Preface

E787 (which was the previous experiment of E949) had really excellent photon veto, and its performance was

Kp2 background rejection : $\sim 0.5\times10^{6}$
Acceptance : 80 %

Kp2 : $K^{+} \rightarrow \pi^{+}\pi^{0}$, $\pi^{0} \rightarrow \gamma\gamma$

In order to overtake the performance even in the E949 severe condition (high beam intensity = more accidentals and false veto), many works were done.

In this poster , we will reveal that :

(1) What kind of modifications were done aiming more rejection in E949.

(2) How much improvement are gained actually ?

(3) How we measured such a big rejection and small acceptance in a reliable way.

Powerful Hermetic Photon Veto System in E949 Experiment

E949

An experiment to measure the branching ratio B($K^+ \to \pi^+ \nu \bar{\nu}$)

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E949 collaboration

and Kentaro MIZOUCHI
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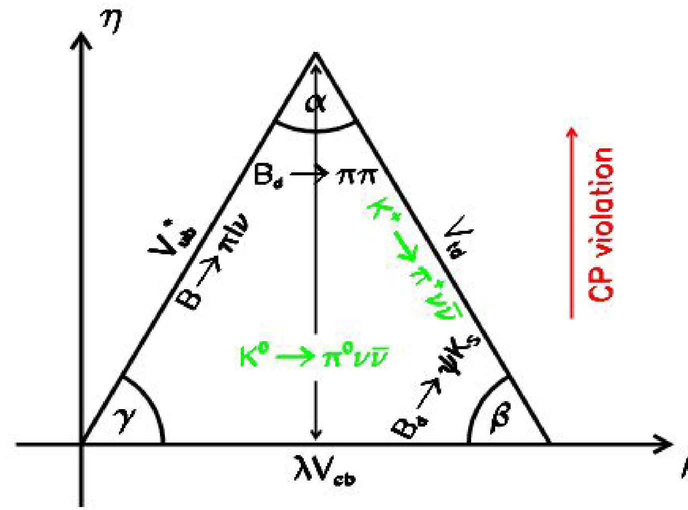
2004 RHIC & AGS Annual User's Meeting
(May 10-14, 2004 at Brookhaven National Laboratory.)

[Introduction] *E949 Experiment*

Measurement of Branching ratio : $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

Golden Mode :

Small theoretical uncertainty (~7%)



E949/E787 new result : $(1.47^{+1.30}_{-0.89}) \times 10^{-10}$

exploring an extremely !!!Rare!!! decay region.

Powerful Background rejection is the key to perform this experiment successfully.

Note : E949 is "stopped Kaon Experiment".

Role of Photon Veto

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

Event Signature : π^+ + nothing
(1) (2)

Two important keys in this experiment:

(1) Accurate and redundant π^+ measurement.

(2) Tight veto on any extra activity except for π^+.

<u>Dominant backgrounds :</u>

$K^+ \to \pi^+ \pi^0$ (called <u>Kp2</u>)

