

# Sensitivity of the Decay

$$K_L \rightarrow \pi^0 \nu \bar{\nu}$$

## at Fermilab KAMI experiment

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# Introduction

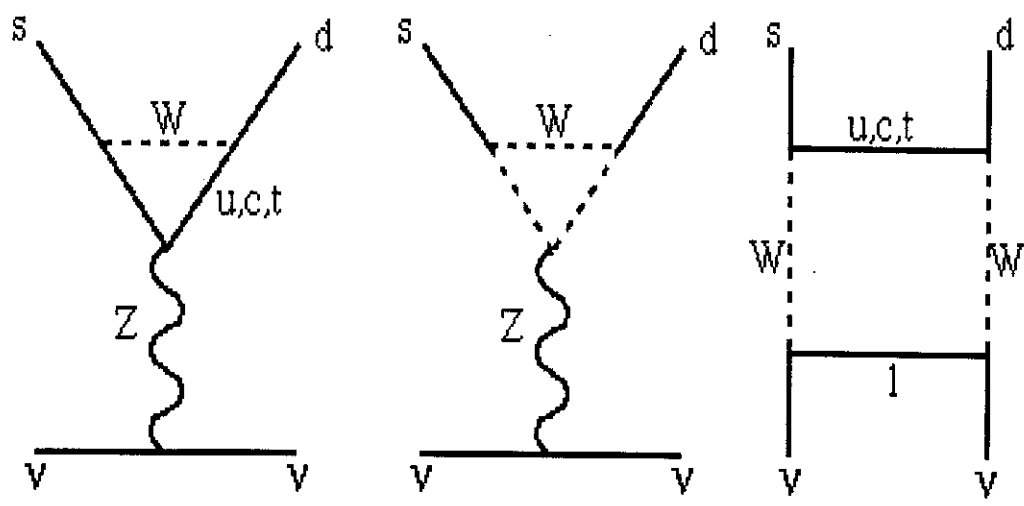
Measurement of  $\text{BR}(K_L \rightarrow \pi^0 \nu \nu)$

Quark Mixing Matrix: CKM Matrix

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Wolfenstein Representation

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



Leading order electroweak diagrams contributing to  $K \rightarrow \pi \nu \bar{\nu}$  in the Standard Model.

$$BR (K_L \rightarrow \pi^0 \nu \bar{\nu})$$

$$\propto |V_{ts}^* V_{td} - V_{td}^* V_{ts}|^2$$

$$\propto \eta^2$$

$\eta$  : Origin of CP Violation

Measurement of  $BR(K_L \rightarrow \pi^0 \nu \bar{\nu})$  :

Powerful method to measure  
the value of  $\eta$

Theoretical error is small. (on the order of 1%)

## Signal

$$K_L \rightarrow \pi^0 \nu \bar{\nu}$$

$$\rightarrow \gamma \gamma \text{ (detect)}$$

## Backgrounds

- $K_L \rightarrow \pi^0 \pi^0$
  - $K_L \rightarrow \pi^0 \pi^0 \pi^0$
  - $\Xi \rightarrow \Lambda \pi^0 (\Lambda \rightarrow n \pi^0)$
  - $K_L \rightarrow \gamma \gamma$
  - $K_L \rightarrow \pi^0 \gamma \gamma$
- etc.

The Most Serious Background

$K_L \rightarrow \pi^0 \pi^0$  with 2 missing  $\gamma$

## KAMI experiment

KAMI experiment(Kaons At the Main Injector)is the next kaon experiment detecting and measuring direct CP violating decay  $K_L \rightarrow \pi^0 \nu \bar{\nu}$  at Fermilab

- Proton beam energy: 120 GeV
- Intensity:  $3 \times 10^{13}$ /pulse
- Repetition cycle: 2.9 sec
- Flat top: 1.0 sec

### KAMI's primary physics goal

1. Observation of direct CP violating decay  $K_L \rightarrow \pi^0 \nu \bar{\nu}$  and measurement within 10 % of accuracy on that branching ratio, corresponding to 5 % of accuracy on  $\eta$

2. Study of the rare decays such as  $K_L \rightarrow \pi^0 e^+ e^-$ ,  $\pi^0 \mu^+ \mu^-$ ,  $\pi^0 \mu^+ e^-$ ,  $\pi^+ \pi^- e^+ e^-$ ,  $\mu^+ \mu^-$ ,  $e^+ e^-$  with  $10^{-13}$  of sensitivity

# The purpose and method of this study

Kaon energy spectrum

→ MC simulation

→ Estimation of  $\#K_L \rightarrow \pi^0 \nu \bar{\nu}$   
and  $\#$ backgrounds

