KOPIO Experiment at BNL

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For KOPIO Collaboration

- theoretical predictions
- principles of measurement
- beam and detector
- sensitivity
- backgrounds and systematics
- conclusion

Kaon Decay Workshop for Young Physicists
KEK, 16 February 2001

4 KOPIO - a search for $K^0 \rightarrow \pi^0 \nu\bar{\nu}$

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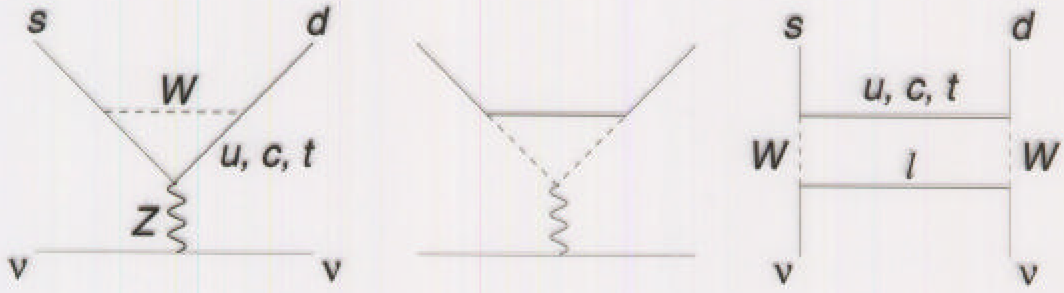
$K_L^0 \to \pi^0 \nu\nu$ Decay



$$B(K_L^0 \to \pi^0 \nu\bar{\nu}) = r_{IB} B(K_L^0 \to \pi^0 e^+ \bar{\nu}) \frac{\tau(K_L)}{\tau(K^+)} \frac{3\alpha^2}{2\pi^2 sin^4\Theta_W} \eta^2 A^4 \lambda^8 X^2($$

$$= (3.1 \pm 1.3) \times 10^{-11}$$

$$X(x) = \eta_X \cdot \frac{x}{8}[\frac{x+2}{x-1} + \frac{3x-6}{(x-1)^2} lnx]$$

$$\eta_X = 0.985, x_t = m_t^2/M_W^2, r_{IB} = 0.944$$

Model independent limit (Grossman & Nir):

$B(K_L \to \pi^0 \nu\bar{\nu}) < 4.4 \times B(K^+ \to \pi^+ \nu\bar{\nu})$
$B(K^+ \to \pi^+ \nu\bar{\nu}) = (1.5^{+3.4}_{-1.2}) \times 10^{-10}$ (BNL 787)

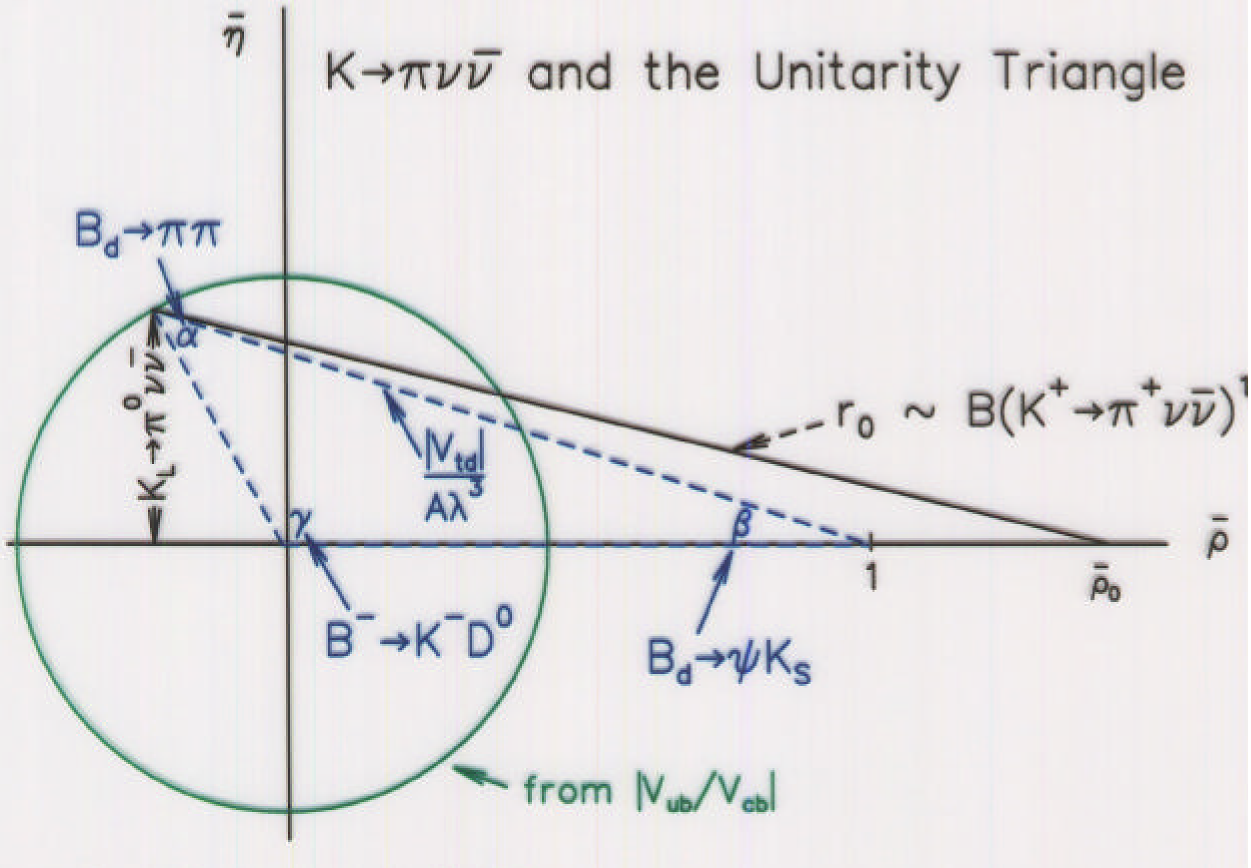
$\Downarrow$

$B(K_L \to \pi^0 \nu\bar{\nu}) < 3.1 \times 10^{-9}$ 95% c.l.