$\pi^0 \to \gamma\gamma$ <u>**mis-detected**</u>

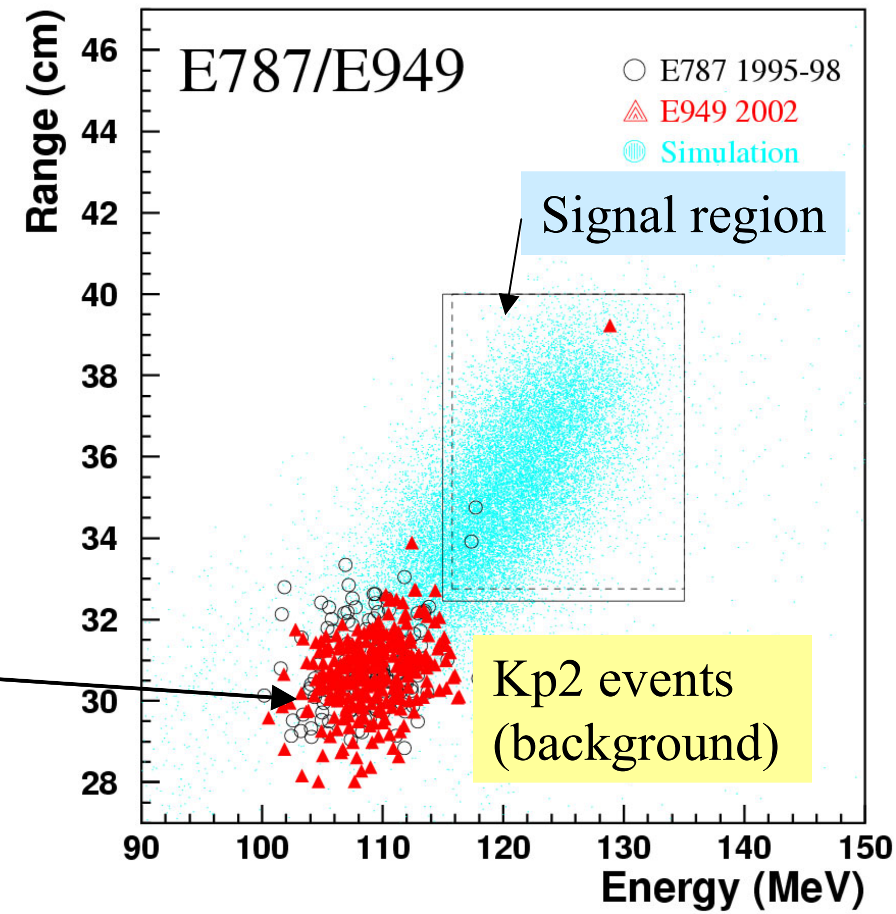


Fig: <u>Final plot after opening the signal box.</u>
(Charged particle energy vs range distribution)

Note

Br = ~ 10^{-10}

kinematical rejection : 10^{-4} (E/P/range)

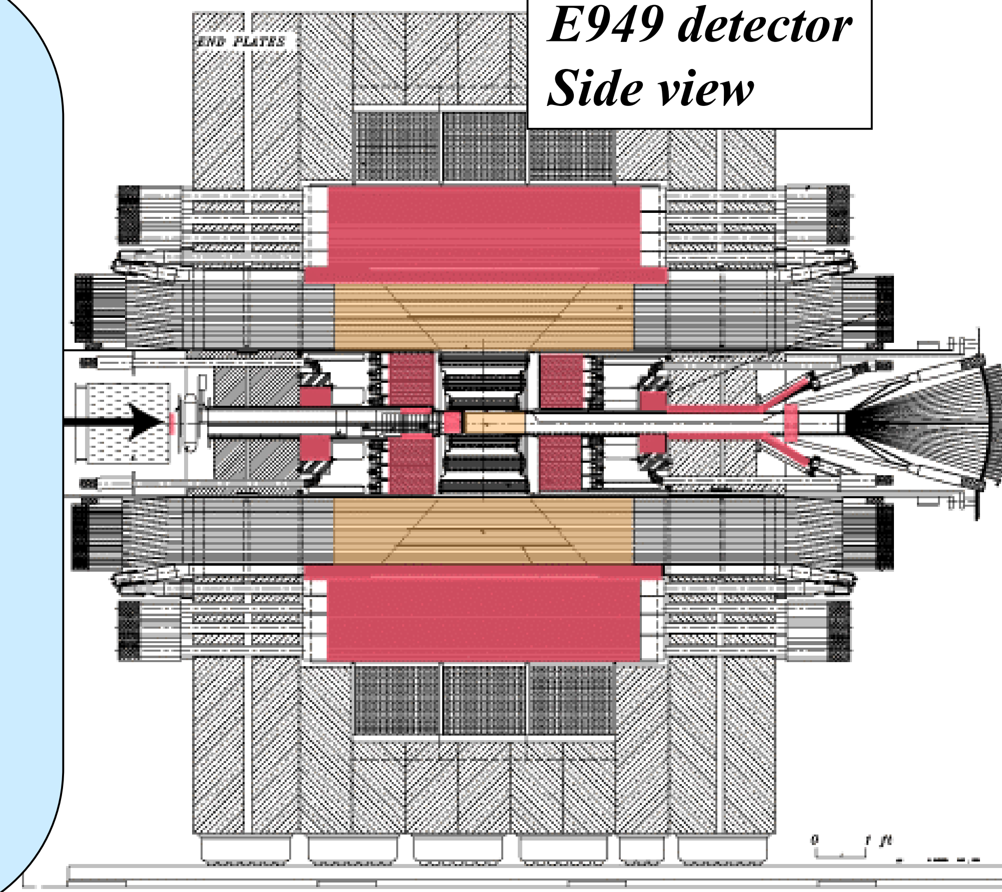
$\longrightarrow$ photon veto rejection should be > 10^{6} .

Photon Veto Related Detectors

Lots of photon veto systems :

BV/BVL : Pb + scintillator
EC : CsI + CCD readout
AD : Pb glass

Collar PV counter,
Micro-Collar PV,
Beam hole PV counter
Up-stream PV counter
Down-strem PV counter
Range stack counter
Target Scintillation Counter …



E949 detector
Side view

Red : photon veto system
Orange : photon veto + charged track measurement

Detail descriptions are skipped, but
Pick out only interesting points.

Efforts to gain more rejection and save acceptance loss !

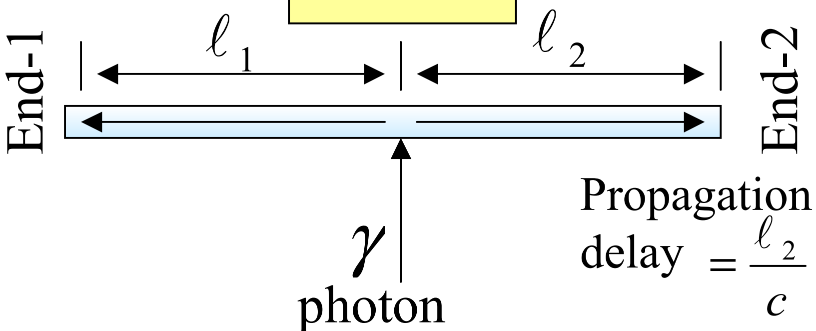
In order to gain more rejection than E787, while keeping acceptance loss at the same level even under the twice high rate beam intensity,
A lot of excellent ideas and works are taken in E949.