# Kaon Energy Spectrum and Production Rate

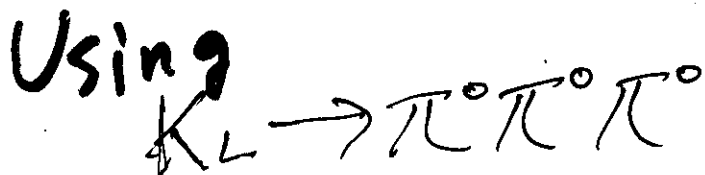
## KAMI Beam Test

### Purpose

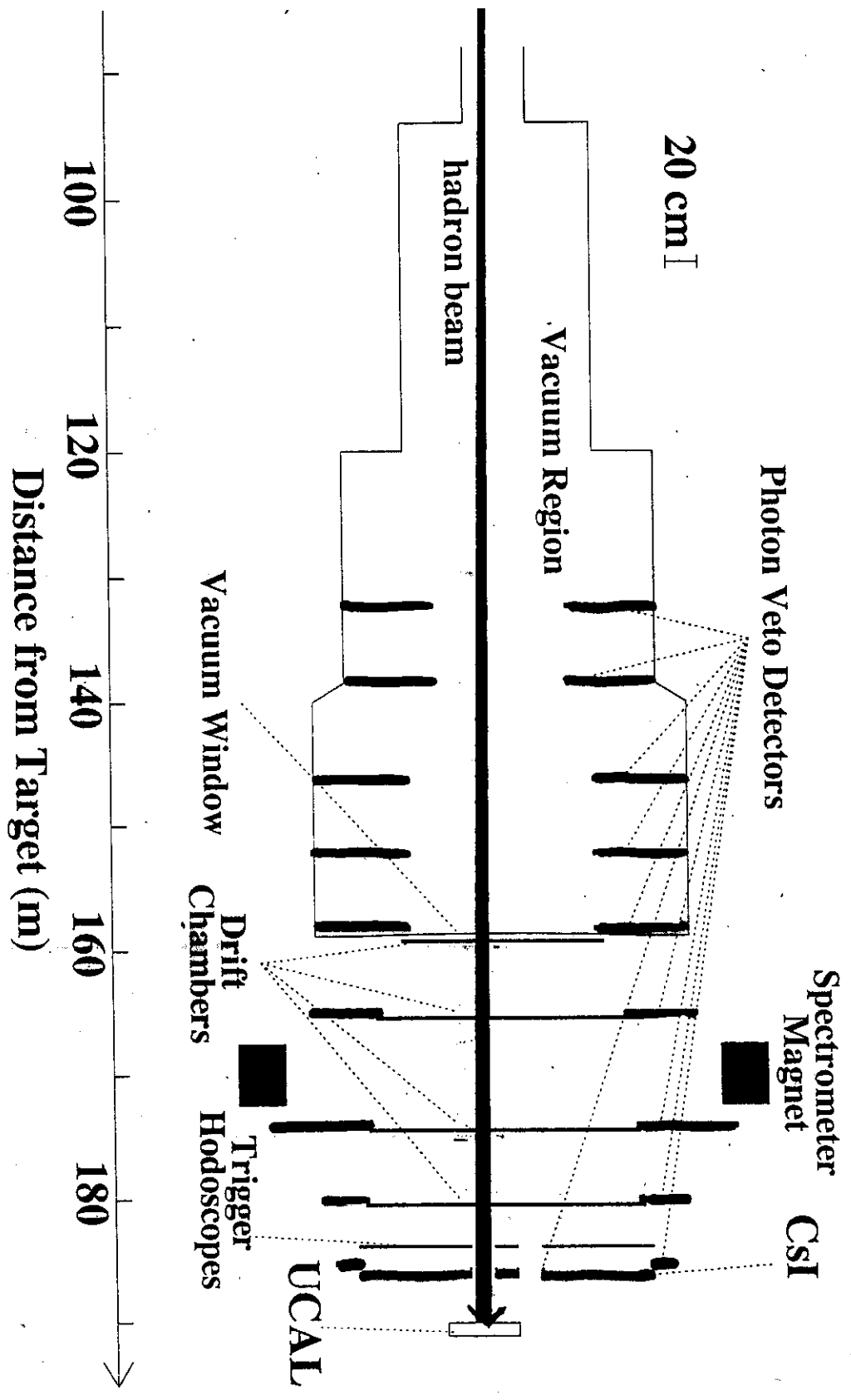
To get kaon energy spectrum and flux, which will help design KAMI experiment.

Data was taken at KTeV Detector using 150 GeV proton beam in January, February, 2000

