Search for $K_L \to \pi^0 \nu \bar{\nu}$ Decay

(KEK-PS E391a Collaboration)

G.Y.Lim

IPNS, KEK

Introduction

Detection Method

Current Status

Summary

Kaon Decay Workshop – KEK – 14 Feb. 2001

High Energy Accelerator Research Organization, ***KEK***

Faculty of Science and Engineering, ***Saga University***

Department of Physics, ***Yamagata University***

Department of Physics, ***Osaka University***

R*esearch* ***C****enter for Nuclear* ***P****hysics, Osaka University*

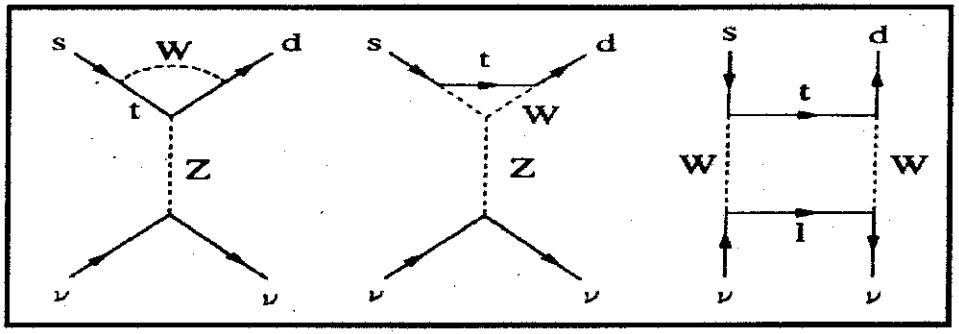
National ***D****efense* ***A****cademy of* ***J****apan*

Department of Physics, ***Ibaraki University***

J*oint* ***I****nstitute for Nuclear* ***R****esearch,* ***Russia***

[redacted]

- *Search for Direct CP Violating Process* $K_L \rightarrow \pi^o \nu \bar{\nu}$ *Decay*



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- $Br(K_L \rightarrow \pi^0 \nu \bar{\nu}) = 6\,\kappa_1 \cdot Im(V_{td}^* V_{ts})^2 X^2(x_t)$

$= 1.94 \cdot 10^{-10} \eta^2 A^4 X^2$

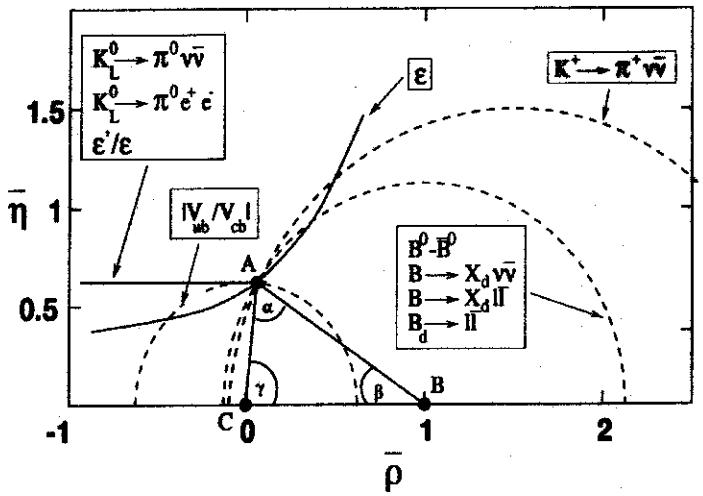
[redacted]

Very Small Theoretical Uncertainty

Precise Measurement of SM Parameters
Chance to meet New Physics

Test of the Standard Model

- Construction of Unitary triangle in K-system



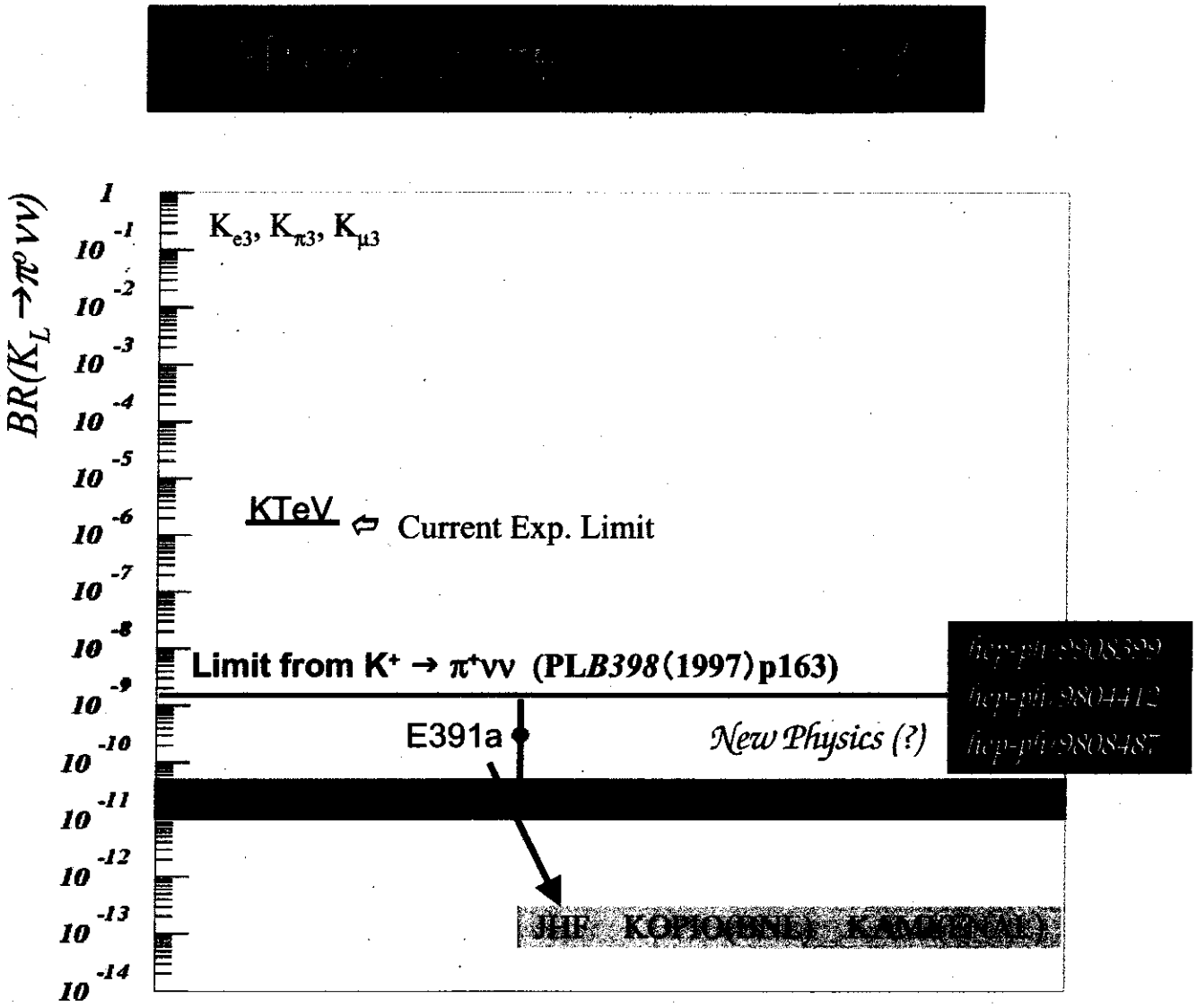
	$K \to \pi \nu\bar{\nu}$	B Factory	LHC
$\sigma(\lvert V_{td}\rvert)$	±10%(9%)	±5.5%(3.5%)	±5.0%(2.5%)
$\sigma(\bar{\rho})$	±0.16(0.12)	±0.03	±0.01
$\sigma(\bar{\eta})$	±0.04(0.03)	±0.04	±0.01
$\sigma(\sin 2\beta)$	±0.05	±0.06	±0.02
$\sigma(\mathrm{Im}\lambda_t)$	±5%	±14%(11%)	±10%(6%)