<u>Three main improvements :</u>

Improvement	TYPE:
(1) Online Trigger modification : Mean-time calculation	(acceptance)
(2) Add more radiation length and cover the 45 degree hole	(rejection)
(3) Reinforce solid angle coverage (especially around beam line.)	(rejection)

Mean-Time Calculation in Online Trigger (BV/BVL)

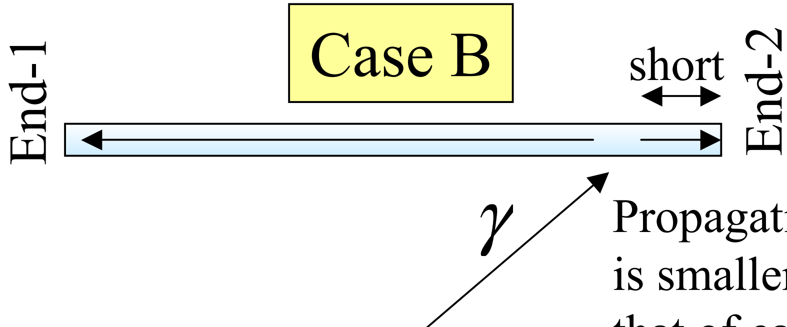
Case A



Propagation delay $= \dfrac{\ell_2}{c}$

(c : speed of light in material)

Case B



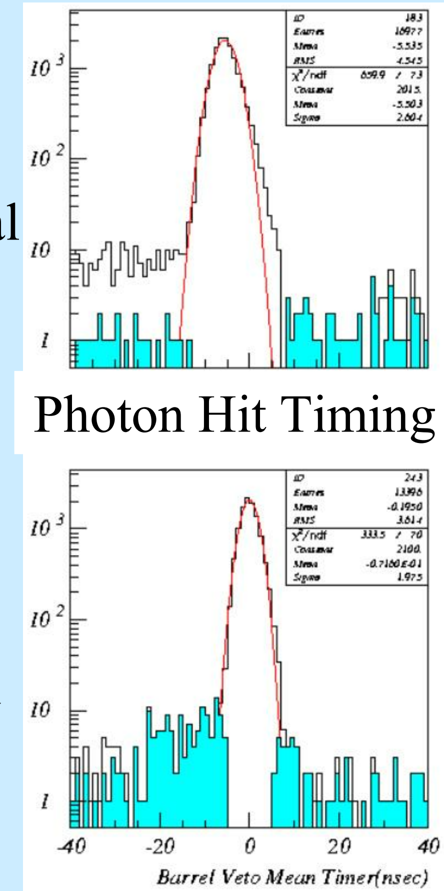
Propagation delay is smaller than that of case-A.

But, Mean-Time $= \dfrac{t_1 + t_2}{2} = \dfrac{\ell_1 + \ell_2}{2c} =$ <u>*const*</u>

<u>Fig: Online Photon Hit Timing distribution</u>

E787 (Normal Analog signal timing)

E949 ***<u>Mean-timed</u>*** signal arrival time



Veto time window is successfully narrowed. (20ns →10ns)

Add more radiation length and cover "45 degree region"