SM

$$1 + \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \equiv \bar{\rho} + i\bar{\eta}$$

$K_L^0 \to \pi^0 \nu\nu$ dominated by direct CP violation



$B(K_L^0 \to \pi^0\nu\nu) = 4 \times 10^{-10} A^4 \eta^2$
$B(K_L^0 \to \pi^0\nu\nu) = 1.56 \times 10^{-4}[Im(V_{ts}^* V_{td})]^2 = 1.56 \times 10^{-4}(Im\lambda_t)^2$

Direct measurement of λ_t to 8%

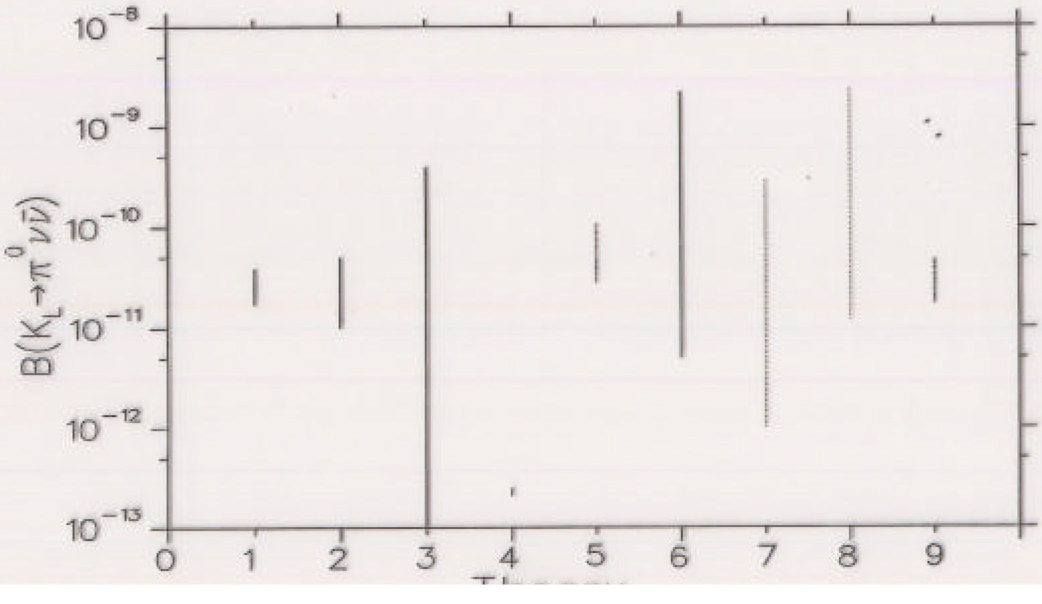
L. Littenberg, Perugia'00

$K_L \to \pi^0 \nu\bar{\nu}$ Beyond the Standard Model

	Who	What	$10^{11} B(K_L \to \pi^0 \nu\bar{\nu})$
1	Buchalla	Standard Model CKM fit	2.8 ± 1.1
2	Plaszczynski/Schune	Conservative SM fit	$1 - 5$
3	Buras, *et al.*	SUSY	$0 - 40$
4	Brhlik, *et al.*	all CP-viol. due to SUSY	$\sim .023$
5	Chanowitz	$SU(2)_L \times SU(2)_R$ Higgs	$2.8 - 10.6$
6	Hattori, *et al.*	4th generation	$0.5 - 220$
7	Xiao, *et al.*	top-color assisted technicolor	$0.1 - 29.5$
8	Xiao, *et al.*	multiscale walking technicolor	$1.2 - 233$
9	Kiyo, *et al.*	seesaw L-R model†	$(1 - 1.2)\times$ SM

G.Isidori, hep-ph/0101121

† predicts spectrum will be altered.



Challenges and Goal

Branching ratio $\sim 3 \times 10^{-11}$

Only neutral particles

$K_L^0 \to \pi^0\pi^0$ **background**
(kinematic reconstruction, effective photon veto)

Background from $n + A \to \pi^0 + X$ **reactions**
(high vacuum)

Background from $\Lambda \to n\pi^0$
(low energy neutral beam)

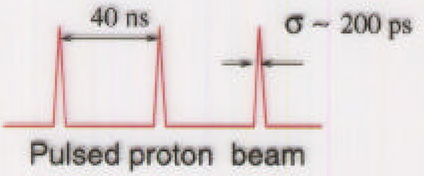
Background from random n's and γ**'s**

Experimental status: $B(K_L^0 \to \pi^0\nu\nu) < 5.9 \times 10^{-7}$ (kTeV)

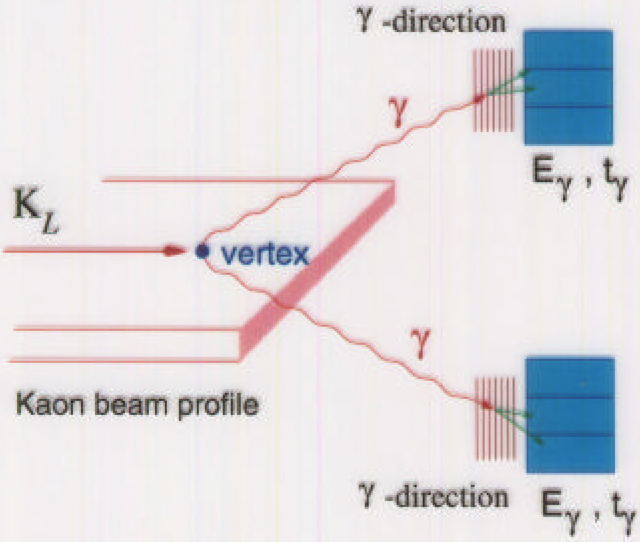
KOPIO goal:
8000 hrs of 10^{14} **p/spill at AGS**
accumulate $1.5 \times 10^{14} K$ **decays**
expect about 60 $K_L^0 \to \pi^0\nu\nu$ **events with** $S/N \sim 2$

