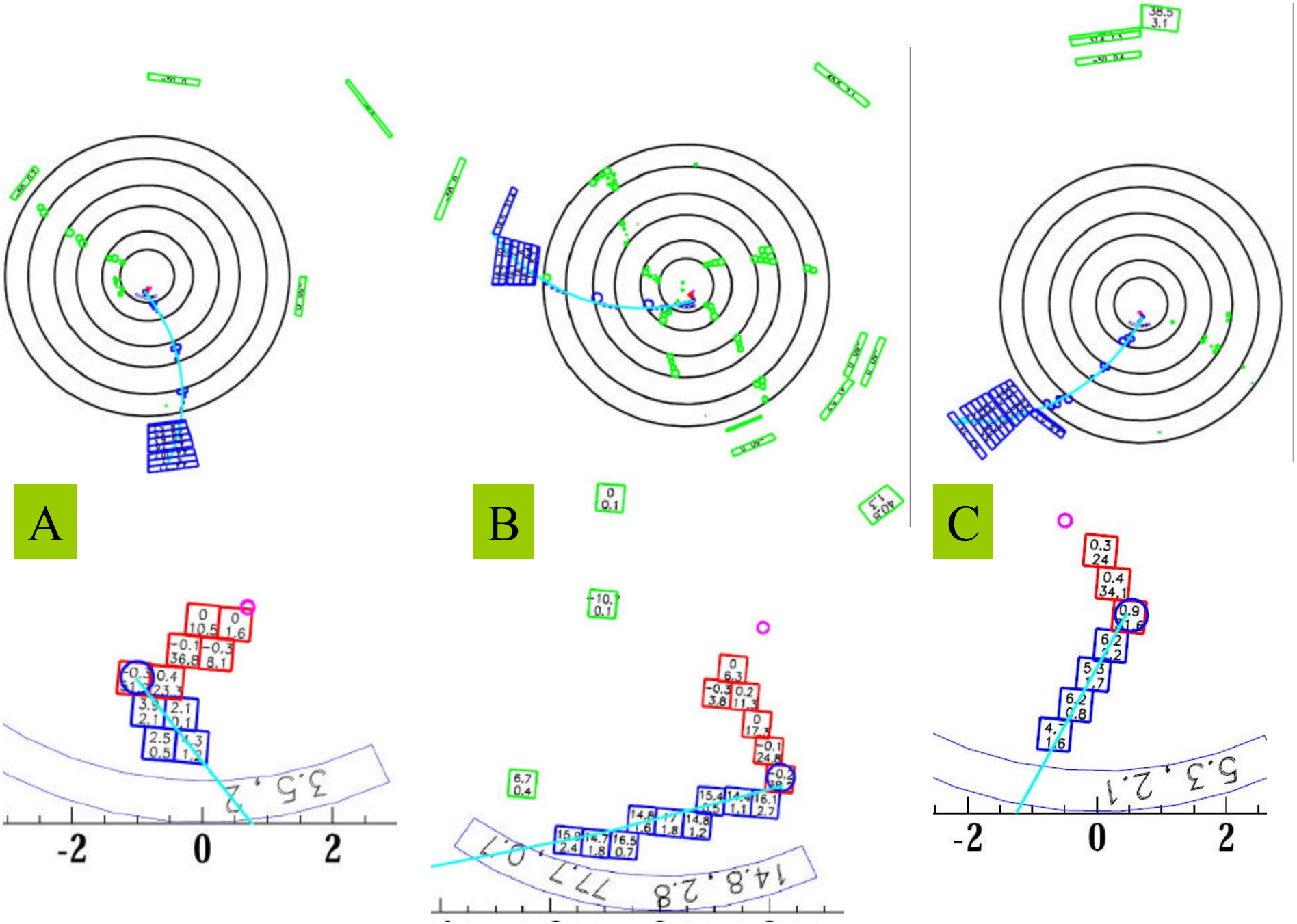
| Region | $N_{\rm exp}$ | $N_{\rm obs}$ |
|---|---|---|
| $CCD_L$ | $0.79^{+0.46}_{-0.51}$ | 0 |
| $PV_L$ | $9.09^{+1.53}_{-1.32}$ | 3 |
| $PV_{looser}$ | $32.4^{+12.3}_{-8.1}$ | 34 |

