12/11/01
NP01@KEK

Rare Kaon Experiment at JHF

-A case study on $K_L \to \pi^0 \nu \bar{\nu}$ experiment -

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Goal of the experiment

- 1000 $K_L \to \pi^0 \nu \bar{\nu}$ events

$$\Rightarrow \frac{\Delta \eta_{stat}}{\eta} = \frac{1}{2}\frac{1}{\sqrt{1000}}$$

$\sim 1.5\%$ ~ theoretical uncertainty

- $S/N > 10$

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

Basic Strategies

- **High acceptance**

$\Rightarrow$ • lower proton rate ($\Rightarrow$ can run w/ other experiments)

• lower K_L & n rates

$\Downarrow$

lower detector rates
lower beam related background rates
smaller rate-related acceptance loss

Assume 100% (geometrical) × 30% (cuts)

= 30% acceptance

- **Higher E_K**

$\Rightarrow$ • Much better γ-veto efficiency.

'Extra 2γ' is the most significant signature of $K_L \to 2\pi^0$ background.

• smaller n/K ratio

= lower n rate

$\Downarrow$

lower...

....

Assume $\langle P_K \rangle \sim 5\,\mathrm{GeV}/c$ $= \frac{E_P}{10}$

Flux

Required flux

$$\frac{1000\text{ evts}}{3\times10^{-11}} \times \underset{\text{acceptance}}{\frac{1}{0.3}} = 10^{14}\ K_L\text{ decays in 1 year}$$

$$10^{14} \times \frac{3\text{ (duty factor)}}{1\times10^{7}\text{ sec/year}} = 30\text{MHz } K_L\text{ decays}$$

(Inagaki's table (CP Violation in K, 1998)

~30MHz K_L decays @ 1E14 ppp, 10° tgt ang.
2GeV/c K, 5.5μstr
2.7m decay volume
(4.3% decay probability))

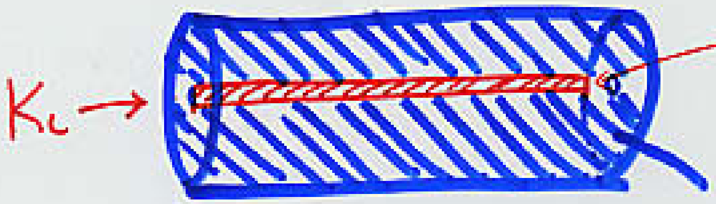
3.6° tgt angle ($P_{T\cdot K}$ ~ 300MeV/c)
5GeV/c P_K ⇒ 6% decay prob.

⇓

≳ 40MHz K_L decays @ 1E14 ppp
(5.5μstr)
available

OK!

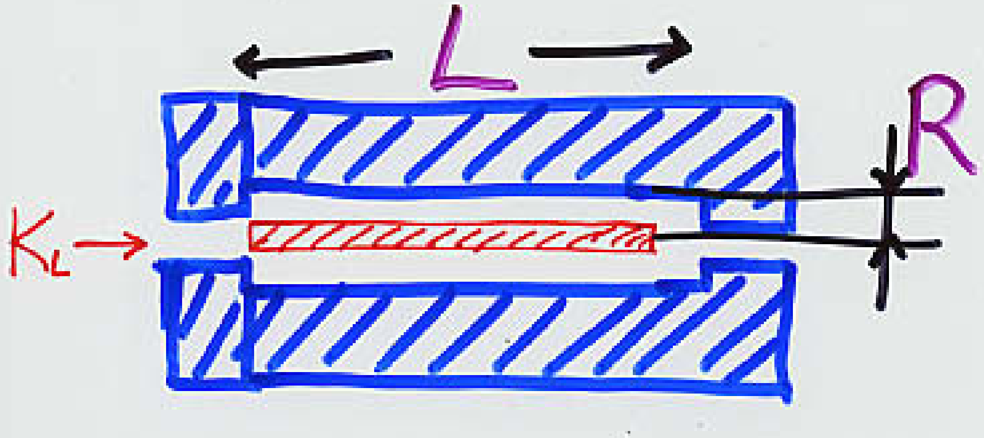
Detector



K_L decay vertices
(30MHz)