Using

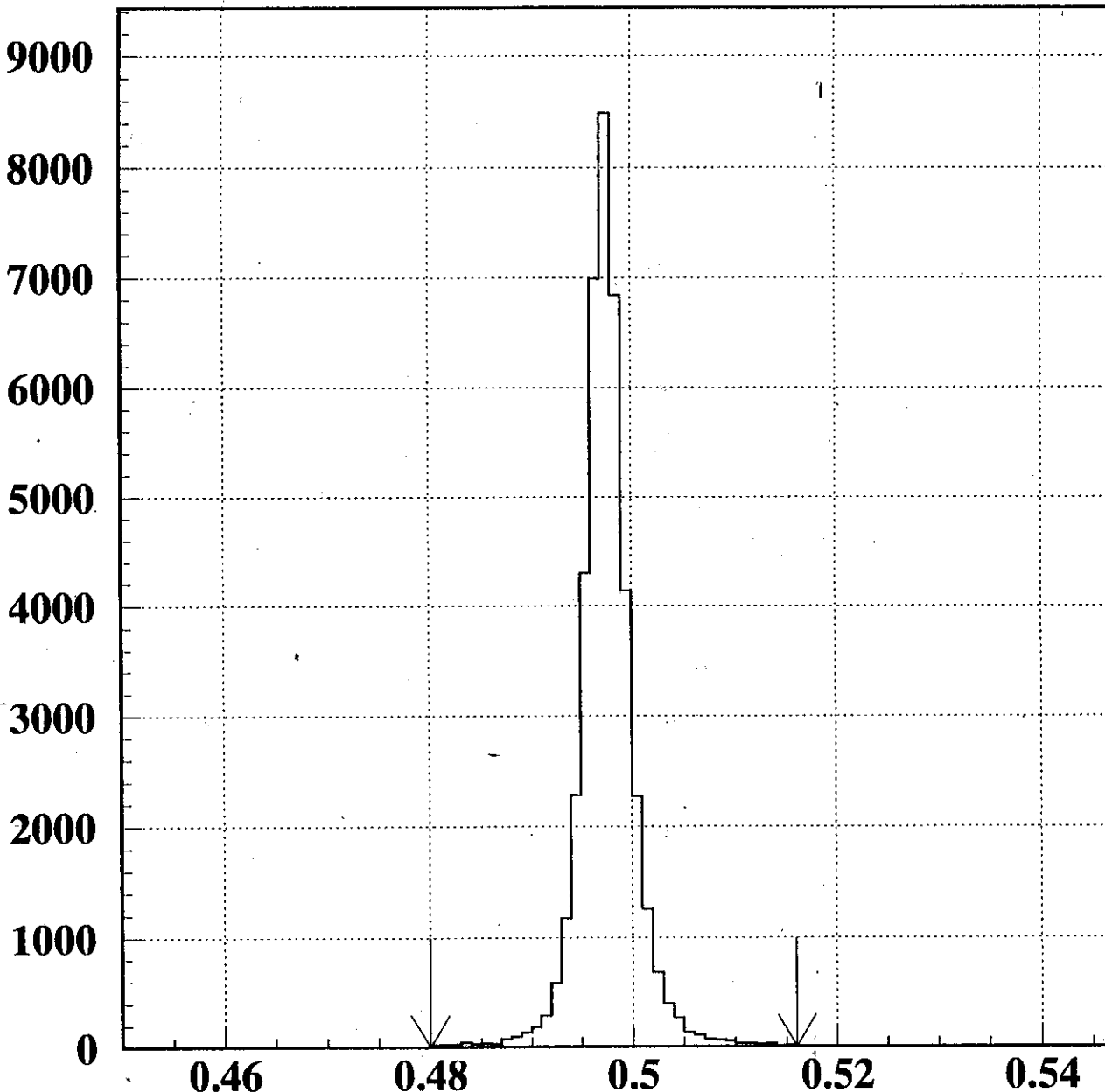


# Beam Test Veicolo Geometry



Run15723-MINBIAS-150GeV-20mr-0B