Principles

KOPIO concept



⟹ K_L^0 momentum via time-of-flight

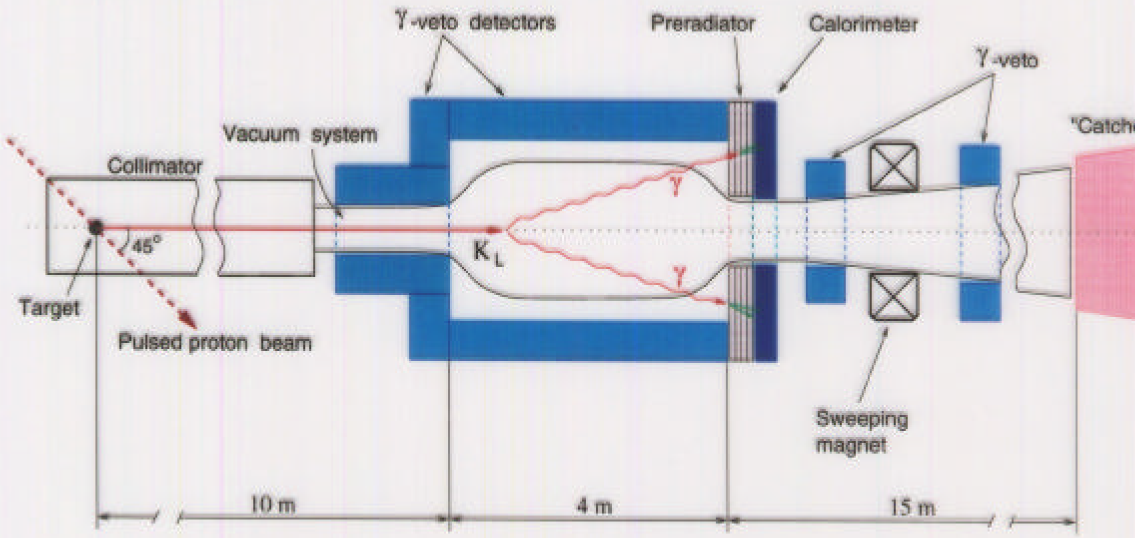


π^0 reconstruction

- **Bunched beam: K_L energy using TOF and PID**
- **preshower: photon direction and PID**
- **EM calorimeter: photon energy**
- **Vertex reconstruction: K_L direction**
- **Efficient photon veto**