γ detector
~100% coverage
used as calorimeter &
γ-veto

- avoid beam halo
- reduce shower overlaps



$$\text{hit rate} \sim 30\,\text{MHz} \times 4 \times \frac{1}{2\pi R L}$$

$$\begin{array}{l} 2\text{ body} \times (27+39)\% \\ 4\text{ body} \times 13\% \\ +\,6\text{ body} \times 21\% \\ \hline 3.1\text{ body} \end{array}$$

example
L=10m, R=0.4m
⇒ 5MHz/m²

γ veto inefficiency due to blinding

example:

$$5\,\mathrm{MHz/m^2} \times 5\,\mathrm{cm} \times 5\,\mathrm{cm} \times t_{dead}$$

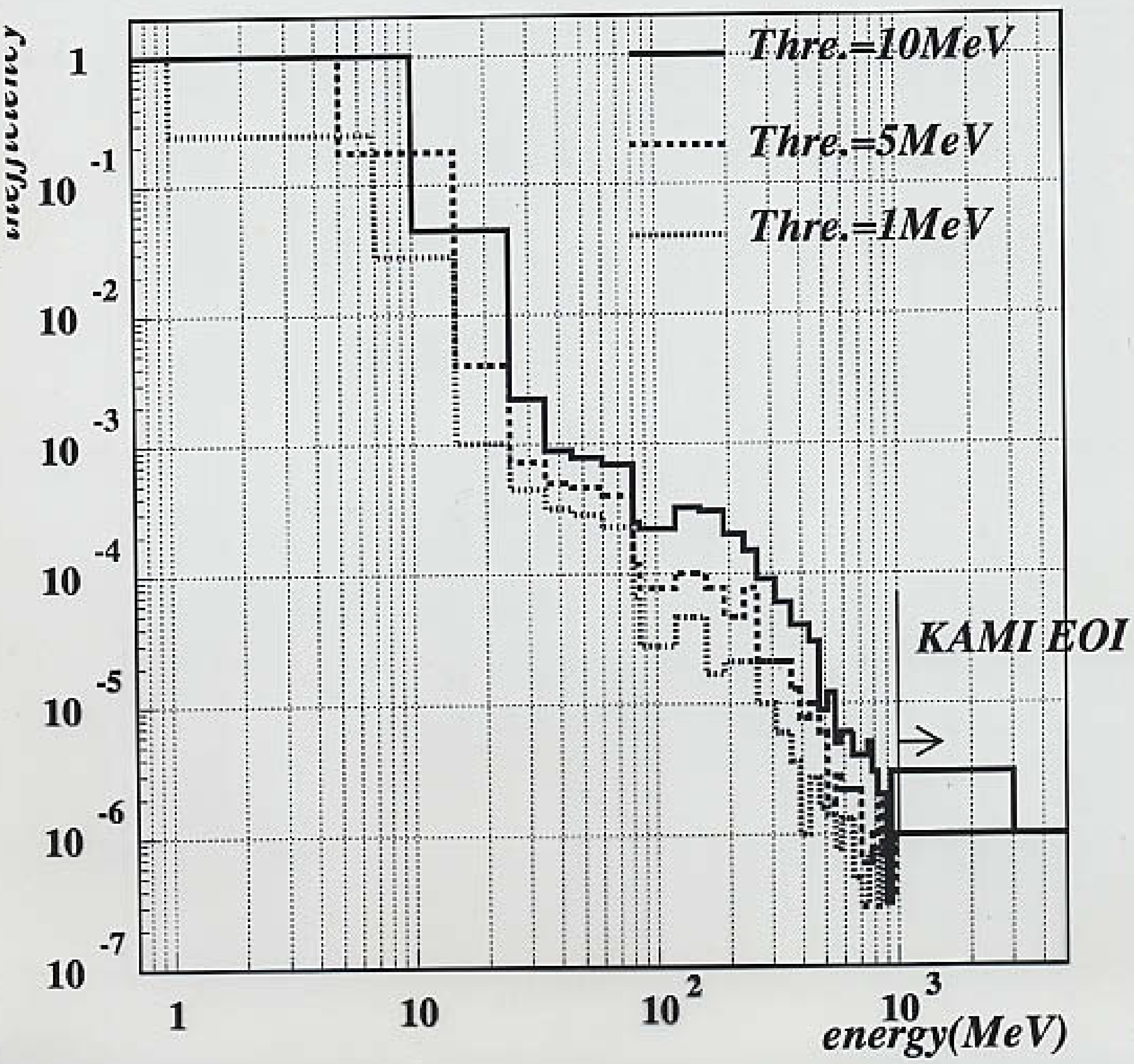
$E_\gamma = 500\,\mathrm{MeV}$ hiding behind 1GeV tail