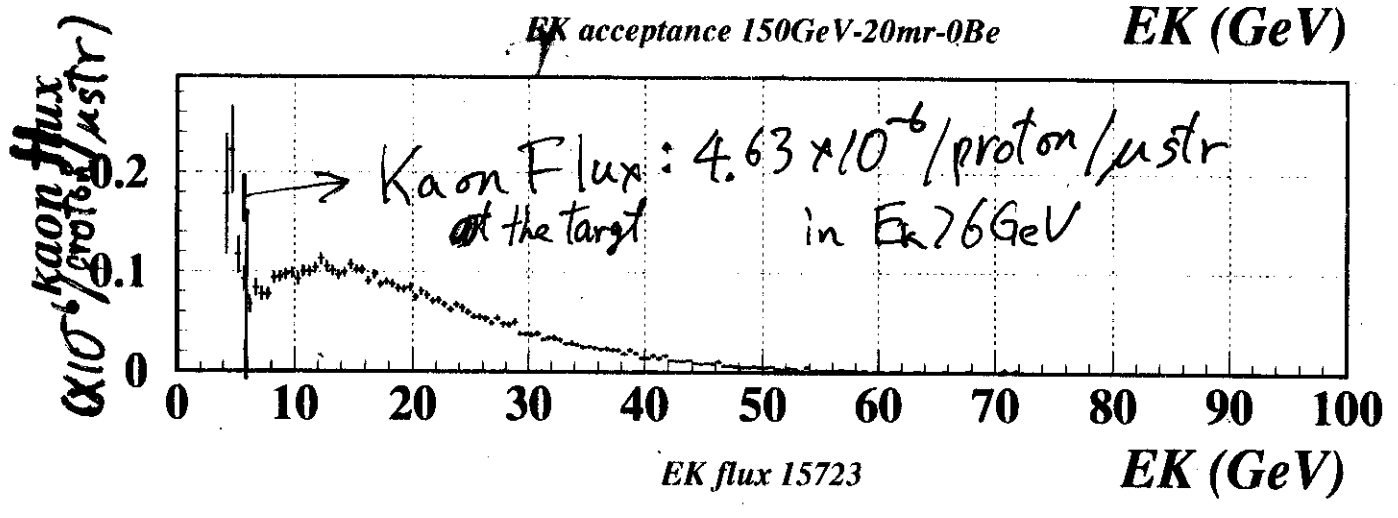
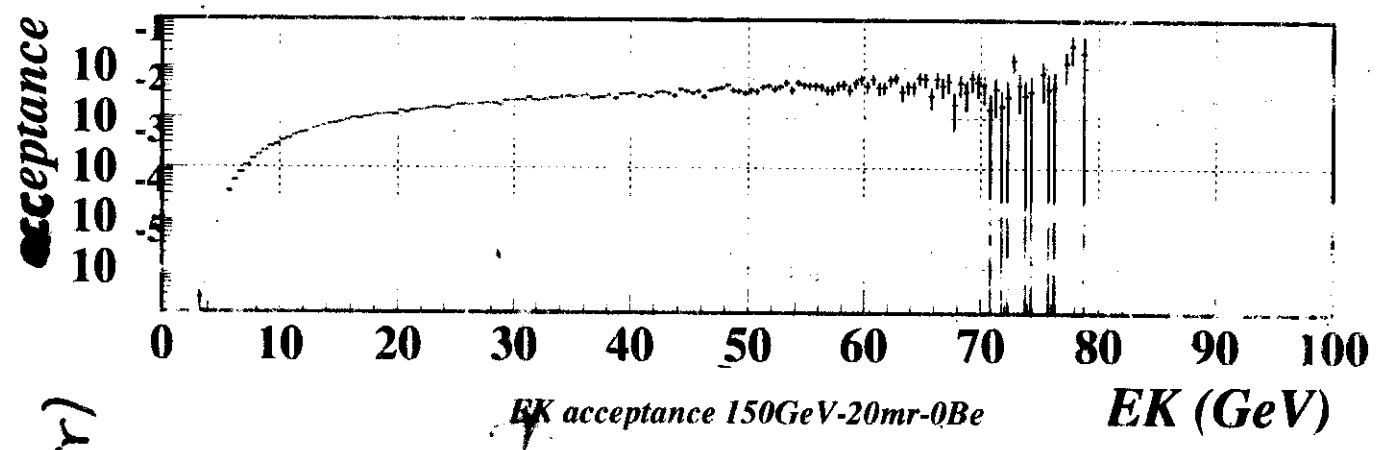
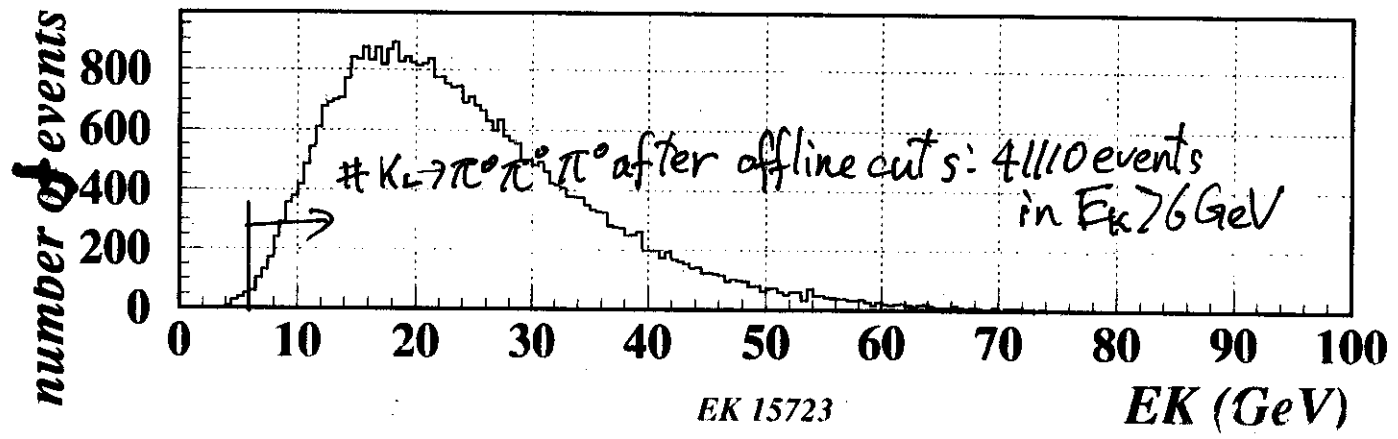
number of events