Detector

Top view of KOPIO detector

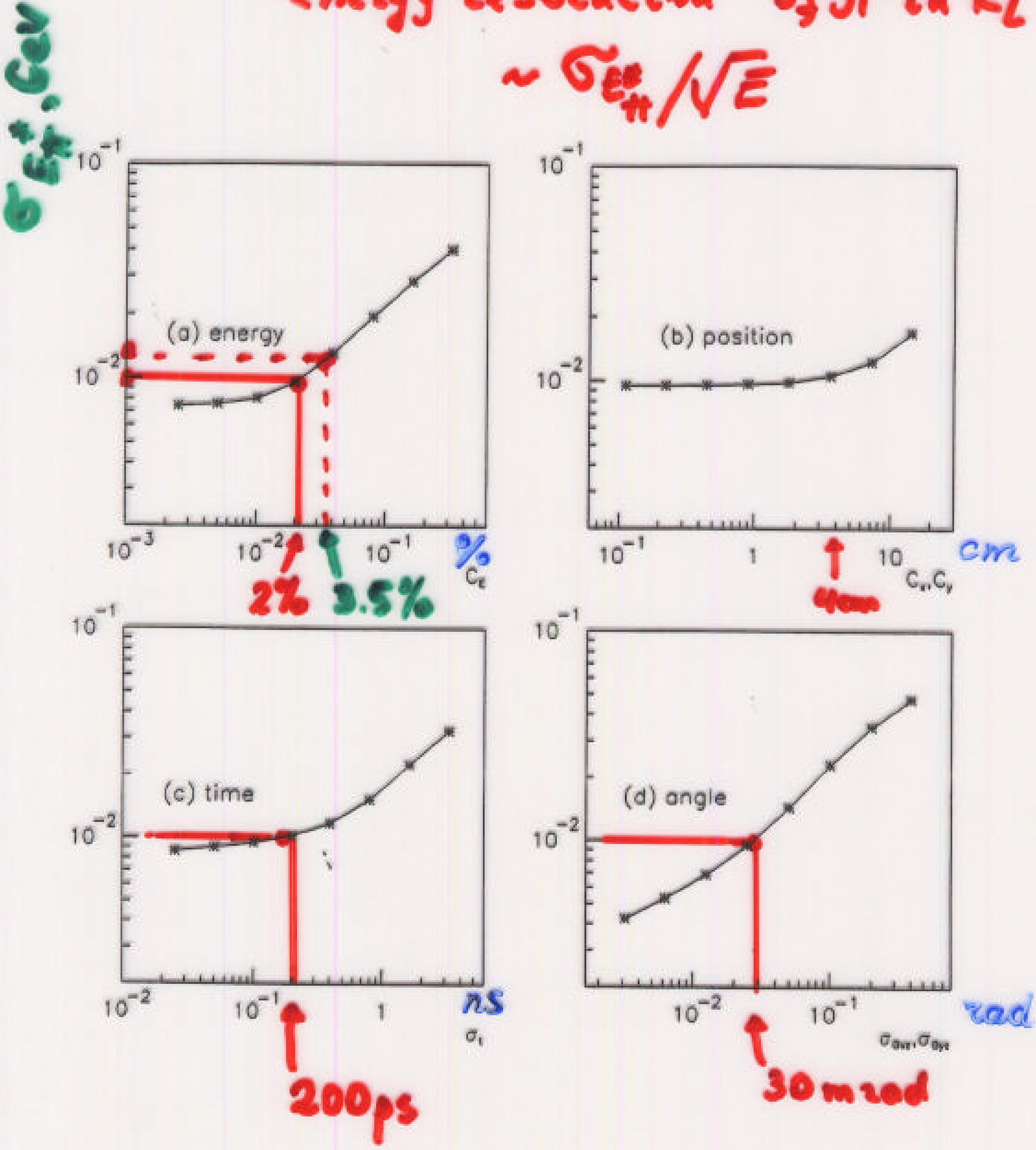


$\Theta = 45°$
$\Delta\Omega = 500\mu$sr(vert - 5 mr horiz ~100 mr)
Pb/plastic veto $\bar{\epsilon}_{\pi^0} \leq 10^{-7}$ $\sigma_t \simeq 70ps/\sqrt{E}$
Preshower/calorimeter $\sigma_E \sim 3.5\%/\sqrt{E}$
$\sigma_\theta \sim$ **24 mrad at 250 MeV** $\sigma_t \simeq 100ps/\sqrt{E}$
Catcher $\epsilon_\gamma \sim 99\%$
Vacuum 10^{-7}

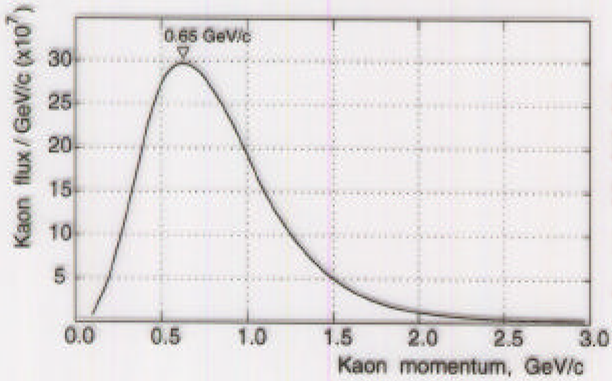
$\sigma_{E^*_\pi}$ vs detector parameters

Energy resolution of π^0 in K_L com

$\sim \sigma_{E^*_\pi}/\sqrt{E}$

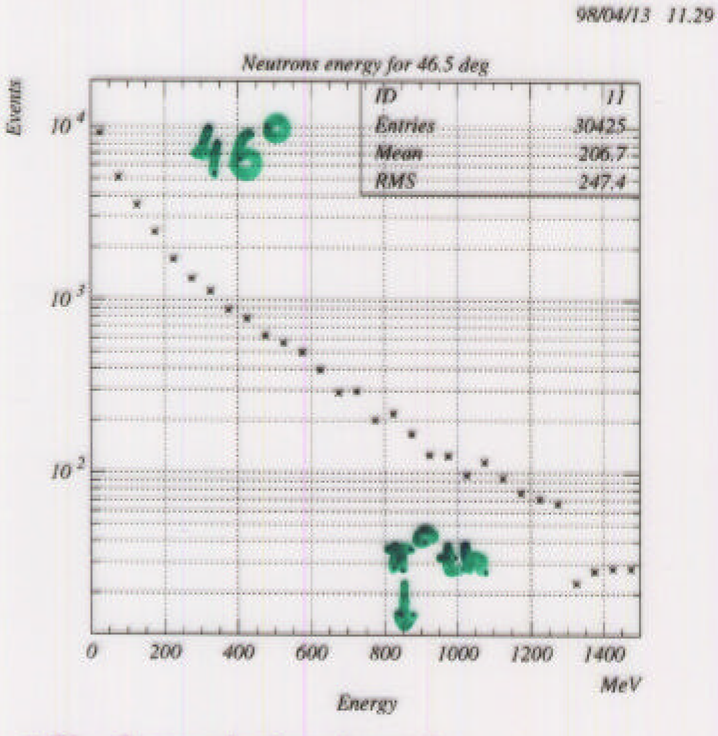


Neutral beam



Microbunched beam at 25 MHz
Large angle
Slow K_L to use TOF
10^{14} **p/spill** $\Longrightarrow 2.6 \times 10^8 K_L$
$4.2 \times 10^7 K_L$ **decays**

Measurenet of neutron and γ flux at 45° at BNL
Threshold = 10 MeV (n)→ 1.7×10^{-6} n/(p·μsr)
(γ)→ 1.0×10^{-6} γ/(p·μsr)



Proton intensity
10^{14} **p/spill**

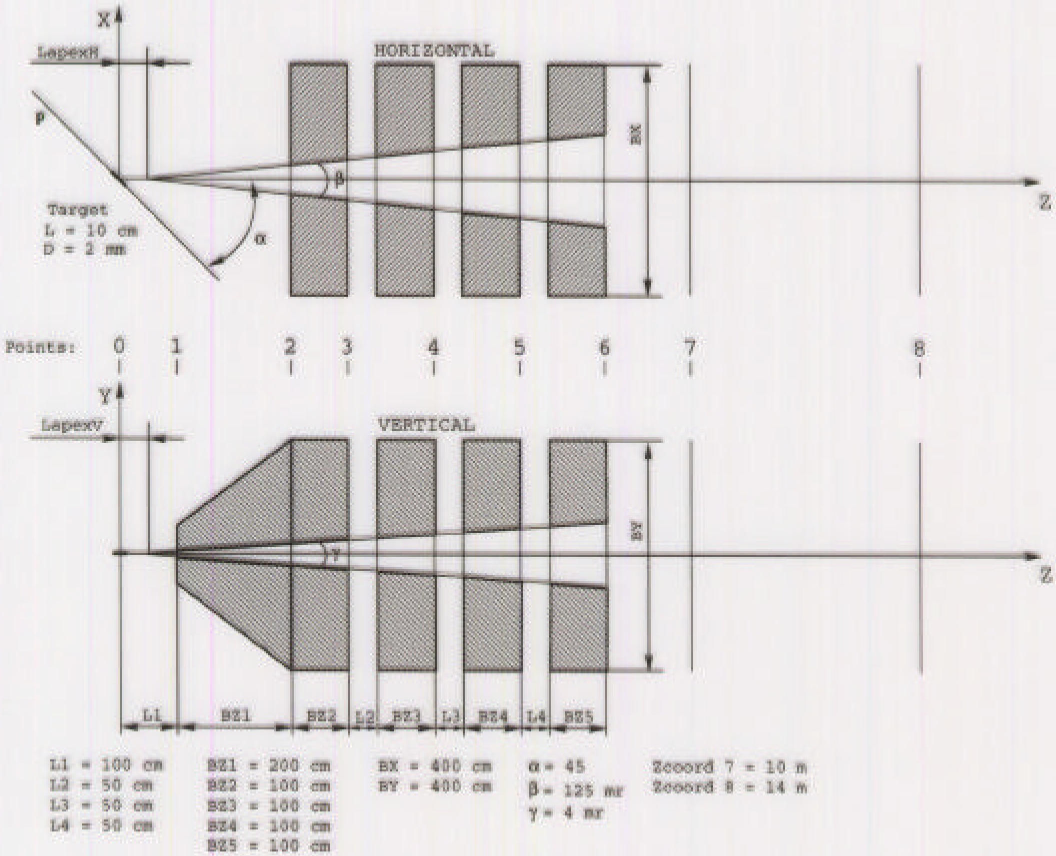
Neutron flux at 45°
8.3×10^{10} **n/spill** $E_n \geq$**10 M**
3×10^9 **n/spill** $E_n \geq$ **850 M**