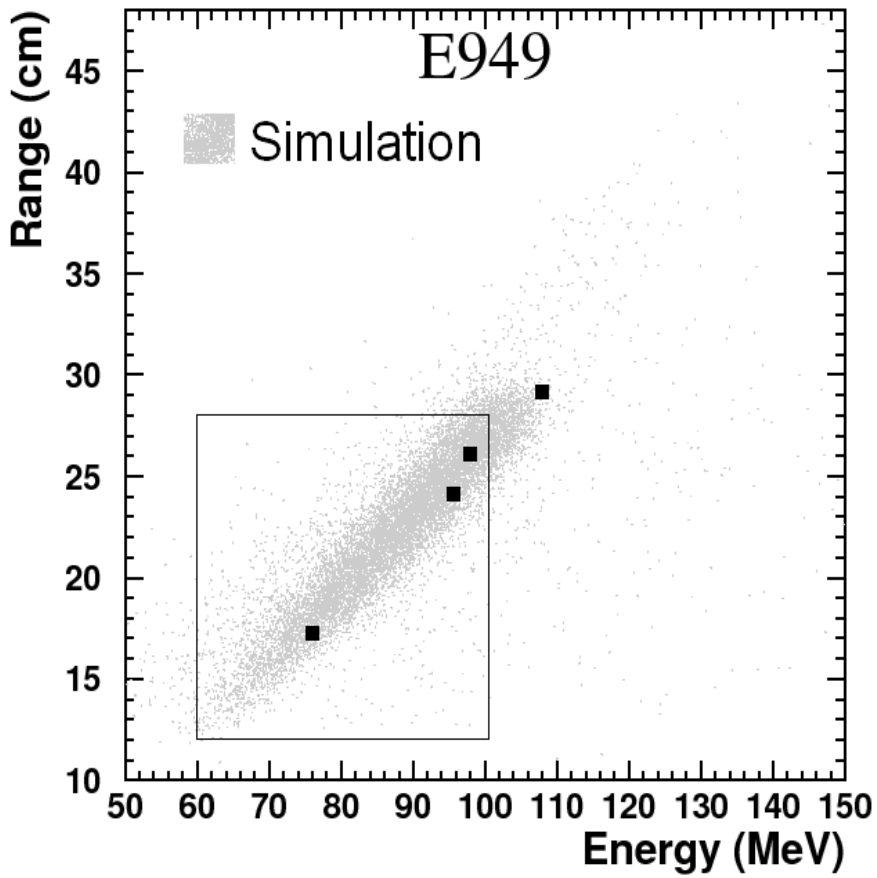
# Backgrounds summary

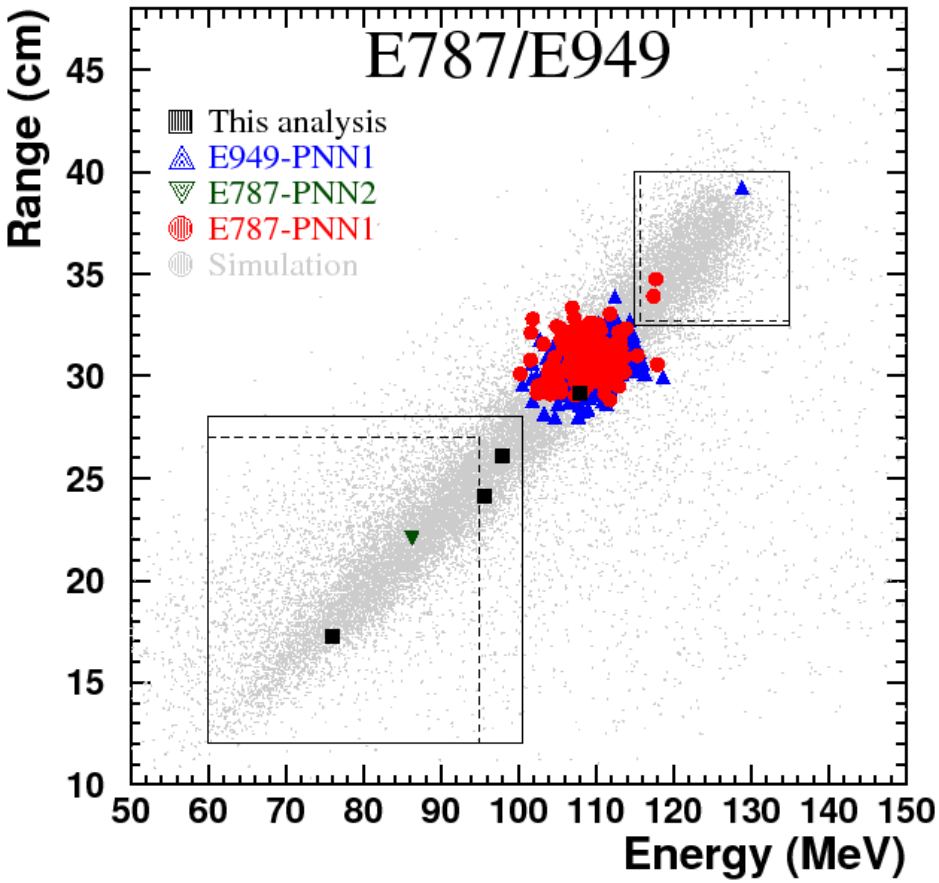
| Process | Bkgd events (E949) | Bkgd events (E787) |
|---|---|---|
| $K_{\pi 2}$-scatter | $0.649 \pm 0.150^{+0.067}_{-0.100}$ | $1.030 \pm 0.230$ |
| $K_{\pi 2\gamma}$ | $0.076 \pm 0.007 \pm 0.006$ | $0.033 \pm 0.004$ |
| $K_{e4}$ | $0.176 \pm 0.072^{+0.233}_{-0.124}$ | $0.052 \pm 0.041$ |
| CEX | $0.013 \pm 0.013^{+0.010}_{-0.003}$ | $0.024 \pm 0.017$ |
| Muon | $0.011 \pm 0.011$ | $0.016 \pm 0.011$ |
| Beam | $0.001 \pm 0.001$ | $0.066 \pm 0.045$ |
| Total bkgd | $0.93 \pm 0.17^{+0.32}_{-0.24}$ | $1.22 \pm 0.24$ |