$3\pi^0$  mass (GeV) , w/cuts (EAST)

$M_{\pi^0\pi^0\pi^0}$  Ge

# Run15723-MINBIAS-150GeV-20mr-0Be

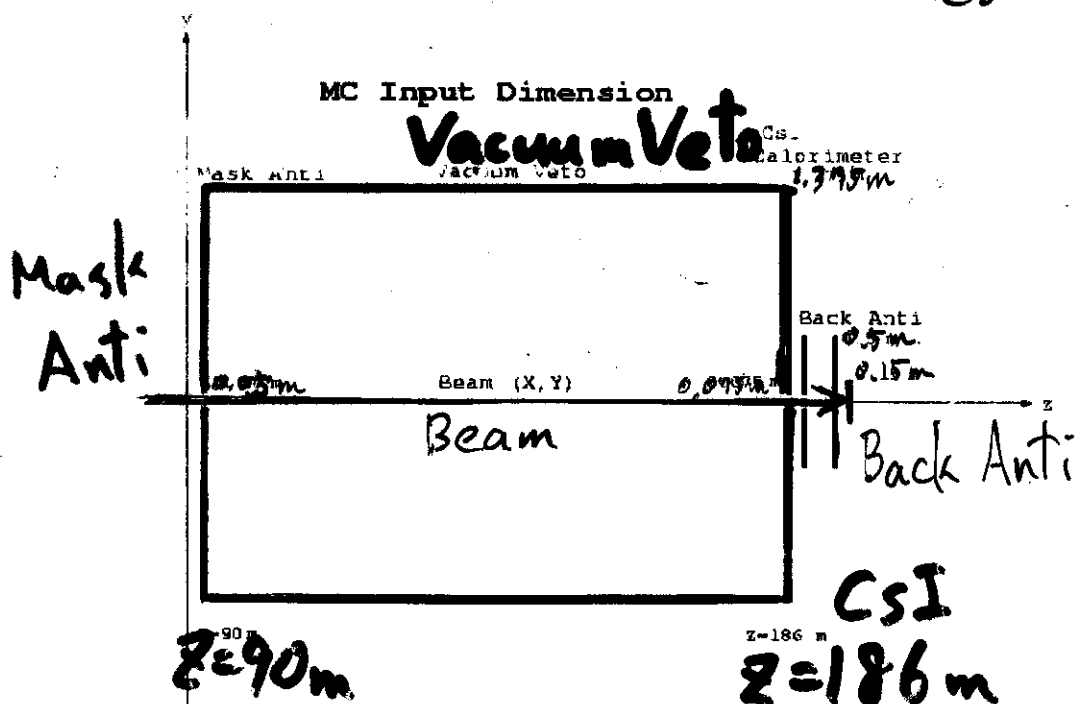


# Estimation of Number of Signal Events and Background Events Simulation

Geometry

Total deposit energy in  
CsI:  $> 5 \text{ GeV}$

Cluster Energy:  $> 1 \text{ GeV}$