Photon flux at 45°
$\sim 2 \times 10^{10} \gamma$**/spill** $E_\gamma \geq 10$ **M**

$\sim 1 K_L$ **decay/microbunch**
$\sim 2 \times 10^3$ **n/microbunch** (~ 70 **with** $E_n \geq 850$ **MeV**)
$\sim 0.5 \times 10^3$ γ**/microbunch**

Neutral beam

Filter of 70 Pb foils 1 mm thick



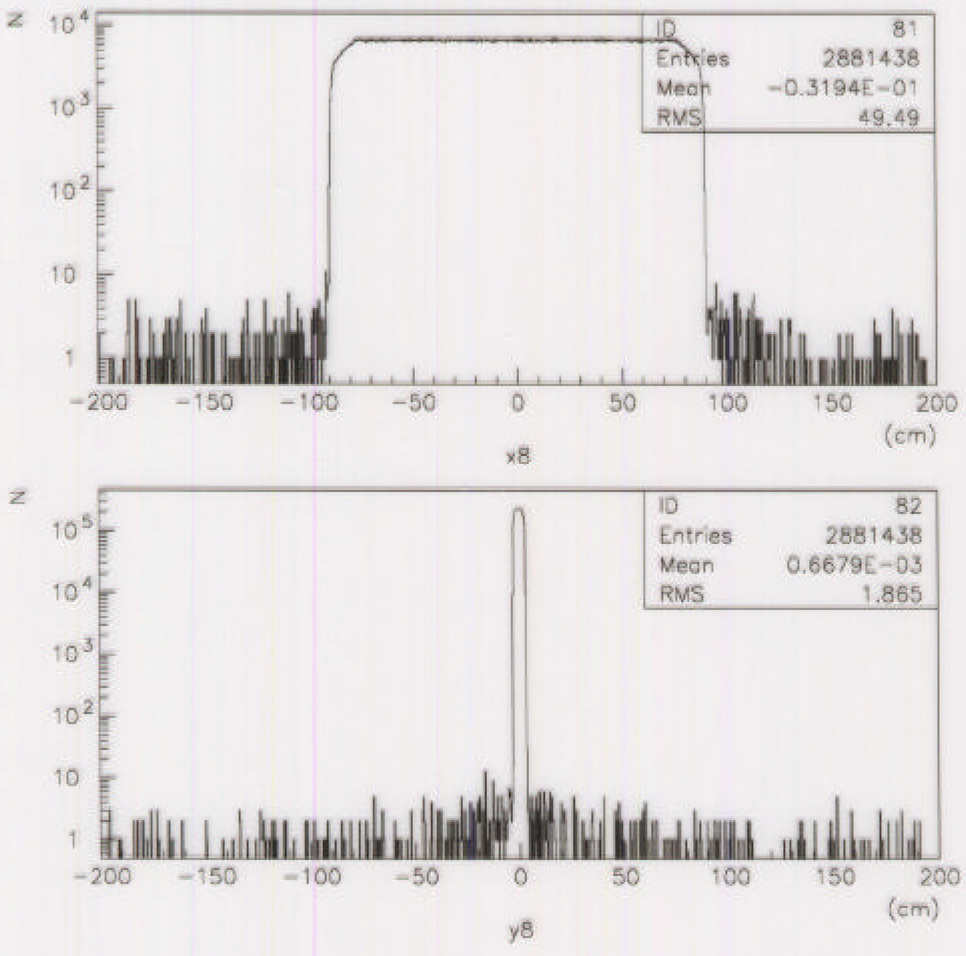
Vertical magnetic field 1.0 - 1.5 T

Reduction of photon flux by 150-200
Reduction of neutron flux by 30%
Kaon beam reduced by 30-40%

Neutral beam

MC based on experimental neutron spectra at 45°
reproduced the AGS-791/871 beam profile at
small angle