$\Rightarrow 2.6\times10^{-4}$

More study using real E distribution & pulse shape analysis is needed.

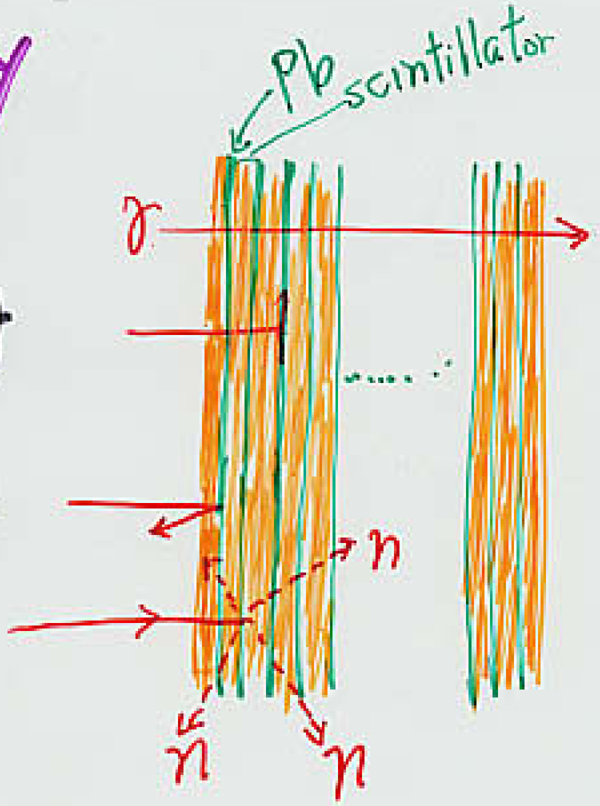
What if we lower the γ veto threshold?

photon inefficiency(1mmPb/5mmScint.)