(A. Buras hep-ph/9905437)

- Comparison with B-system

⇒ Tests the Standard Model / New Physics

KEK-PS E391a (Search for $K_L^0 \rightarrow \pi^o \nu\bar{\nu}$ Decay)



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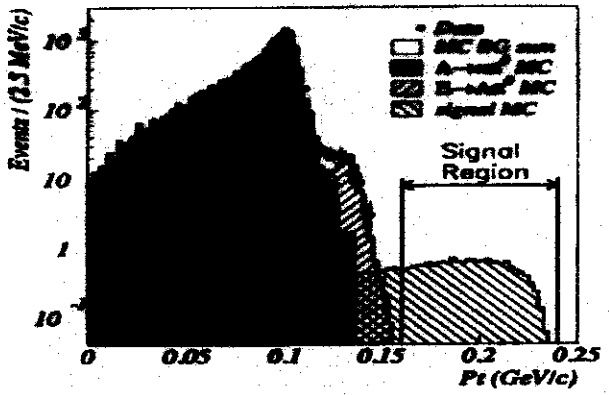
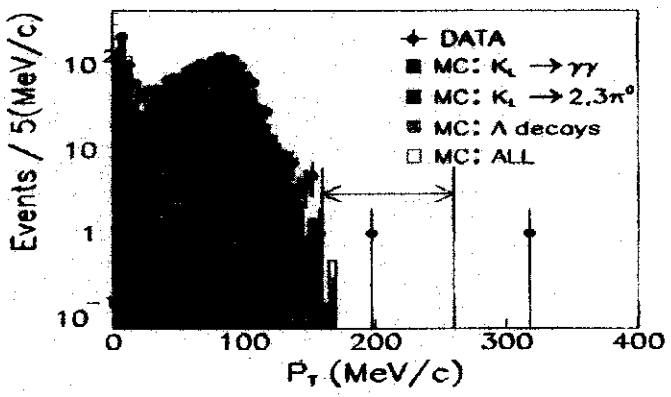
KTeV at FNAL - Single π^0 having high P_T

[redacted] $< 5.9 \cdot 10^{-7}$



Phys. Rev. D61 (2000)