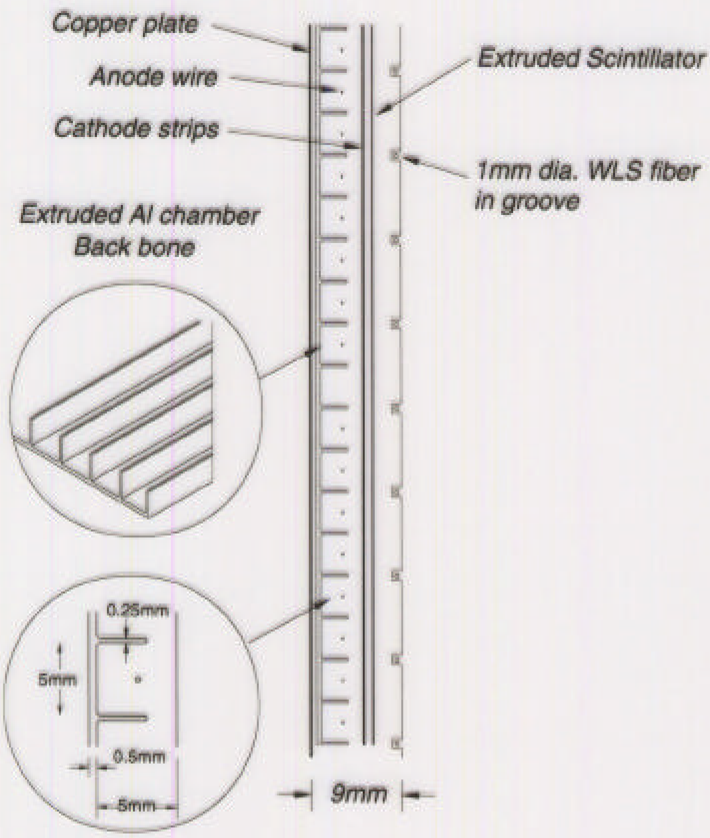
Beam profile at preshower (14 m from target)
Fraction of neutrons ($E_n \geq 10$ MeV) in halo $\sim 10^{-4}$



Expected neutron halo intensity $\sim (5-8) \times 10^6$ n/spill
0.1-0.2 neutron/microbunch

Preshower

photon converter 0.4 mm Cu
drift chamber cell 5 x 5 mm, 70 ns drift time
3mm extruded plastics with WLS readout
module 9 mm
60 modules provide $2X_0$
position resolution $\sim 150\mu m$
$\sigma_\theta = 24$ mr at $E_\gamma = 250$ MeV
$\sigma_\theta = 15$ mr at $E_\gamma = 450$ MeV