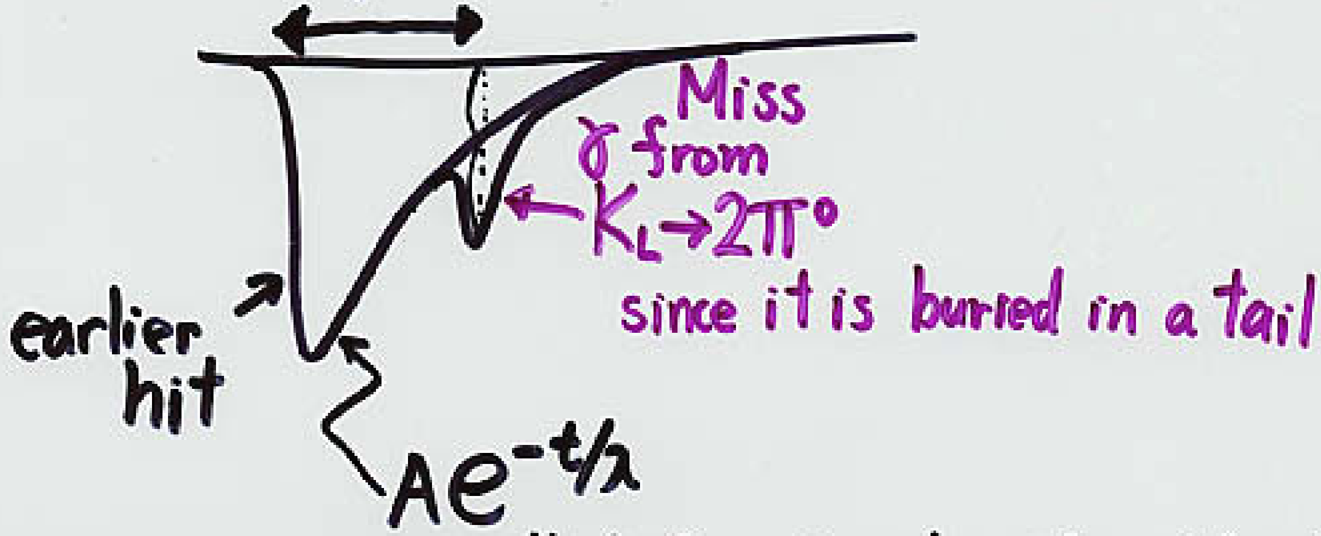


γ veto inefficiency

- Punch through
- Sampling effect
- Back scattering
- photo nuclear interaction



- Blinding



assume that for $0 \sim t$, it is blind against pulse height $\underset{E}{\wedge} < Ae^{-t/\lambda}$.

$$t_{blind} = -\lambda \ln E/A$$

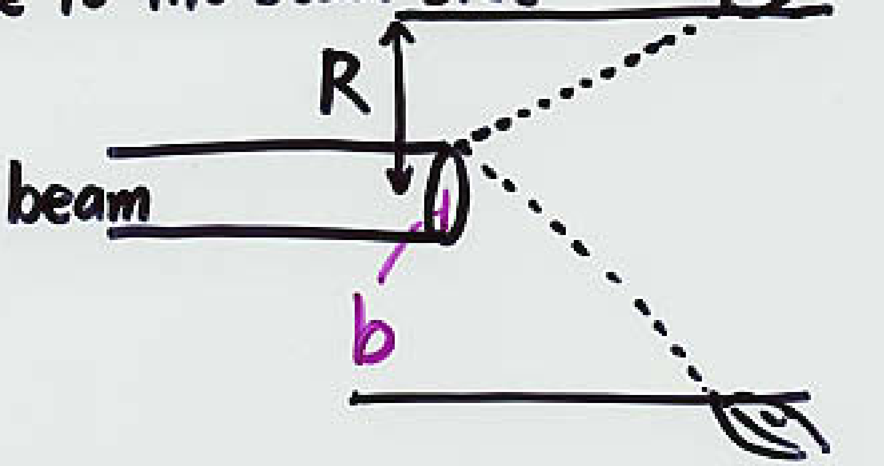
example: $\lambda = 30$ ns, $A = 1$ GeV

E	t_{dead}
10 MeV	140 ns
100 MeV	70 ns

Energy resolution of the γ detector

• P_T resolution for π^0

- due to the beam size



$$\frac{\Delta P_T}{P_T} \sim \frac{\sigma_{beam}}{R} = \frac{b/\sqrt{6}}{R} \times 2 \underset{\sim}{\ } \text{example:} \sim \frac{2.6mr/2 \times 30m}{40cm \cdot \sqrt{6}} \times 2$$

(error on both γ)