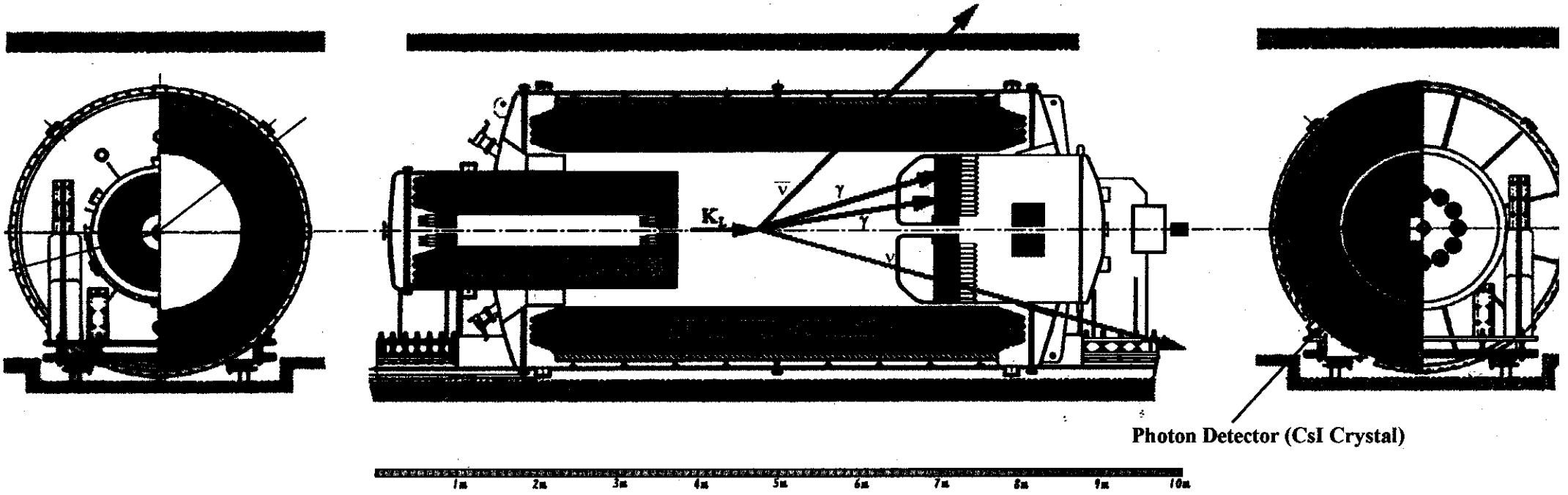
[redacted] $< 1.6 \cdot 10^{-6}$



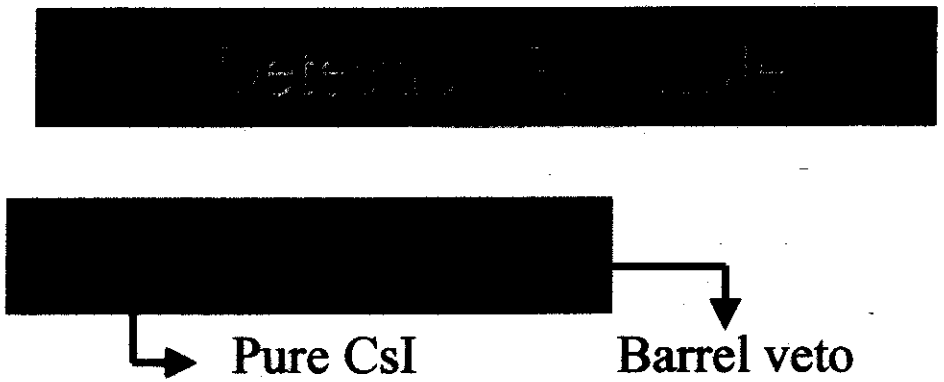
Phys. Lett. B447(1999)

[redacted]

E391a Detector



Photon Detector (CsI Crystal)



K_L Decays have additional particles !

Extremely small branching ratio

How to reject backgrounds

Decay Mode	Branching Ratio	Additional Particles
$\pi^o\pi^o\pi^o$	21.13 %	4γ
$\pi^+\pi^-\pi^o$	12.55 %	2Ch
$\pi^+\mu^-\nu$	27.18 %	2Ch
$\pi^+e^-\nu$	38.78 %	2Ch
γγ	$5.86 \cdot 10^{-4}$	
γγγ	$<2.4 \cdot 10^{-7}$	1γ
$\pi^o\gamma\gamma$	$1.68 \cdot 10^{-6}$	2γ
$\pi^o\pi^+e^-\nu$	$5.18 \cdot 10^{-5}$	2Ch
$\pi^+e^-\nu\gamma$	$3.62 \cdot 10^{-3}$	2Ch
$\pi^+\mu^-\nu\gamma$	$5.7 \cdot 10^{-4}$	2Ch
$\pi^+\pi^-\gamma$	$4.61 \cdot 10^{-5}$	2Ch
$\pi^o\pi^o\gamma$	$<5.6 \cdot 10^{-6}$	3γ
$\mu^+\mu^-\gamma$	$3.25 \cdot 10^{-7}$	2Ch
$e^+e^-\gamma$	$10.0 \cdot 10^{-6}$	2Ch
$e^+e^-\gamma\gamma$	$6.9 \cdot 10^{-7}$	2Ch

Decay Mode	Branching Ratio	Additional Particles
$\pi^o\gamma e^+e^-$	$<7.1 \cdot 10^{-7}$	1γ 2Ch
$\pi^+\pi^-$	$2.06 \cdot 10^{-3}$	2Ch
$\mu^+\mu^-$	$7.15 \cdot 10^{-9}$	2Ch
e^+e^-	$9 \cdot 10^{-12}$	2Ch
$\pi^+\pi^-e^+e^-$	$3.5 \cdot 10^{-7}$	4Ch
$\mu^+\mu^-e^+e^-$	$2.9 \cdot 10^{-9}$	4Ch
$e^+e^-e^+e^-$	$4.1 \cdot 10^{-8}$	4Ch
$\pi^o\mu^+\mu^-$	$<5.1 \cdot 10^{-9}$	2Ch
$\pi^oe^+e^-$	$<4.3 \cdot 10^{-9}$	2Ch
$\pi^o\nu\nu$	$<5.9 \cdot 10^{-7}$	
$e^+\mu^-$	$<4.7 \cdot 10^{-12}$	2Ch
$e^+e^-\mu+\mu-$	$<6.1 \cdot 10^{-9}$	4Ch
$\pi^o\mu^+e^-$	$<6.2 \cdot 10^{-9}$	2Ch

PDG2000

[redacted]

[redacted]

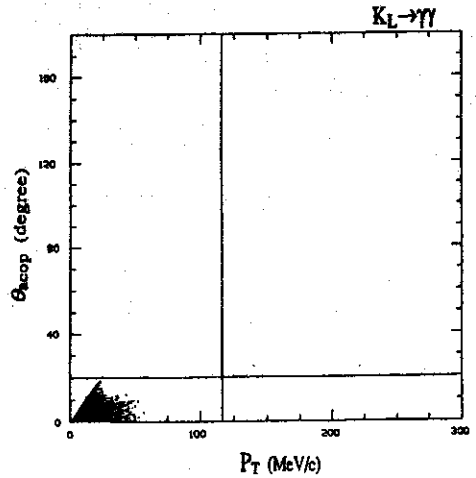
Kinematical constraints

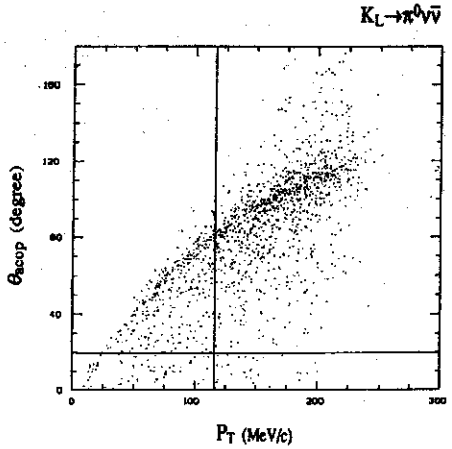
P_T Cut

$P_T =$ [redacted]