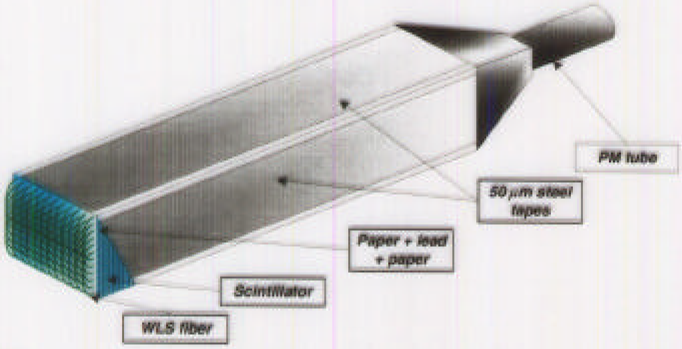


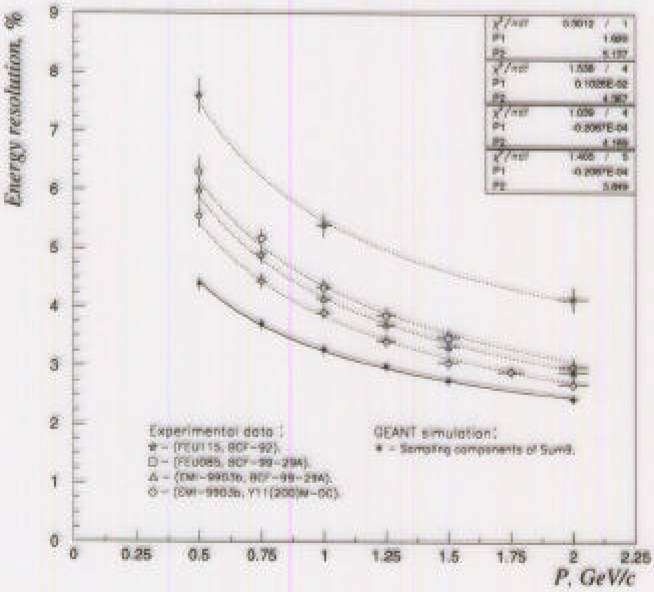
Calorimeter

- **Pb/scintillator**

240-300 layers (0.25-0.35)mm/(1.5-2.0)mm

beam test of 3x3 array $\sigma_E \leq 4\%/\sqrt{E}$

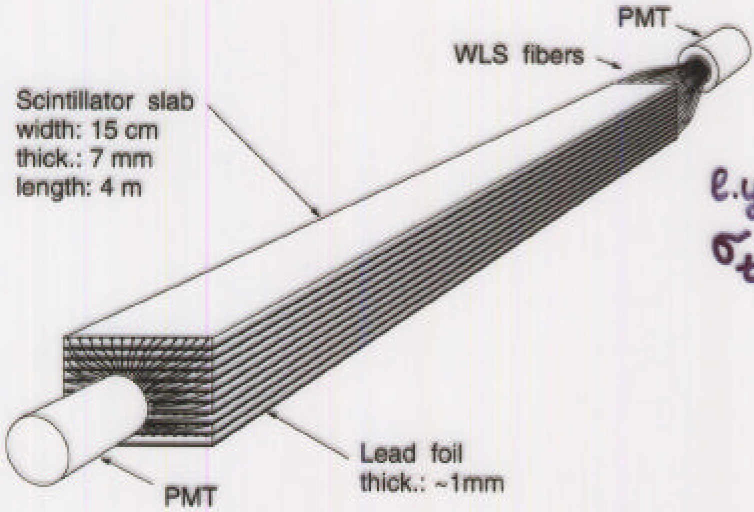




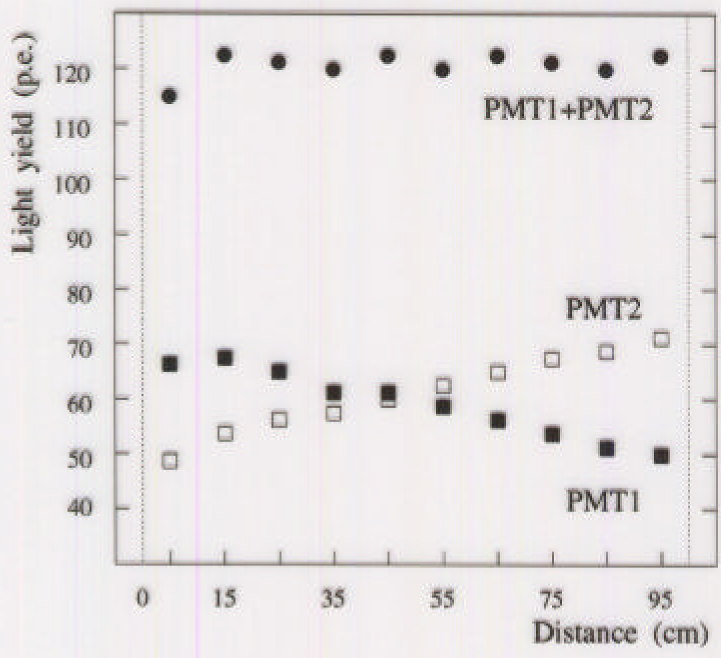
- **PbWO crystals**

$\sigma_E \simeq 1.5\%/\sqrt{E}$ **obtained in beam test of 3x3 array**

Barrel veto

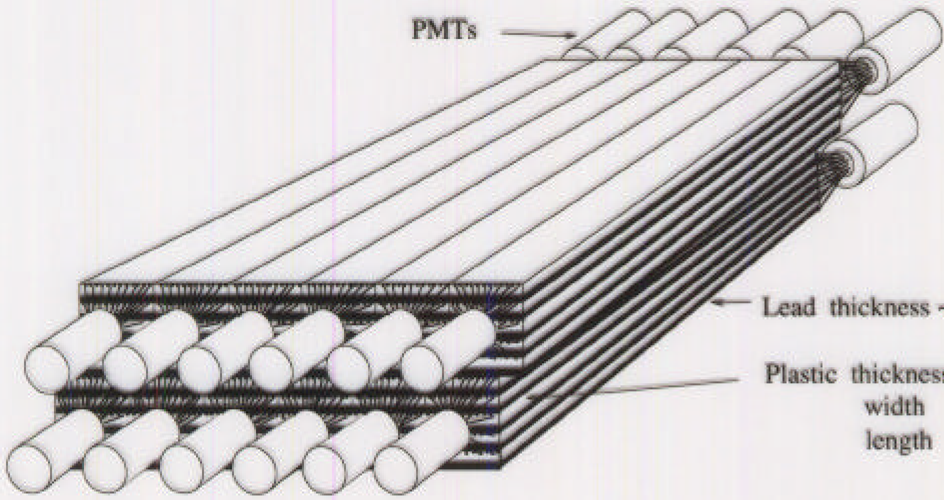


l.y. ~ 130 p.e./MIP
$\sigma_t = 350$ psec



Barrel veto

Element of the veto system



Number of the lead-plastic layers: 80 - 100.

Number of WLS fibers per a plastic slab : 14 - 20.

2 PMT per 10 - 15 scintillator slabs.

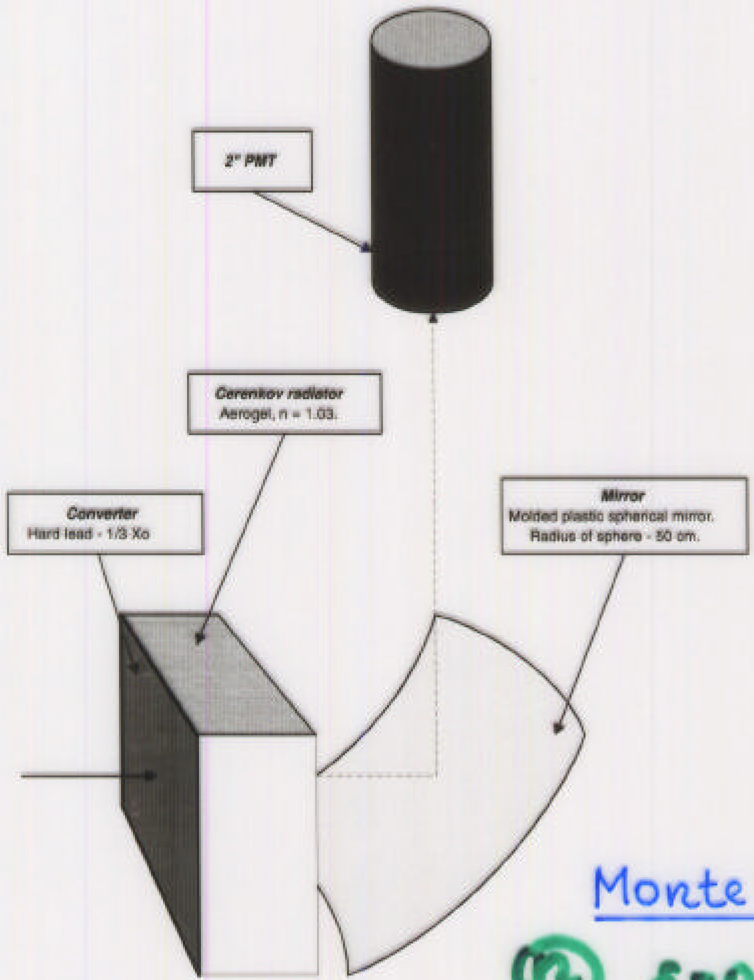
1 PMT views ~ 150 - 200 fibers.

Light yield in a single layer : ~ 18 - 20 p.e. per MIP.