# Sensitivity

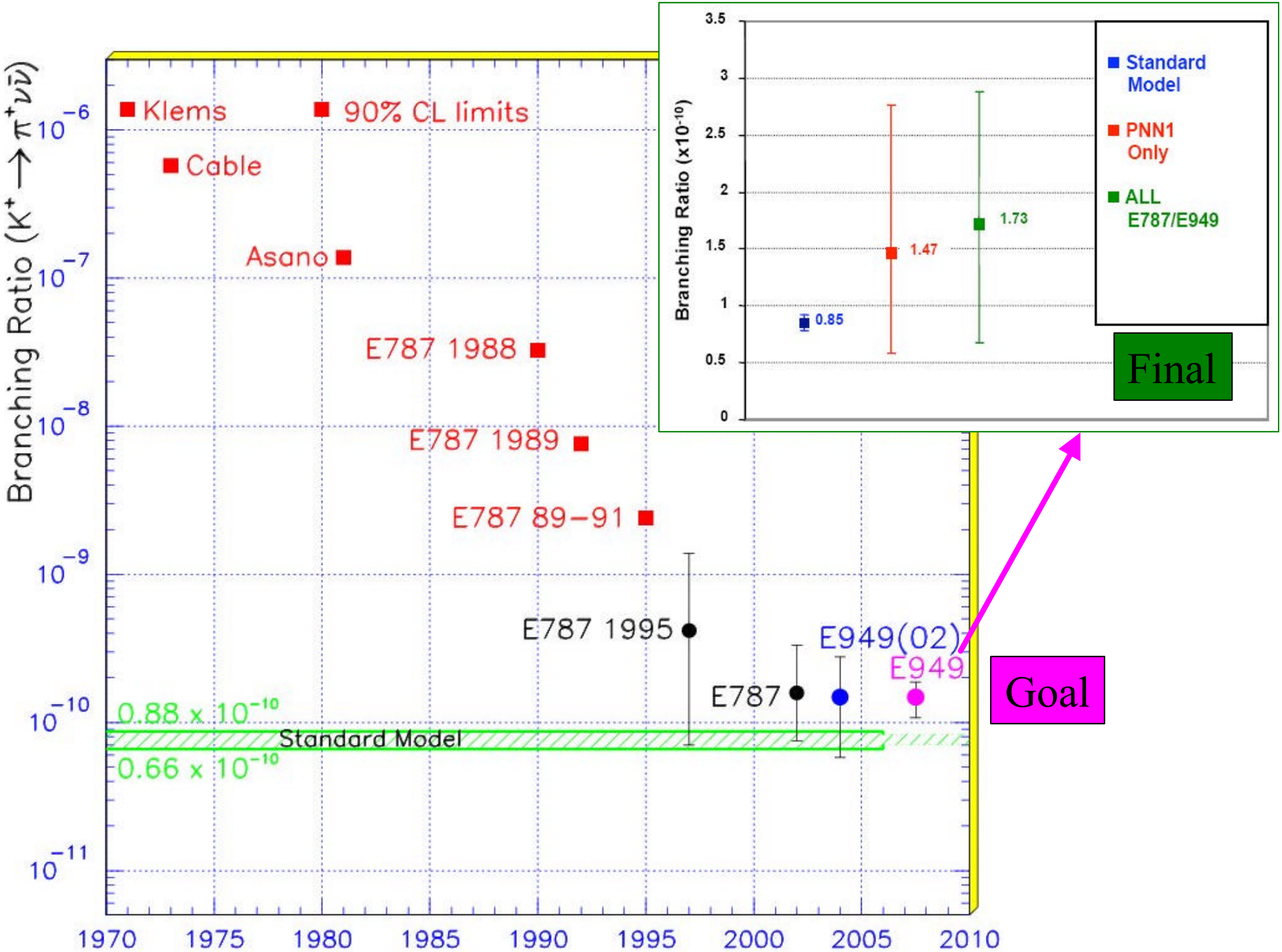
| | E949 pnn2 | E787 pnn2 |
|---|---|---|
| Total Kaons | $1.70 \times 10^{12}$ | $1.73 \times 10^{12}$ |
| Total Acceptance | $1.37 \times 10^{-3}$ | $0.84 \times 10^{-3}$ |
| SES | $4.3 \times 10^{-10}$ | $6.9 \times 10^{-10}$ |


A
B
C
-2
0
2
-2
0
2




- $BR(pnn2)=(7.89\pm^{9.26}_{5.10})\times 10^{-10}$
- $BR(K^+\rightarrow\pi^+\nu\bar{\nu}) =(1.73\pm^{1.15}_{1.05})\times 10^{-10}$


Branching Ratio ($K^+ \to \pi^+ \nu\bar{\nu}$)
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
Klems
90% CL limits
Cable
Asano
E787 1988
E787 1989
E787 89−91
E787 1995
E787
E949(02)
E949
0.88 x $10^{-10}$
Standard Model
0.66 x $10^{-10}$
1970
1975
1980
1985
1990
1995
2000
2005
2010
Goal
Branching Ratio (x$10^{-10}$)
3.5
3
2.5
2
1.5
1
0.5
0
0.85
1.47
1.73
Standard Model
PNN1 Only
ALL E787/E949
Final