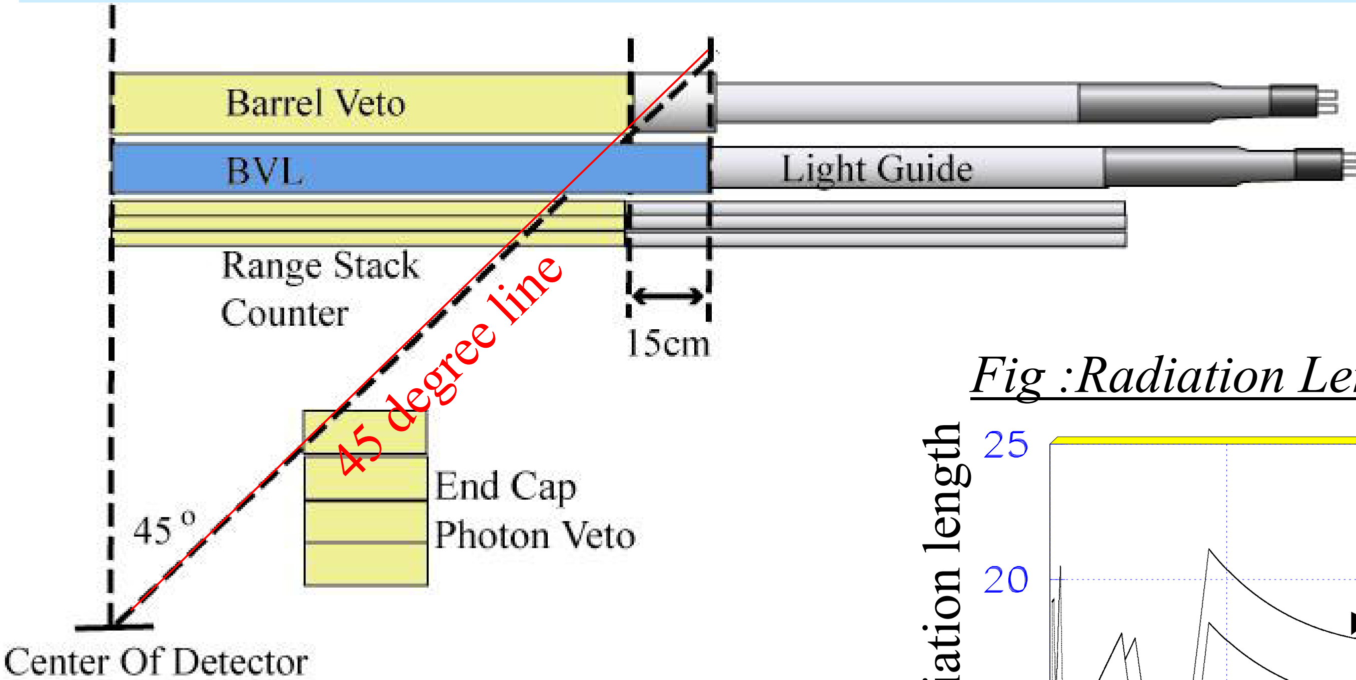
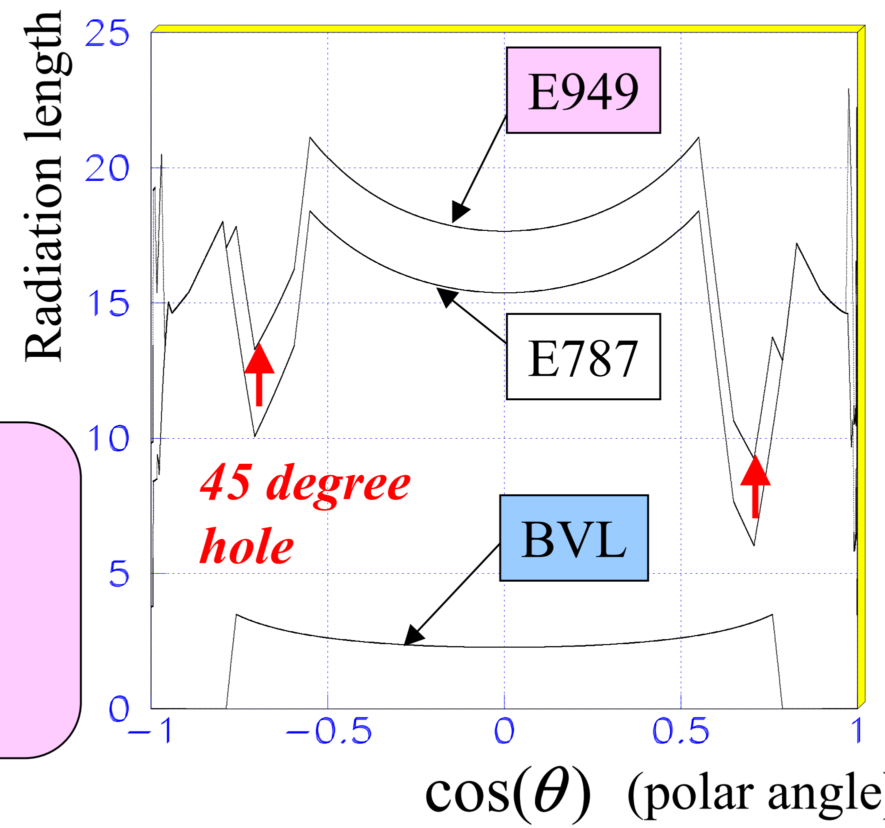


Fig :Radiation Length vs polar angle



BVL was installed in order to

(A)add radiation length and,

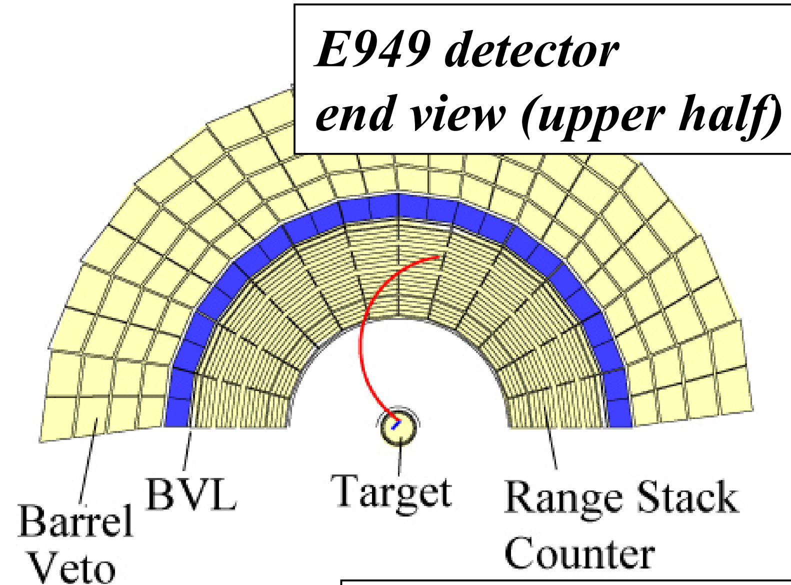
(B)cover 45 degree region.