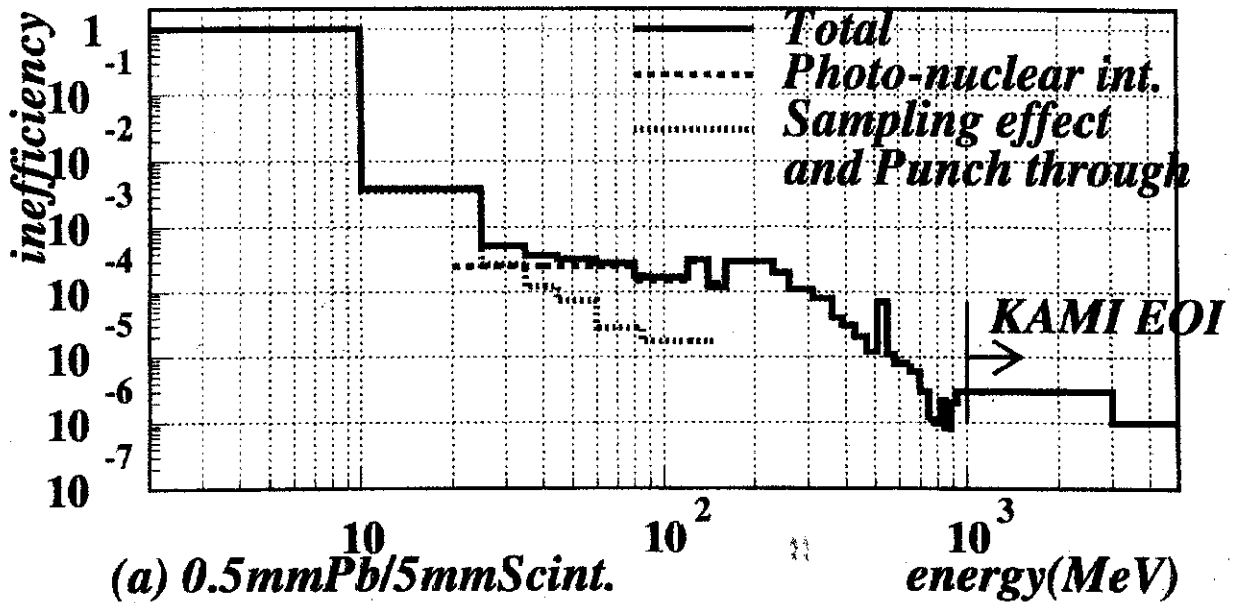


# kaon decay:  $6.05 \times 10^{13}$  in  $Z = 90 - 186 \text{ m}$ ,  
in 1 year

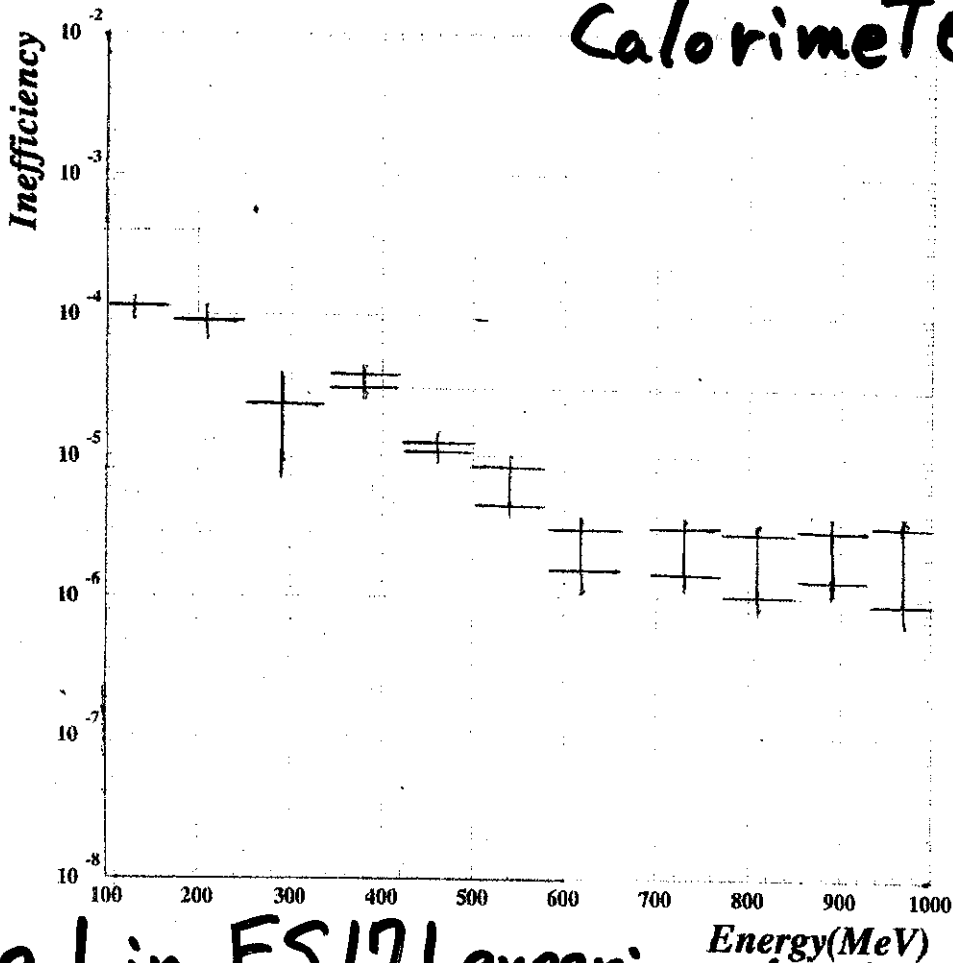
$$BR(K_L \rightarrow \pi^0 \nu \bar{\nu}) = 3 \times 10^{-11}$$

# Inefficiency of Sampling Calorimeter

Photon Detection Inefficiency (Vacuum Veto)