Coplanar angle θ

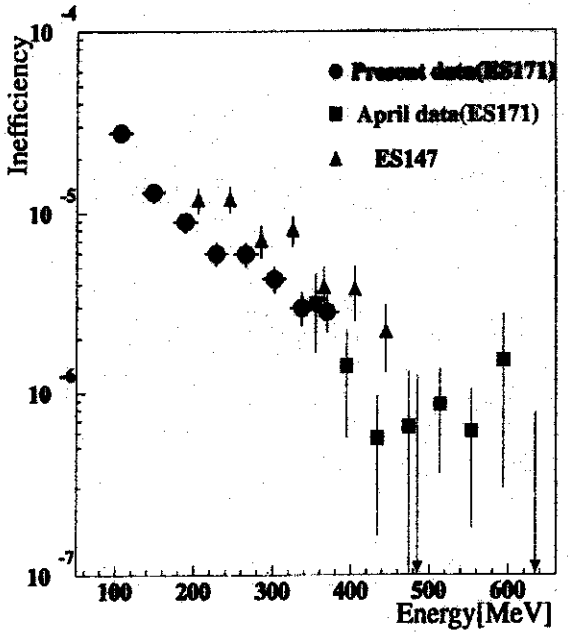
[redacted] Direction





Detector Performance

Inefficiency of γ detection (ES147, ES171)



H.Watanabe, *Master Theses(1998)*

Inefficiency for charged particles (T296)

Particle	Total events	Tail events	Inefficiency (1)	Inefficiency (2)
e^+	4.7×10^4	13	$(2.8 \pm 0.8) \times 10^{-4}$	$(3.2 \pm 0.9) \times 10^{-4}$
π^+	6.1×10^4	0	$< 1.6 \times 10^{-5}$	$< 1.6 \times 10^{-5}$
e^-	4.1×10^4	5	$(1.2 \pm 0.5) \times 10^{-4}$	$< 1.3 \times 10^{-4}$
π^-	1.93×10^5	115	$(6.0 \pm 0.6) \times 10^{-4}$	$(6.0 \pm 0.6) \times 10^{-4}$
p	1.97×10^5	10	$(5.0 \pm 1.6) \times 10^{-5}$	$(5.0 \pm 1.6) \times 10^{-5}$

NIM A359 p478 (1995)

B.G. from $K_L \rightarrow \pi^- e^+ \nu$ Decay

↳ *Separating charged veto*

Estimation of Background Events

No. of background events for Br($K_L \to \pi^0 \nu \bar{\nu}$)= $3 \cdot 10^{-11}$

- From other K_L Decay

$K_L \to \pi^0\pi^0$	0.3
$K_L \to \pi^+\pi^-\pi^0$	<0.1
$K_L \to \gamma\gamma$	<0.1
$K_L \to \pi e\nu$	<0.1

- From Beam

Outside K_L decay	<< 0.1
K_L interaction (10^{-7} Torr.)	<< 0.1
Λ^0 Production	0.15
Gamma rays	negligible
π^0 production by neutrons	0.15
π^0 production by halo neutrons	< 0.1

[redacted]

[redacted]

Additional Particles

High P_T (> 120 MeV)

[redacted]

Considered as a main source of BG

Relatively large BR : $9.27 \cdot 10^{-4}$ (PDG2000)

Two missing gammas

Inefficiency of γ detection < 10^{-4}

Could be achieved !! ⇦ ES147, ES171

High P_T

[redacted]

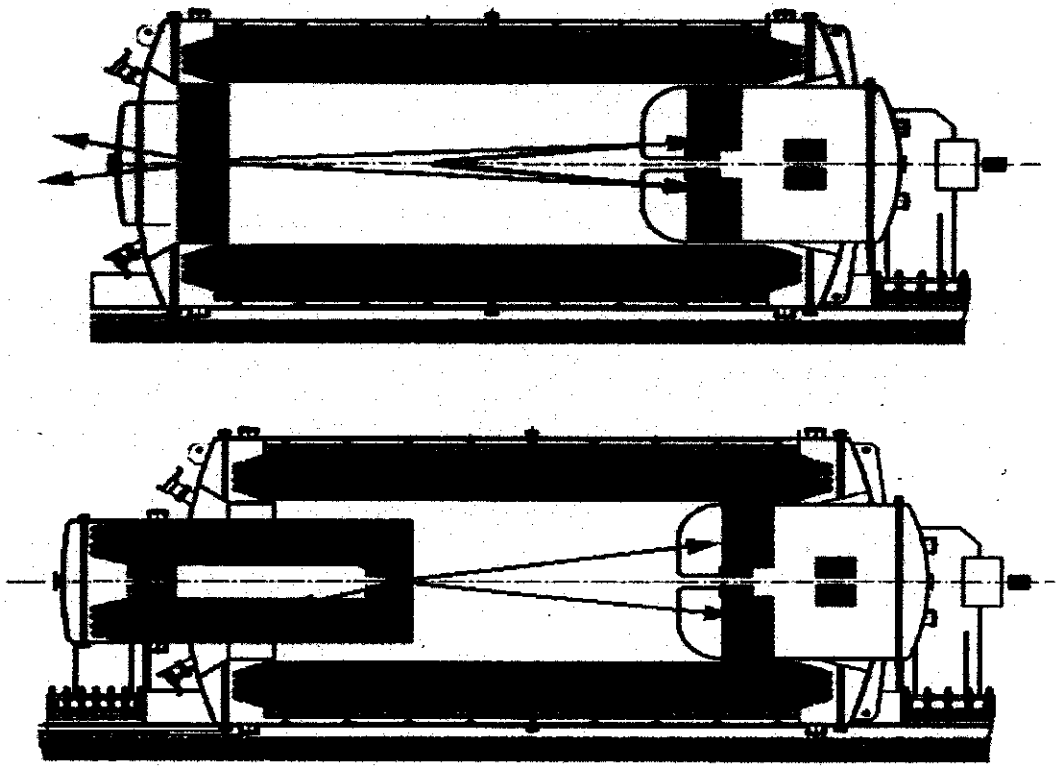
- Outside K_L Decay
- K_L Interaction : Regeneration, π^0 production
- Gamma Rays : Accidentals, Over veto, π^0 production
- Neutrons : π^0 production
- Λ^0 production
- Something else ?