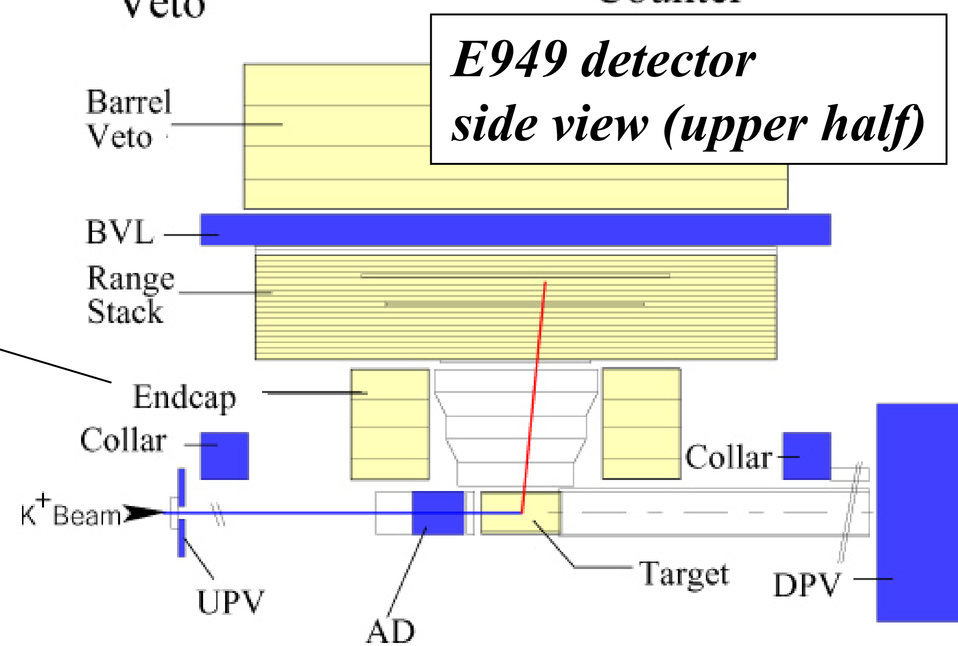
Reinforce Solid Angle Coverage (especially beam line region)

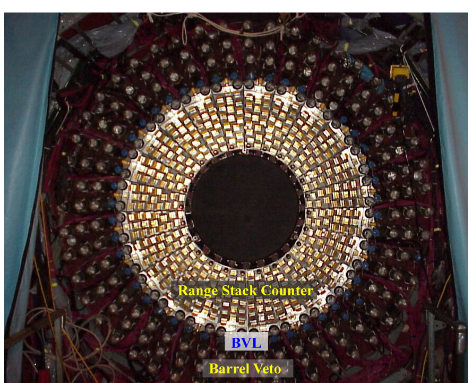
<u>Note:</u>

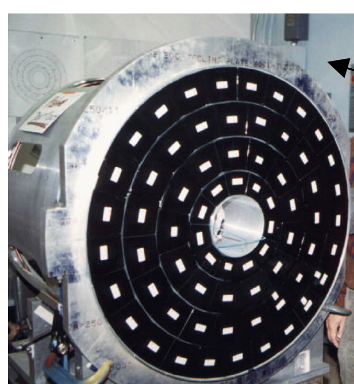
Blue : Updated Photon veto (PV) in E949

Yellow : PV used since E787









Analysis issues

E949 ran for 12 weeks in 2002 and collect data with the updated photon veto system.