$\sim$ 8%

- due to E resolution

$$\frac{\Delta P_T}{P_T} \sim \frac{\Delta E}{E} \cdot \sqrt{2}$$

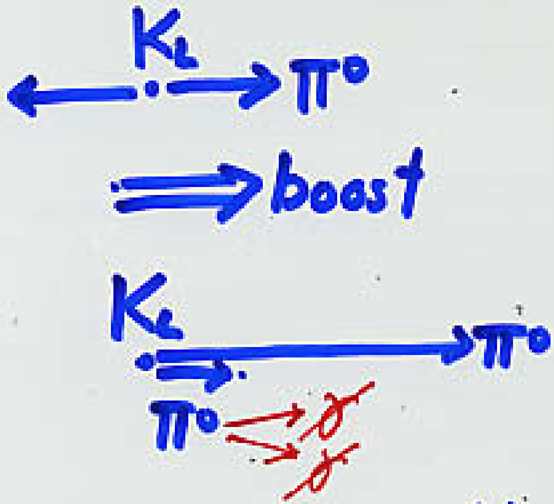
$$\Downarrow$$

$$\frac{\Delta E}{E} \sim \frac{1}{\sqrt{2}} \cdot 8\%$$

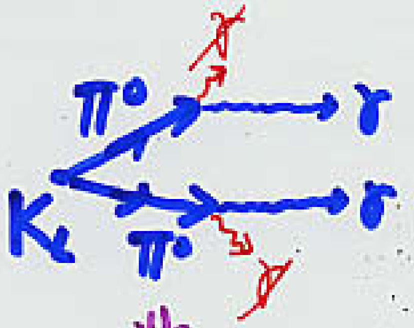
$\lesssim 6\%$ is good enough

$K_L \to \pi^0\pi^0$ backgrounds

even pair bkg



odd pair bkg



$$E_{\gamma_1}+E_{\gamma_2}=E_{\pi^0}>\gamma_K\left(\frac{M_K}{2}-p^*_{\pi^0}\beta_K\right)$$