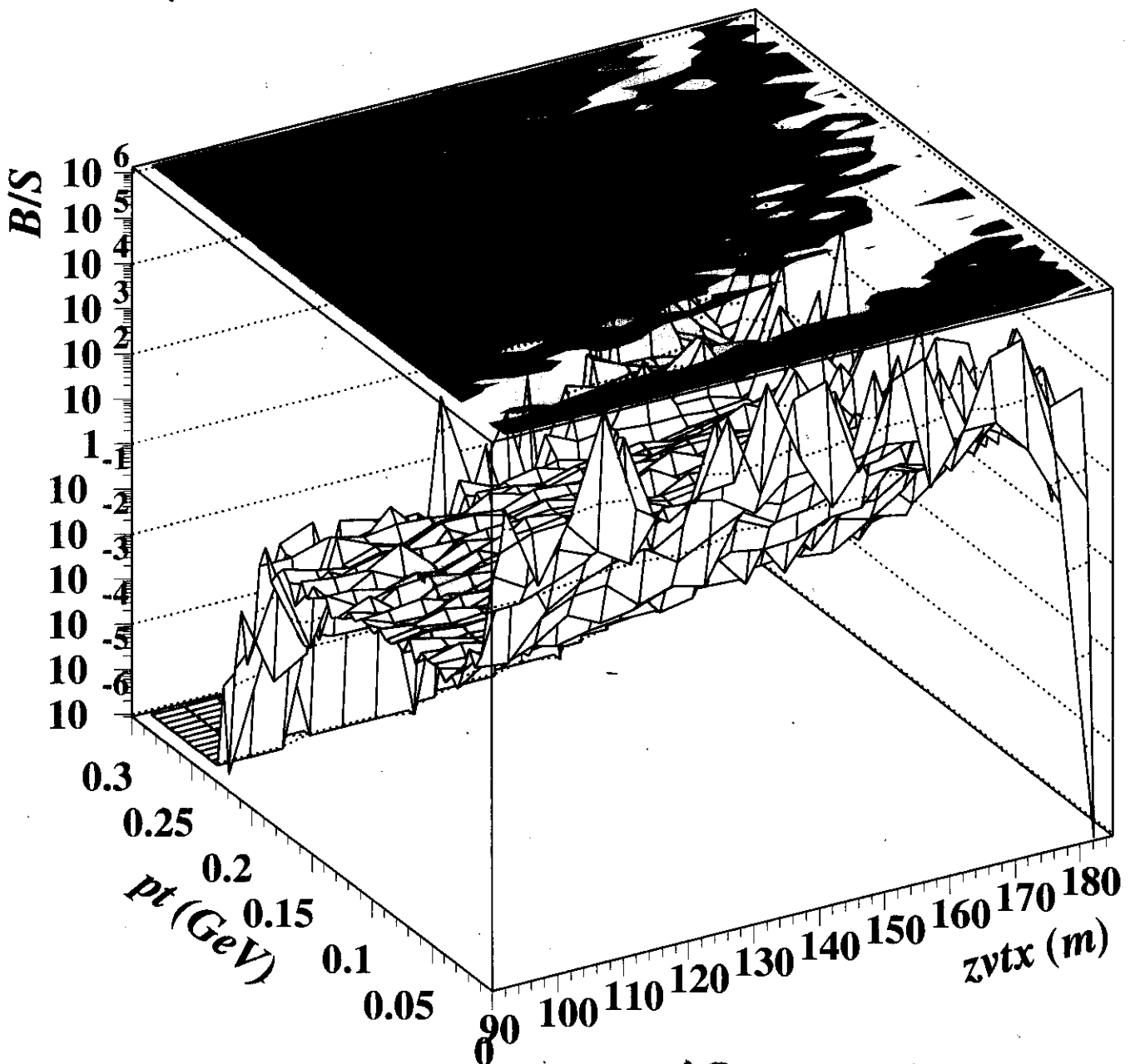


# Inefficiency of CsI Calorimeter



Studied in ES171 experiment at KEK  
and with EGS simulation

# Optimization of cut region

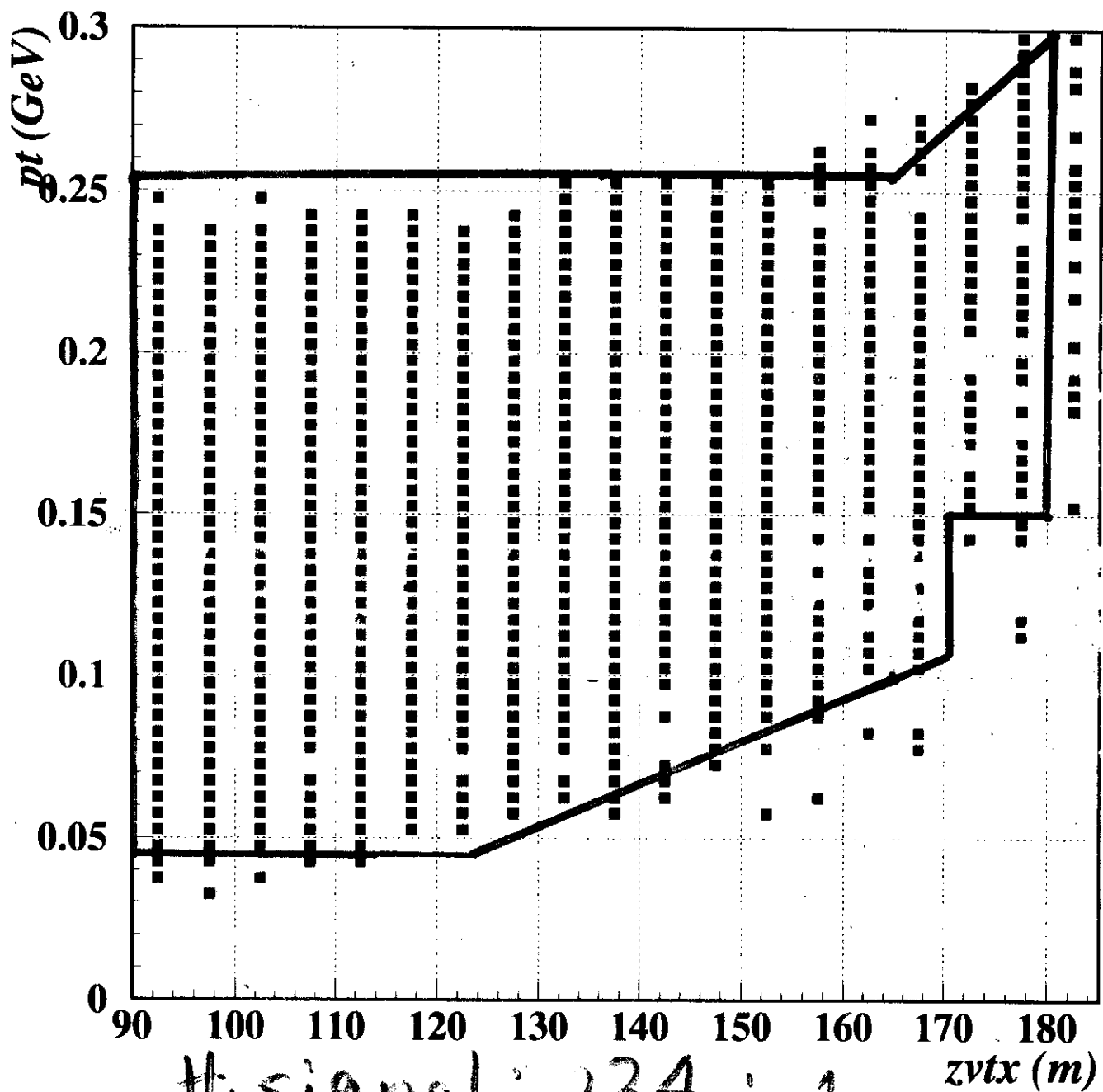


$$z_{\text{CsI}} - z_{\text{vtx}} = \frac{r_{12}}{m_{\pi^0}} \sqrt{E_1 E_2}$$

$z_{\text{CsI}}$ : the position of CsI,  $z_{\text{vtx}}$ : z-vertex.  
 $r_{12}$ : the distance between clusters;  $m_{\pi^0} = 135 \text{ MeV}$   
 $E_1 (E_2)$ : the energy of cluster 1 (1 + 2)