We reveal the improvement brought by the PV update/modifications and show …

(1) How to measure the rejection /acceptance accurately

(2) How to control backgrounds :
aggressive background control

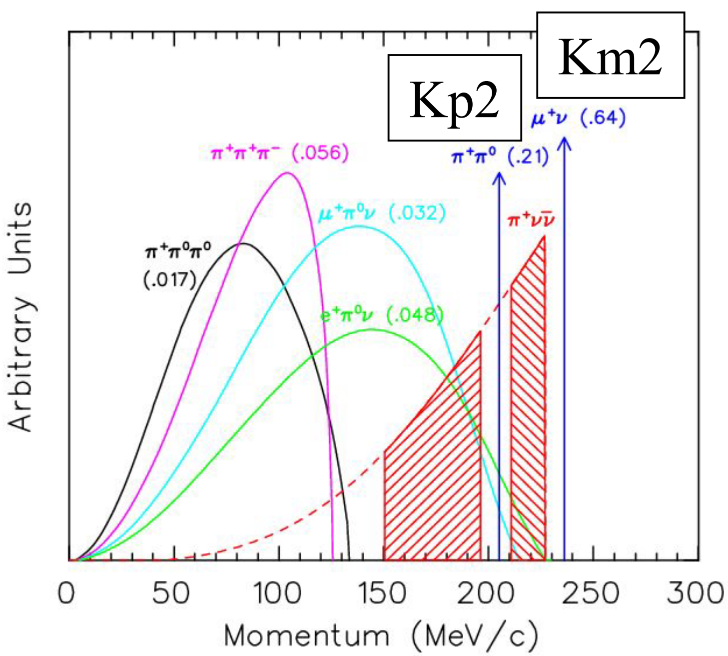
(3) Final E949 Result : rejection and acceptance.

Reliable Rejection/Acceptance measurements

E949 has reliable measurement system of veto performance with real data (not from Monte Carlo).

Background rejection : $K^+ \rightarrow \pi^+\pi^0$ (Kp2)

False veto and acc. Loss : $K^+ \rightarrow \mu^+\nu$ (Km2)



Thanks to the accurate and redundant charged track measurement.

→ Two body decays can be tagged well.

Monochromatic
Energy/Momentum/Range

Can Collected clean control samples !!!
and measure acc, rej directly.

How to veto photon(s)

Veto algorithm :

Veto the event, if the energy sum in the given time window > threshold

One example : parameter set used in actual analysis.

	T_{offset} [ns]	T_{win} [ns]	E_{thr} [MeV]
BV	0.50	4.50	0.20
BL	0.75	2.00	0.00
EC	0.25	2.25	3.80
RD	-0.75	1.50	3.80
…	…	…	…

Noticeable points

(1) Not reconstruct π^0

Critical if a photon escape to beam line direction.

(2) Do not use charged particle information.

Independency should be kept for correct background estimation.

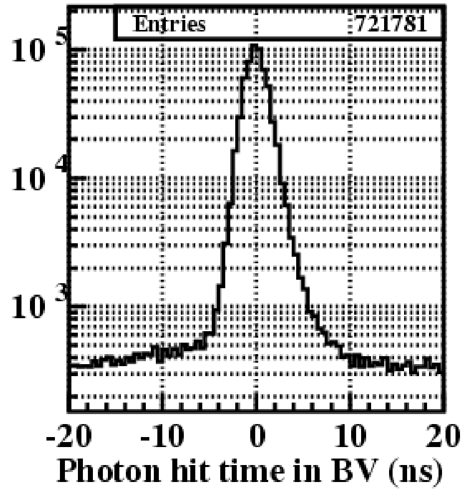
$$\text{Kp2\_total\_rej} = \text{kinematics\_rej} \times \text{photonveto\_rej}$$

Parameter scan and How to find the best parameter set

The reason why parameter scan is required :

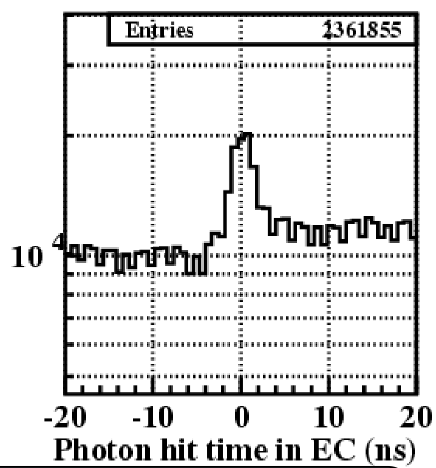
BV hit timing

Clean photon peak.
but Photo-nuclear interaction tail.



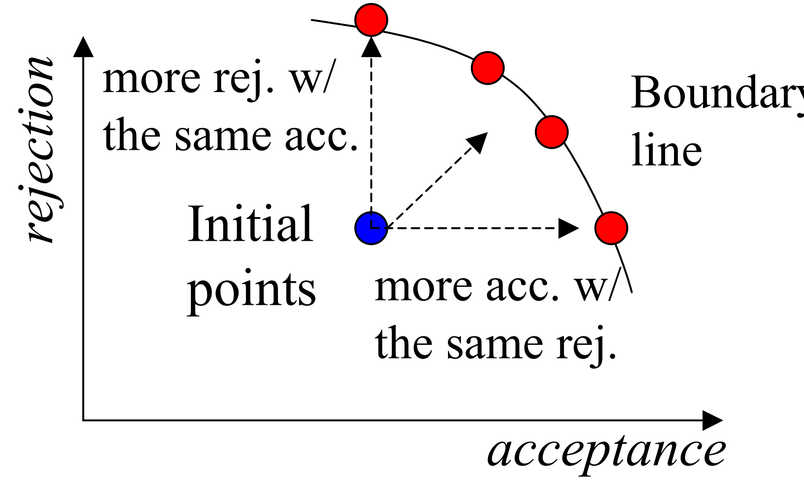
EC hit timing

many accidentals.
But certainly have photon hits



Balance of tightness compare to other PV systems should be ***optimized.***

Rej vs Acc trade-off curve.