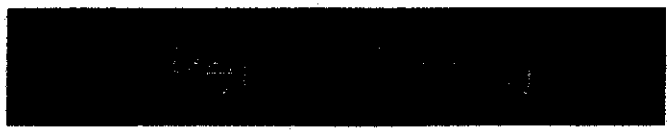
Double Decay Chamber
Highly vacuumed decay region
Pencil Beam
Try and Error

[redacted]

Reject decay outside of fiducial region

No direct hit of beam particles



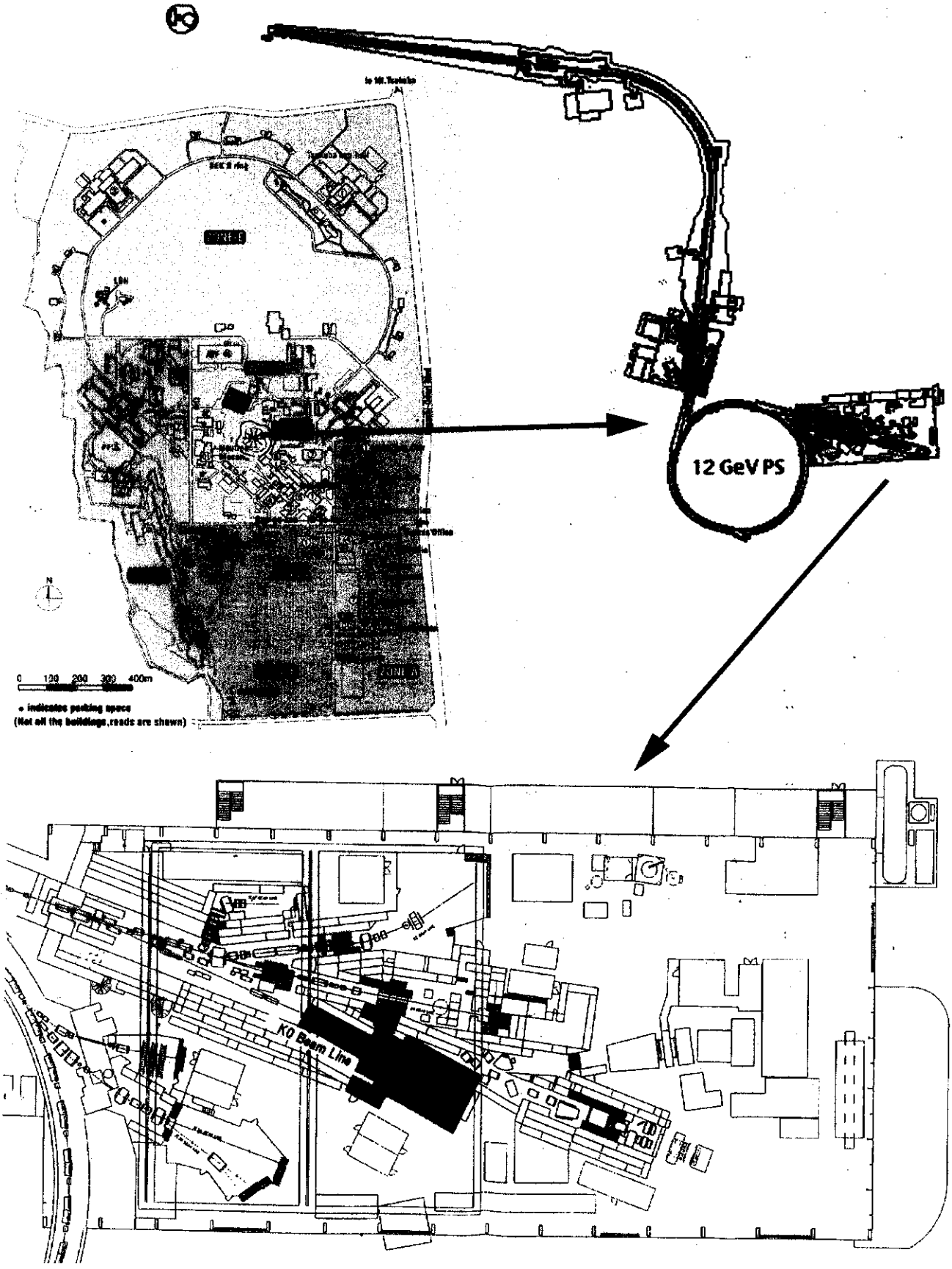


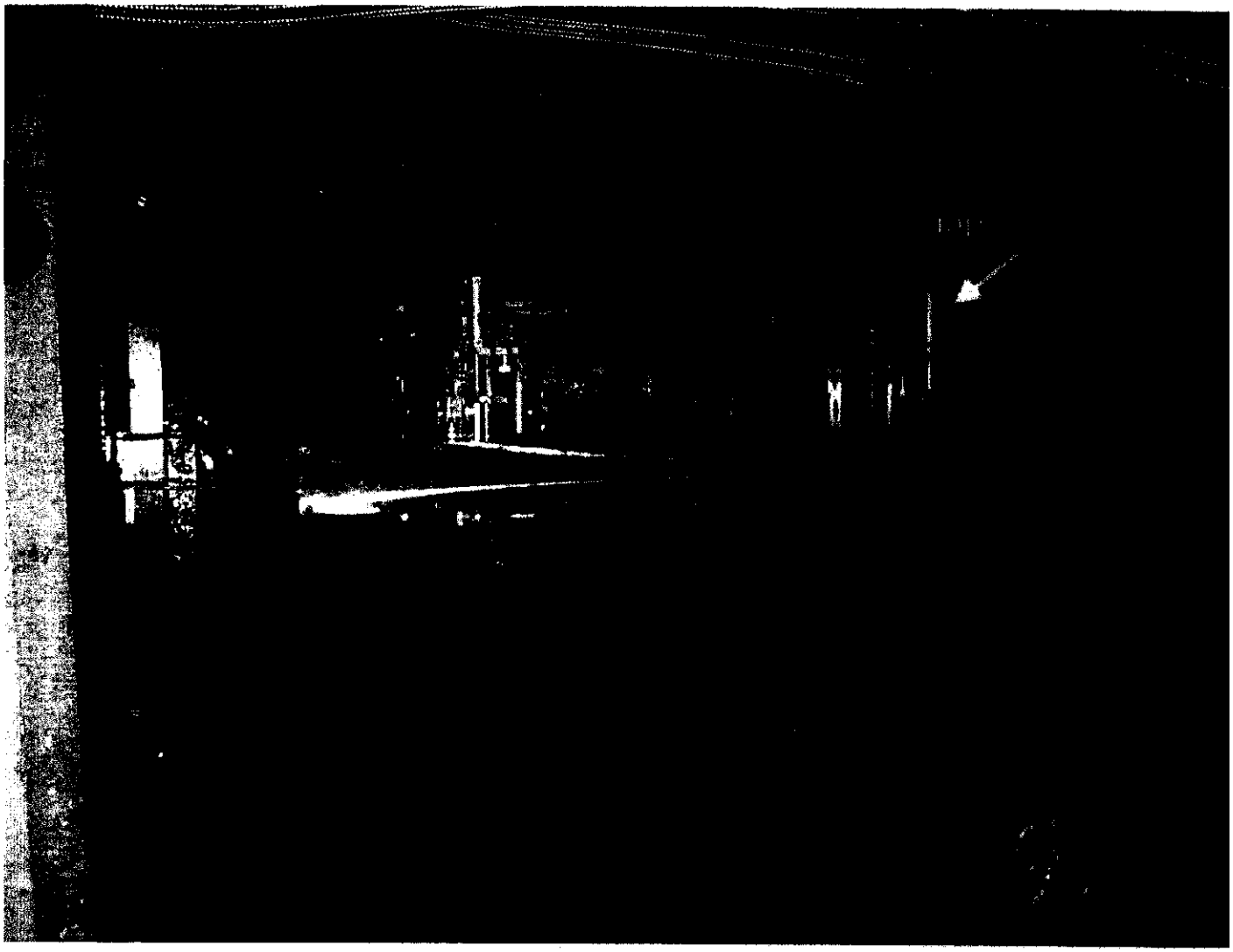
- Single π^0 having high P_T
  - Vertex **Reconstruction**
  - No P_T of K_L
- Suppression of Backgrounds related to beam