### min. of accuracy on eta

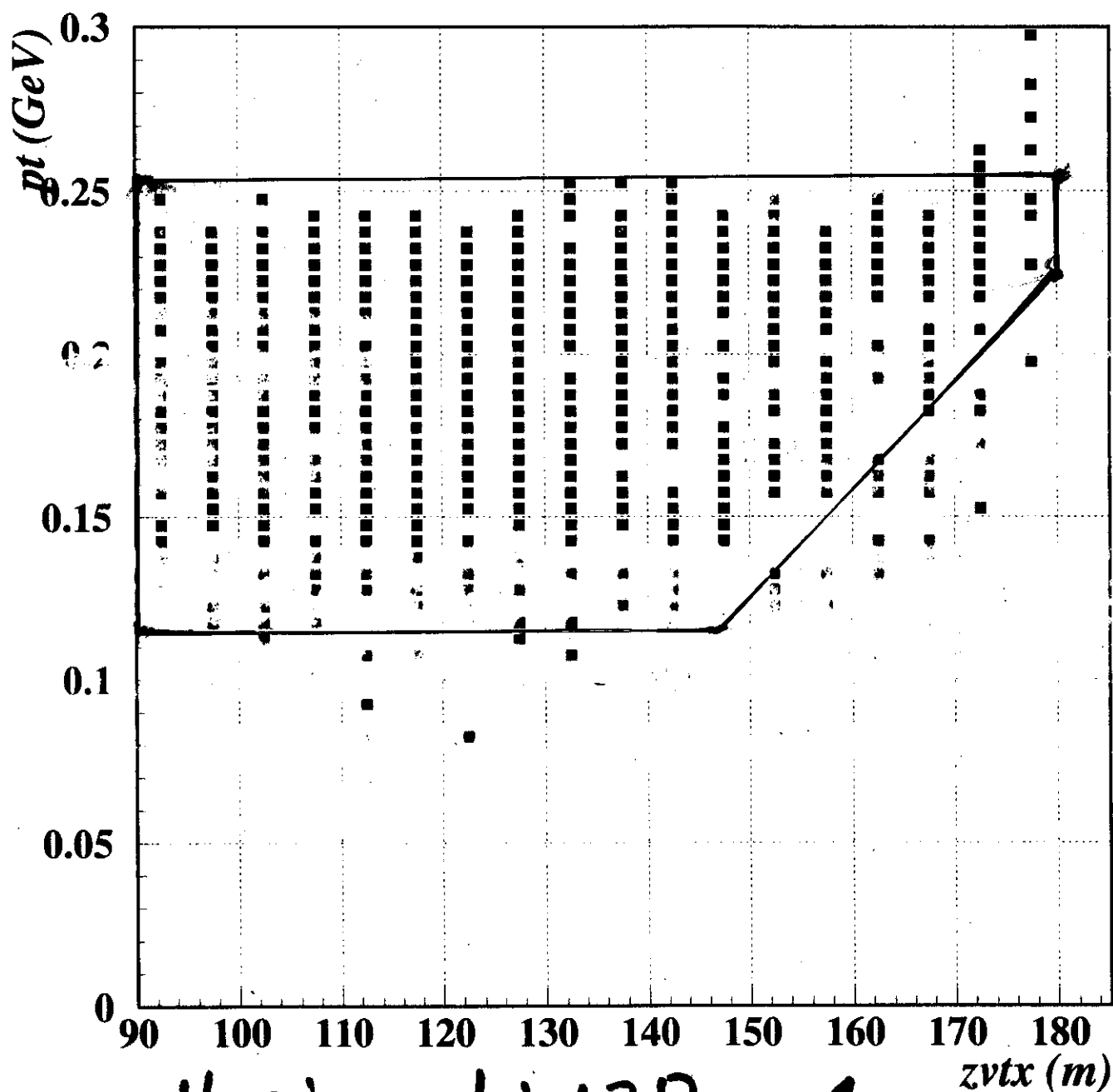


# signal : 234 in 1 year

B/S : 0.68

$\Delta\eta/\eta$  : 4.2%

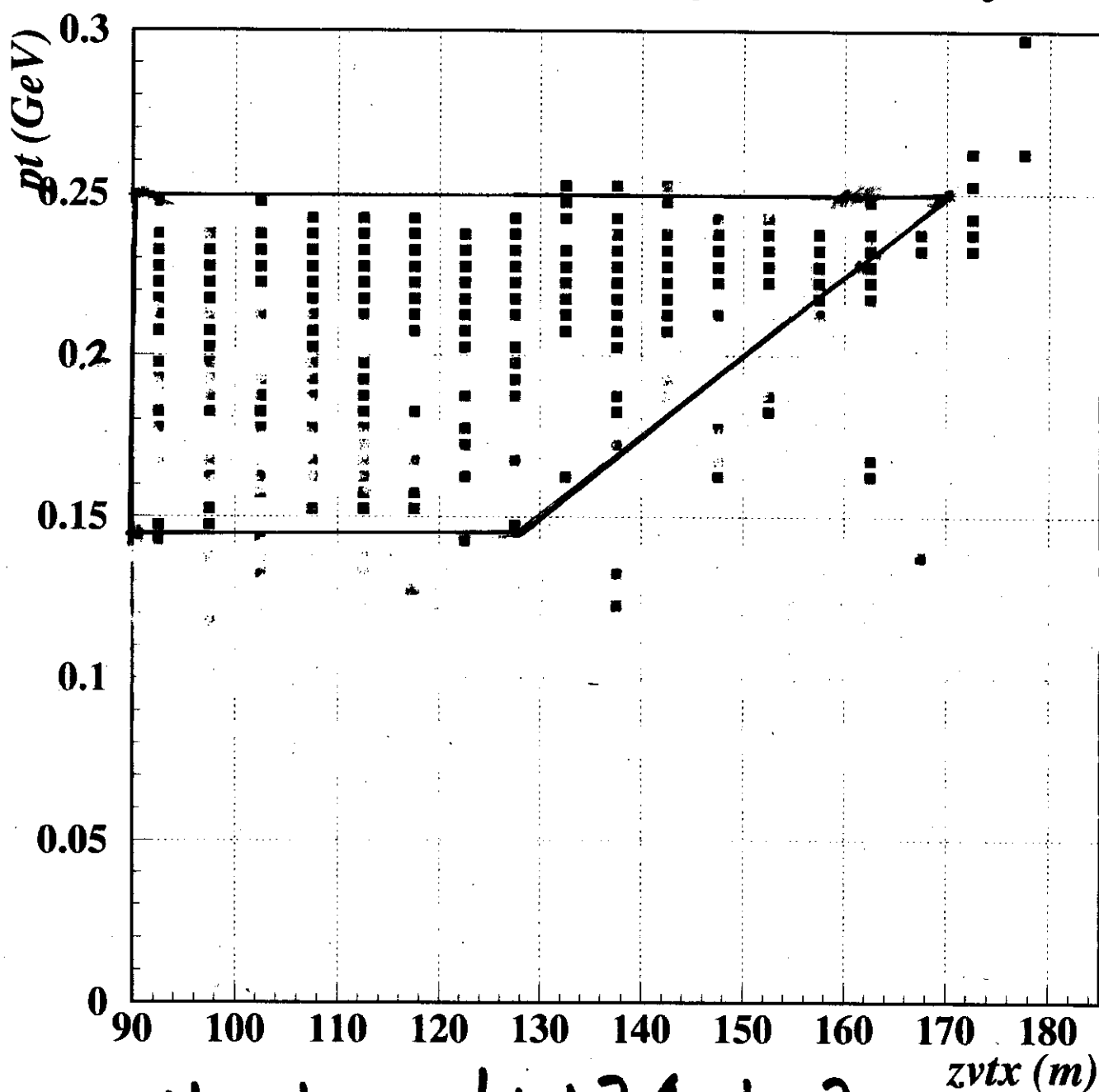
### 5 percents of accuracy on eta in 1 yr



#Signal: 137 in 1 year

B/S: 0.31

## 5 percents of accuracy on eta in 3 yr



# signal: 124 in 3 years  
B/S : 0.24

## Conclusion

Using kaon energy spectrum and flux from 2000 Winter KAMI Beam Test, we estimated #sig. and #bkg. at KAMI experiment.

### Optimization of Cut Region

| $\Delta\eta/\eta$ | Running time | #signal | B/S  |
|-------------------|--------------|---------|------|
| Min.(4.2%)        | 1yr          | 234     | 0.68 |
| 5%                | 1yr          | 137     | 0.31 |
| 5%                | 3yr          | 124     | 0.24 |

Using realistic kaon energy spectrum and photon detection inefficiency, we find KAMI can measure  $\eta$  within 5 % .