Search boundary line.
(= can not gain further improvement)

(A) Find the most efficient cut set.

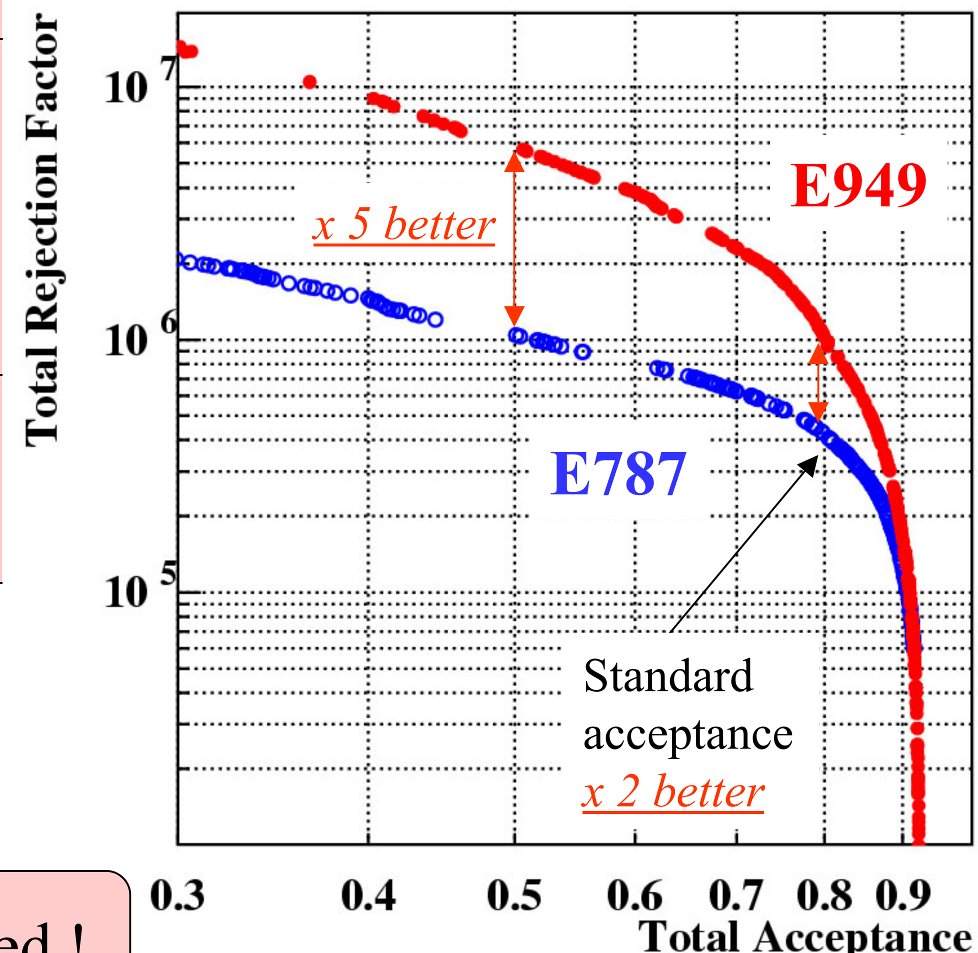
(B) Get a trade-off function between acc and rej
→ used as **Aggressive** bkg control

E949 acceptance and rejection

E787 ('98)	E949
<u>Online rejection</u>	
7250 ± 2550	6550 ± 1025
<u>Offline rejection</u>	
~50	175.7 ± 7.4
<u>Total rejection</u>	
$(0.47 \pm 0.2) \times 10^6$	$(1.15 \pm 0.23) \times 10^6$

Note : Both rejection are measured at the same acceptance points (80%).

Acc. vs Rej. Curve.



Twice better rejection is achieved !

$K^+ \to \pi^+ \nu\bar{\nu}$ Analysis background summary

Background Type	Total Background	
Kp2	0.216 ± 0.023	*Well suppressed!*
Km2	0.044 ± 0.005	
…	…	

[@ BNL colloquium by David Jaffe]

<u>Aggressive background control</u> :

Loosen or tighten veto parameters based on the estimated/required background number.

Actually, thanks to the powerful detector update, E949 photon veto had a enough rejection, therefore we loosened cuts and earned ~5 % acceptance finally.

Well,

The strongest points in E949 is

There are many available way/method to understand or know much about itself (detector performance, background measurement and so on.).

AND

Remember that more rejection is gained compared with E787 at low acceptance region.

=> Can we do something with these excellent abilities ?

Yes.

Single photon inefficiency Study

Special trigger :

collect the one photon mis-detected kp2 events.

↓

Kinematics of the missing photon can be determined.