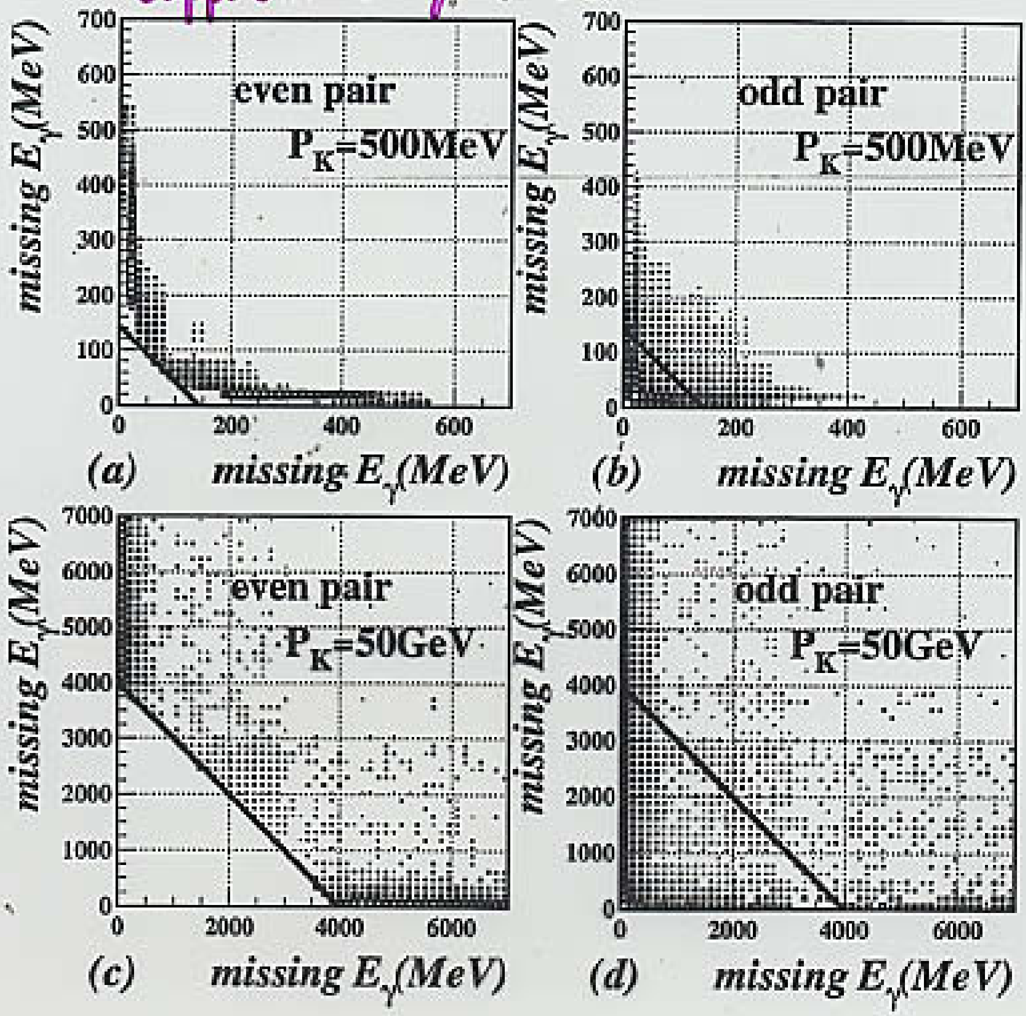
missed γ

⇓

suppressed by γ-veto

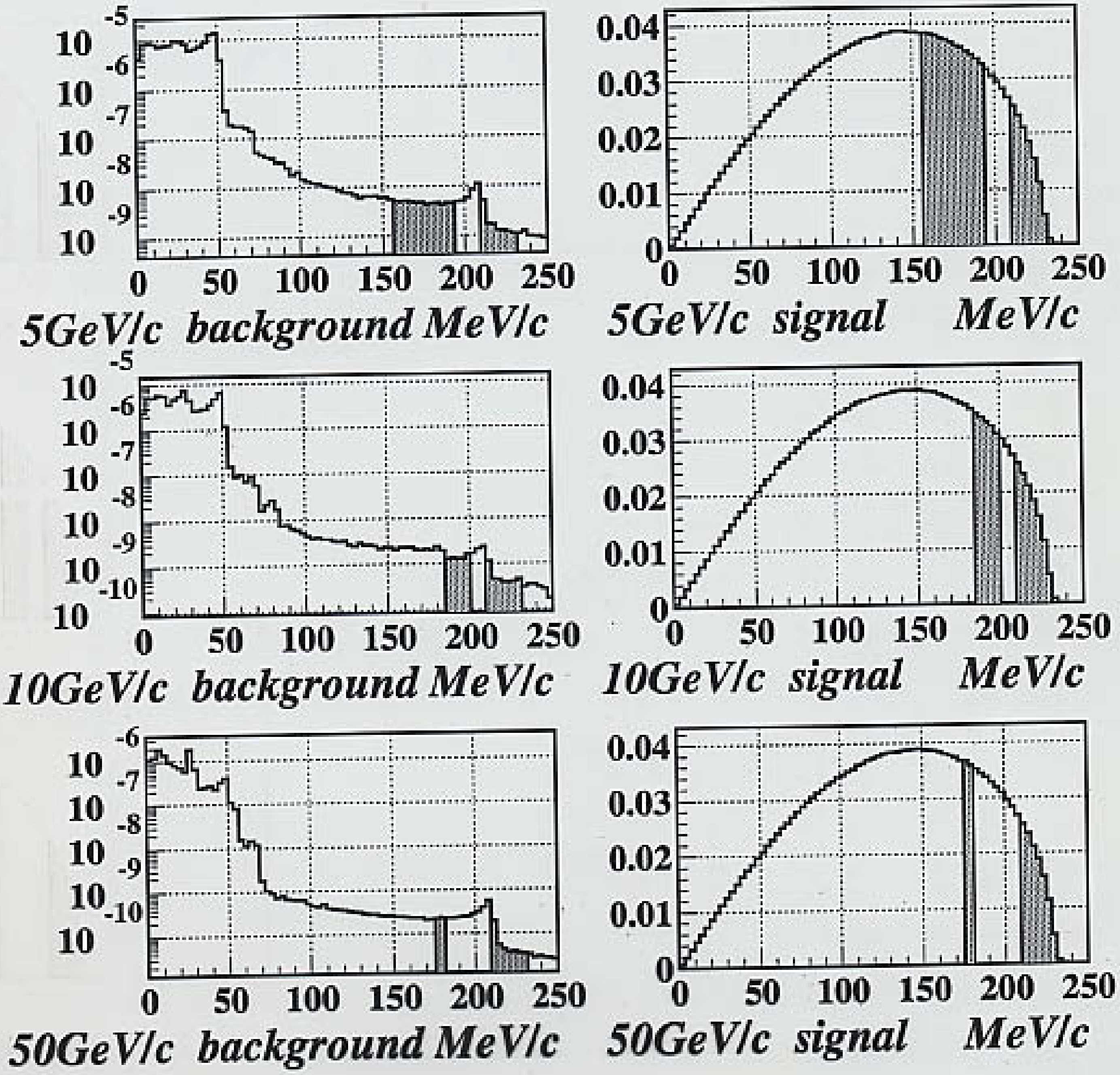
⇓

wrong Z & P_T



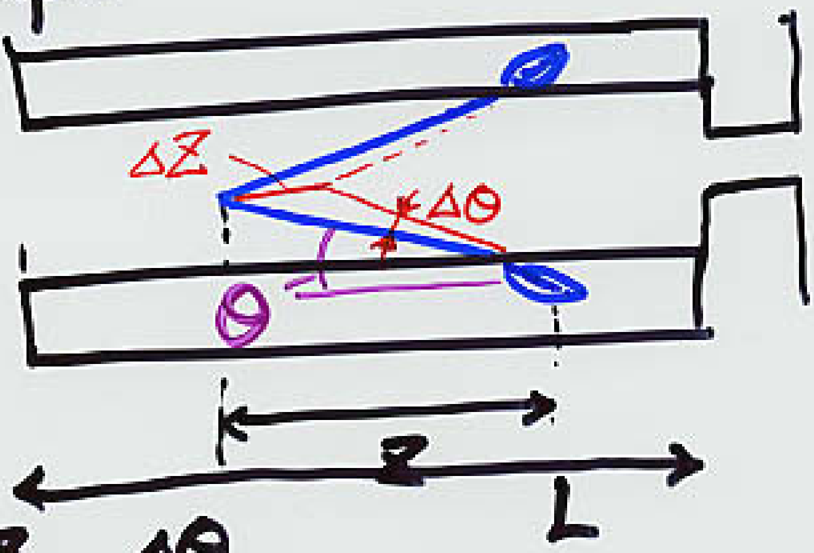
P_T cut

Pt 1mmPb/5mmScint



Can we further suppress odd-pair backgroung?

- example



$$\frac{\Delta Z}{Z} \sim \frac{\Delta \Theta}{\Theta}$$

$$\Theta \sim \frac{0.1\,\mathrm{GeV}}{1\,\mathrm{GeV}} \sim 0.1$$

$$Z \sim \frac{R}{\Theta} \sim \frac{0.4\,\mathrm{m}}{0.1} \sim 4\,\mathrm{m}$$

To get

$$\frac{1}{10} \sim \frac{\Delta Z}{L} = \frac{Z}{L} \cdot \frac{\Delta \Theta}{\Theta} \sim \frac{4\,\mathrm{m} \cdot \Delta\Theta}{10\,\mathrm{m} \cdot 0.1}$$

$\Delta\Theta \sim 0.025$ is required

1mm Pb

ultimate

$$\Delta\Theta_\gamma \sim \frac{14\,\mathrm{MeV}}{500\,\mathrm{MeV}} \sqrt{\frac{1\,\mathrm{mm}}{5\,\mathrm{mm}}} \cdot \frac{1}{\sqrt{2}}$$

~ 0.01 for 1GeV γ

even pair background

$$K + n \to \Lambda + X$$
$$\hookrightarrow n\pi^0$$

⋮

- How to <u>measure</u> the background level and shape
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