- Low Energy Beam - Free from hyperon B.G.

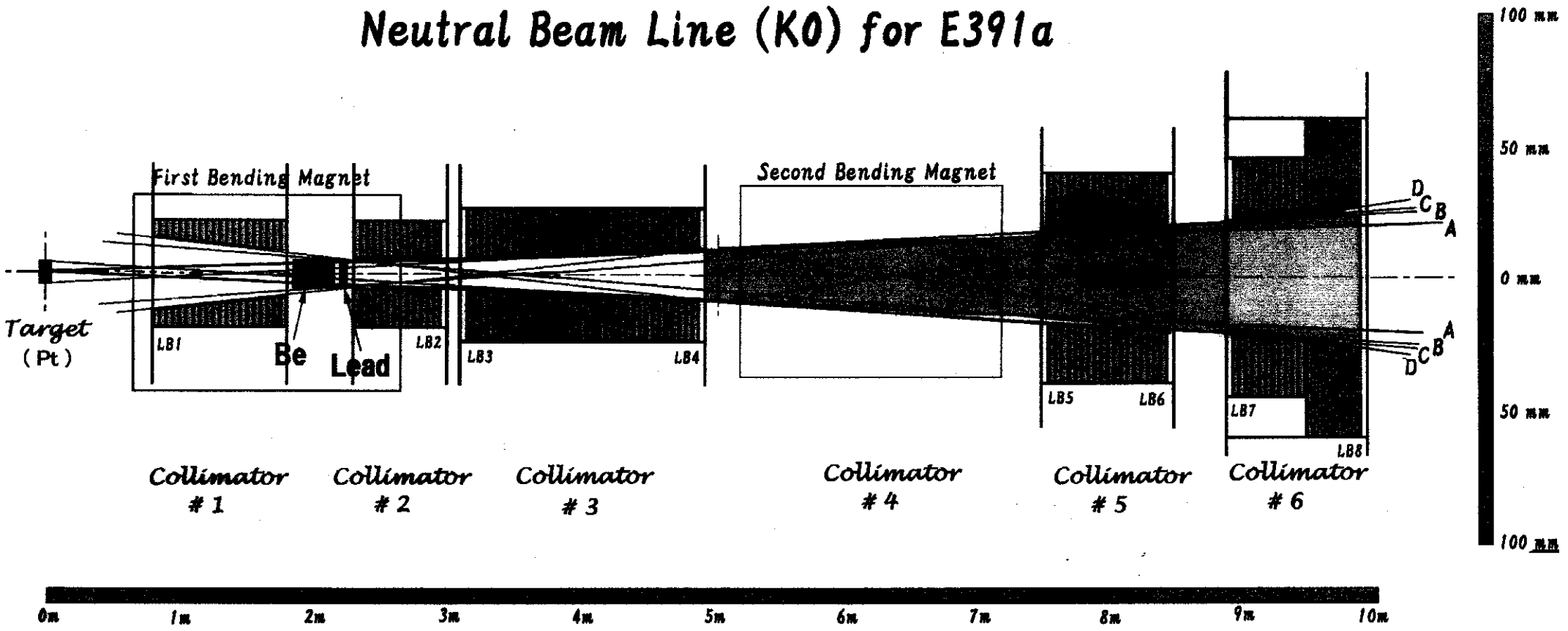
- **Dec. 1997 – Experiment was approved**
- **Detector inefficiency study**
  T296, ES147, ES171
- **Beamline construction (March, 2000)**
  Beam survey (April, Dec., 2000)
- **Development/Checking of detector elements**
  Proto-type barrel veto (T466)
  CsI (T458, T473)
  CeF_3 (T466)