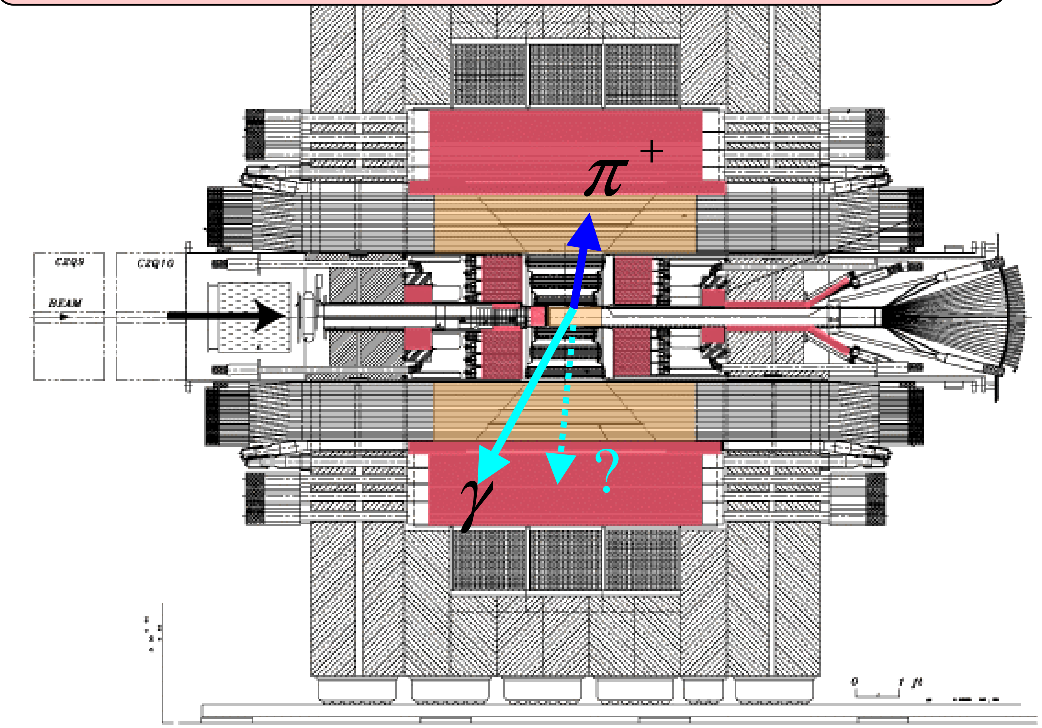
Note : stopped kaon experiment.

↓

Photon Inefficiency map

(as a function of detector geometry and photon energy)

A kind of X-ray test of our detector.



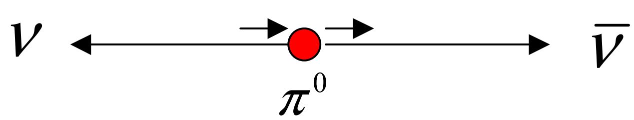
This is pretty powerful study; We can reveal that

(1) Detector hole, photon interaction with dead material

(2) Photonuclear interaction, giant delta resonance (energy vs missing probability)

And also have a Physics impact !

Can explore the decay : $\pi^0 \rightarrow \nu\bar{\nu}$



Helicity suppression

π^0 : spin 0

ν : (pure) left-handed

World record :

$Br < 8.3\times10^{-7}$

(**E787** experiment)

But, if right-handed neutrinos exist and couple with Z^0, this decay will occur.

(1) Decay into weak interaction (unknown) particles instead of $\nu\bar{\nu}$

There was a discussion on $\pi^0 \rightarrow \tilde{\gamma}\tilde{\gamma}$: light photino

[Sov. J. Nucl. Phys 47, 296 (1988)]

(2) Discussion/Expectation from cosmology : $\gamma\gamma \rightarrow \pi^0 \rightarrow \nu\bar{\nu}$ (Radiation)

Impact on some cooling models of universe

Advantage in $\pi^0 \to \nu\bar{\nu}$ *analysis*

Analysis Method

(1)Tag $K^+ \to \pi^+\pi^0$ events.

(2)Search for the events have no activity except for π^+.

(1) $K^+ \to \pi^+\pi^0$
$\downarrow$
(2) $\pi^0 \to \nu\bar{\nu}$

Now, E949 have the best sensitivity in the world;

(1)Excellent tagging ability to Kp2 events

$\pi^+ \to \mu^+ \to e^+$ decay chain

Independent and accurate E/P/range measurement of charged particles.

(2) Superior photon veto ability to E787.

Advantage is enhanced more in low acceptance region.

(3) Reliable Background subtraction

Background estimation from the convolution of single-photon ineff, Which is much reliable than Monte Carlo expectation.

Summary

(1) Powerful hermetic veto (covering 4pi solid angle)
Reject any extra activity.

(2) Highly reliable rejection/acceptance measurement with real data.
And aggressive background control.

(3) Big improvement : More than twice rejection at 80 % acceptance even in the severe beam condition.

(4) Have the best sensitivity in the world for $\pi^0 \to \nu\bar{\nu}$

Appendix :Newly installed detector subsystems

(B) Beam line PV