- Constructed on March, 2000
  - 5 stages of collimator
  - 2 stages of bending magnet
- Beam survey – April, Dec., 2000
  - Profiles of particles (gamma, neutron)
  - Energy distribution
  - Thermal neutron flux – Source of over veto
  - Count for K_L


12 GeV PS
K0 Beam Line

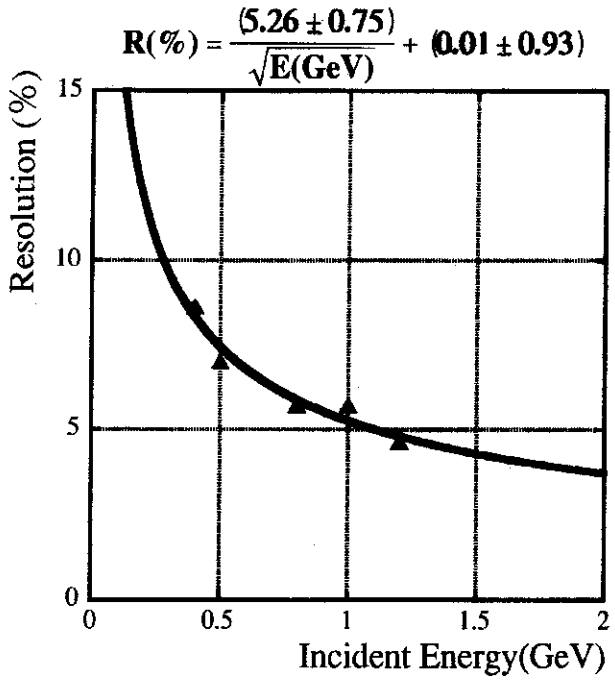


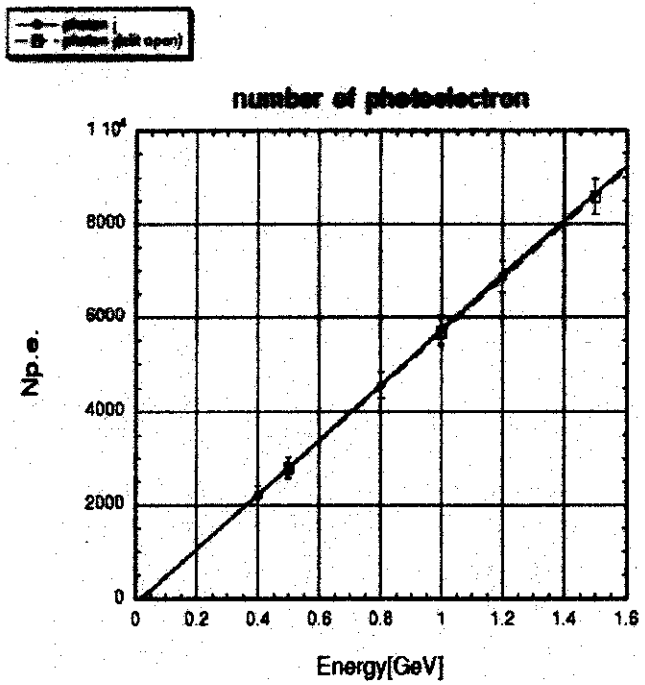
Neutral Beam Line (K0) for E391a



- Pb(1mm)+Scin.(5mm) sandwich calorimeter
  - Wave Length Shifter fiber readout
  - Injection-molding scintillator
- 1m test module
  - Development of construction procedure
  - Beam test (June, 2000) : Num. of Photoelectron
  - Mechanical test for construction
- reach to 10^{-4} inefficiency (1MeV threshold)

[redacted]





5.3% Resolution in 1GeV

Ave. Num. Of P.E. = 5.7/MeV

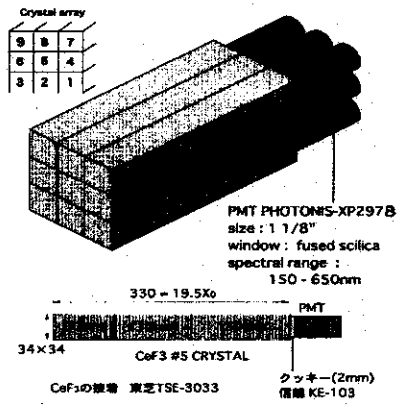
Possible to put 1 MeV Threshold

→ < 10^{-4} inefficiency

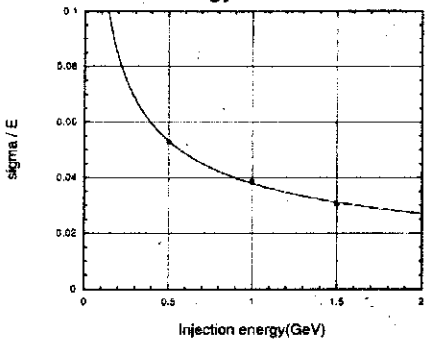
[redacted]

- Candidate of main detector for the next stage
- Succeed to grow large size of crystal
- Beam test (June, 2000)

CeF_3 Detector



Energy resolution



$$\frac{\sigma}{E(\mathrm{GeV})} = \frac{3.72\times10^{-2}}{\sqrt{E(\mathrm{GeV})}} + 6.36\times10^{-3}$$

Effect of beam dispersion !
→ Using different machine

Kaon Decay Workshop for Young Physicists

KEK, Institute of Particle and Nuclear Studies

February 14(Wed) — 16(Fri), 2001

February 14 (Wed), Building #4, Seminar Room 345 (3rd floor)

Welcome address (9:55-10:00)

(1) On-going / Scheduled Experiments (10:00-11:45)

a) From E787 to E949 and the future: stopped-kaon experiments for $K^+ \to \pi^+ \nu \bar{\nu}$
------ Takeshi KOMATSUBARA (KEK)

b) $K^+ \to \pi^+ \pi^0 \gamma$ experiment (KEK/E470) ---------- Jun IMAZATO (KEK)

c) $K_L^0 \to \pi^0 \nu \bar{\nu}$ experiment (KEK/E391a) ---------- Gei Youb LIM (KEK)

— Lunch — (11:45-13:15)

(2) R&D (Beam) (13:15-14:25)

a) Production Target Monitor (E391a) ---------- Takahiro SATO (KEK)

b) Neutral Beam Line (E391a) ---------- Gei Youb LIM (KEK)

c) Sensitivity of the Decay of $K_L^0 \to \pi^0 \nu \bar{\nu}$ at Fermilab KAMI Experiment
-------- Mitsuhiro MATSUMOTO(Osaka)

(3) R&D (Detector-1) (14:25-14:55)

a) Performance Test for CeF_3 Crystal (E391a) ---------- Ryuichi CHIBA (Yamagata)

b) High-QE PMT (E391a) ---------- Takao INAGAKI (KEK)

c) Calorimeter with WLS-Fiber Readout (E391a) -------- Akio MIURA (Yamagata)

— coffee break — (14:55-15:15)

(4) R&D (Detector-2) (15:15-16:30)

a) WLS Fiber Readout (KAMI) ---------- Katsushige KOTERA (Osaka)

b) Performance Test for PWO Cherenkov Detector (E949) - Masaaki KOBAYASHI (KEK)

c) Performance Test for GSO-bar (E949) ---------- Yoichi TAMAGAWA (Fukui)

(5) R&D (Detector-3) (16:30-17:45)

a) Inefficiency of Lead/scintillator Sandwich Calorimeter (KAMI) - Ken SAKASHITA (Osaka)

b) γ-ray Inefficiency due to Overlapping Clusters (KAMI) -- Takayuki ISHIKAWA (Osaka)

c) A study of the separation of neutron from γ in the energy range to 12 GeV (E391a)
------- Hiroaki WATANABE (Saga)

18:00-

Welcome Party at KEK (building #4, room 414)

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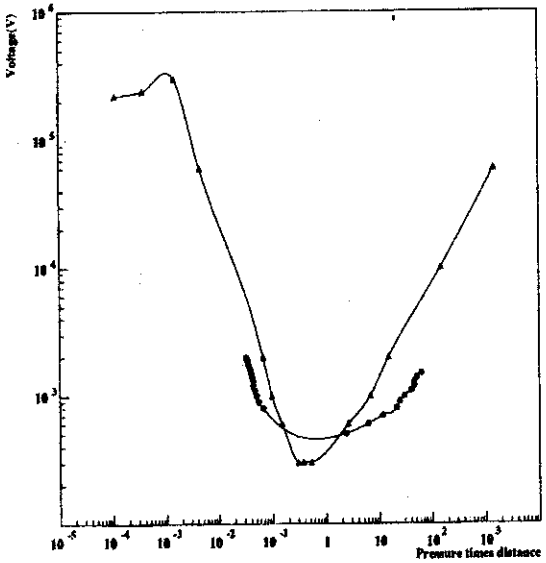

図 3.1: Pashen による放電曲線

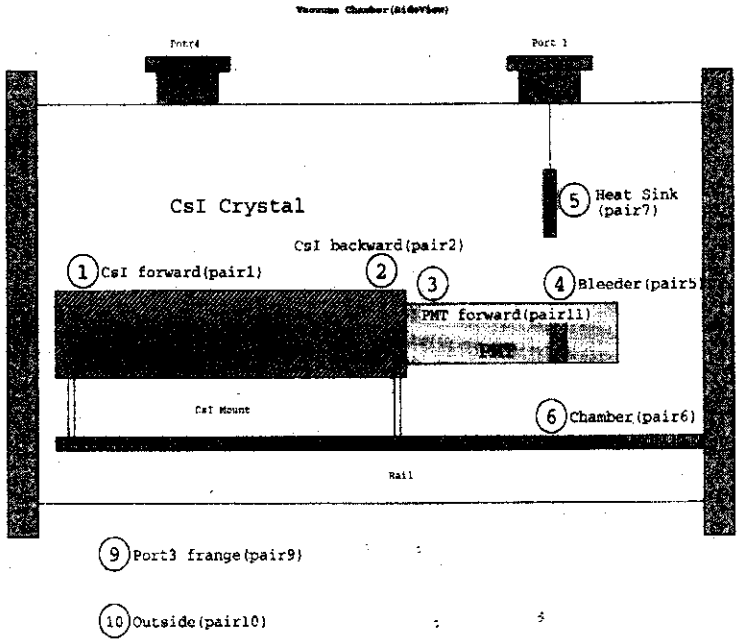

図 5.1: CsI Module をヒートシンクで冷却した時の熱電対の配置

T. Miyahara, *Master Theses* (2000)

Main detector to detect gammas

- Recycling of previous PS experiment
  - Checking all modules (PMT)
  - Energy resolution : 2% at 1GeV ⇦ T458
- Question of response in vacuum
  - Discharge of PMT
  - Temperature
  - Continue the test for large number

Schedule

- 2001
  - Construction of front veto
    barrel veto
- 2002
  - Vacuum Chamber
  - Detector Assembly
  - Start data taking

- JHF - 2007(?)

✧ $K_L \rightarrow \pi^0\nu\bar{\nu}$ *Decay*

- Direct CP violation process
- Precise determination of CP violation parameter
- Sensitive to new physics

✧ *KEK-PS E391a*

- Two-step experiment
  - 10^{-10} (KEK-PS) → 1000 events (JHF)
  - Realistic approach to extremely rare decay
- Aiming to start data taking within 2002