Veto & calorimeter: $\sigma_E \sim (4-5)\%/\sqrt{E}$
$\sigma_\theta \sim$ **80 mrad**
$\sigma_t \sim 50ps/\sqrt{E}$

Catcher

background from $K_{\pi 2}$ with 1 photon in beam hole
$E_\gamma > 100$ MeV probability $\sim$ few$\times 10^{-3}$
$\epsilon_\gamma \sim 99\%$ needed
neutron flux ~ 70 n/microbunch ($E_n \geq 850$ MeV)
"neutron-blind" $\epsilon_n \leq 1\%$
beam photons $\sim 2 - 5\gamma$/microbunch $E_\gamma \geq 10$ MeV



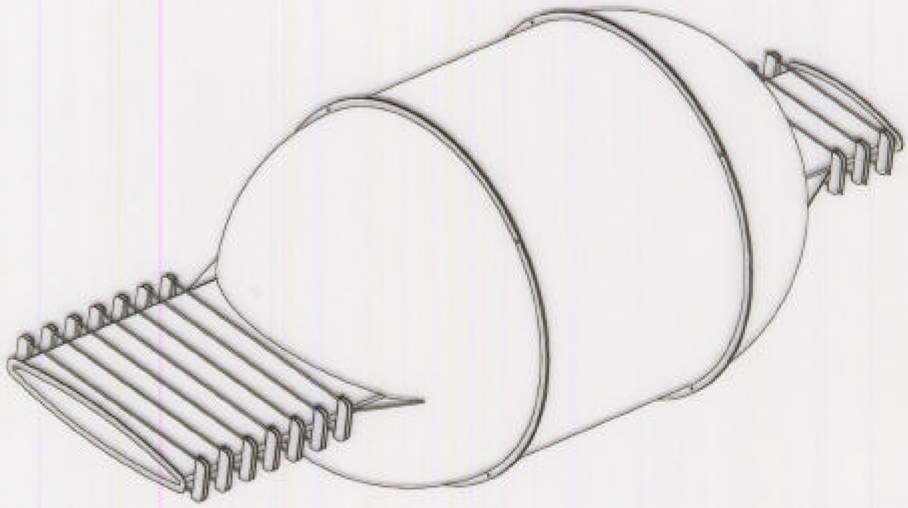
Monte Carlo

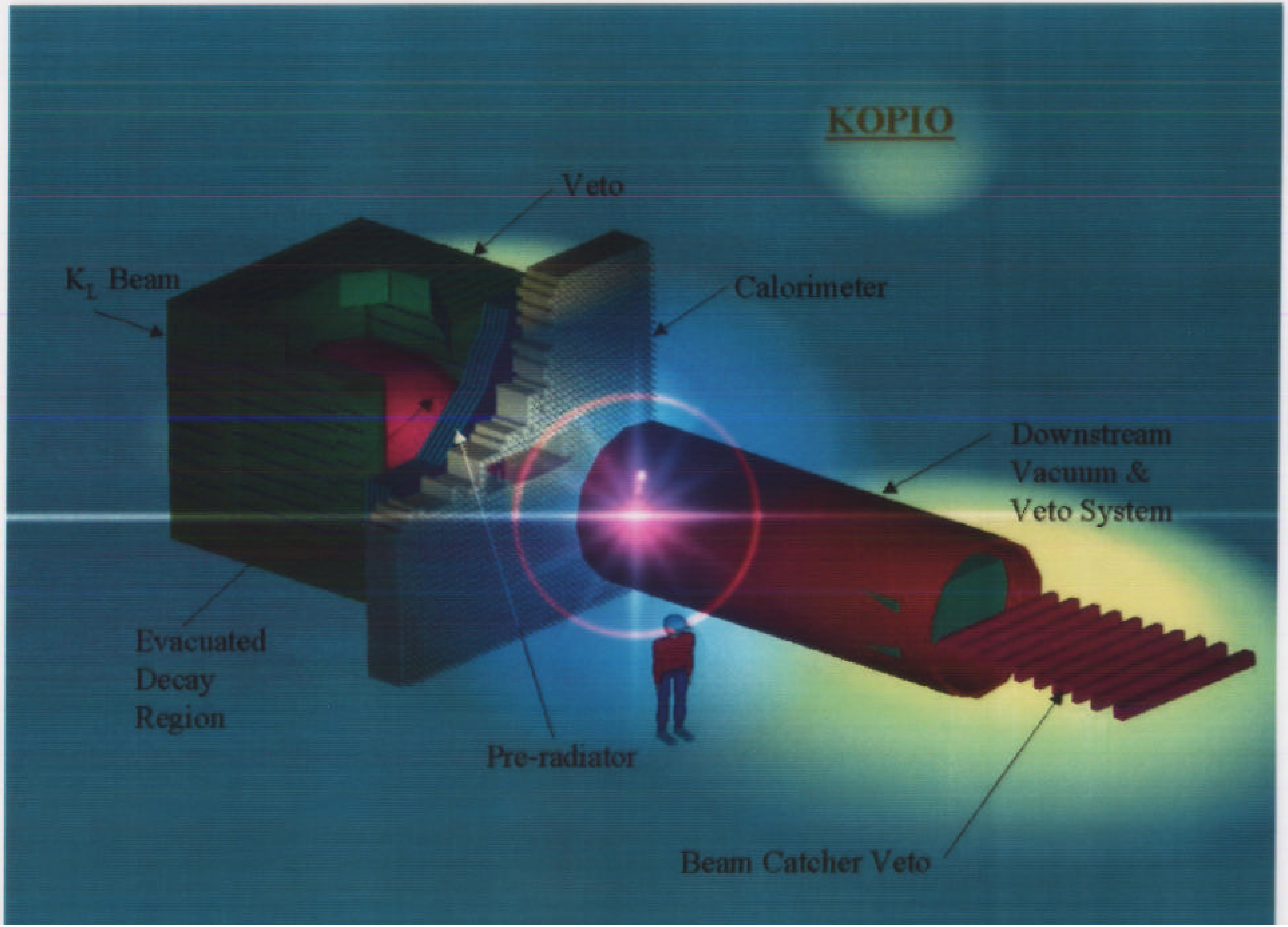
(n) ε=0.34% 1500
ε= 4% 3000

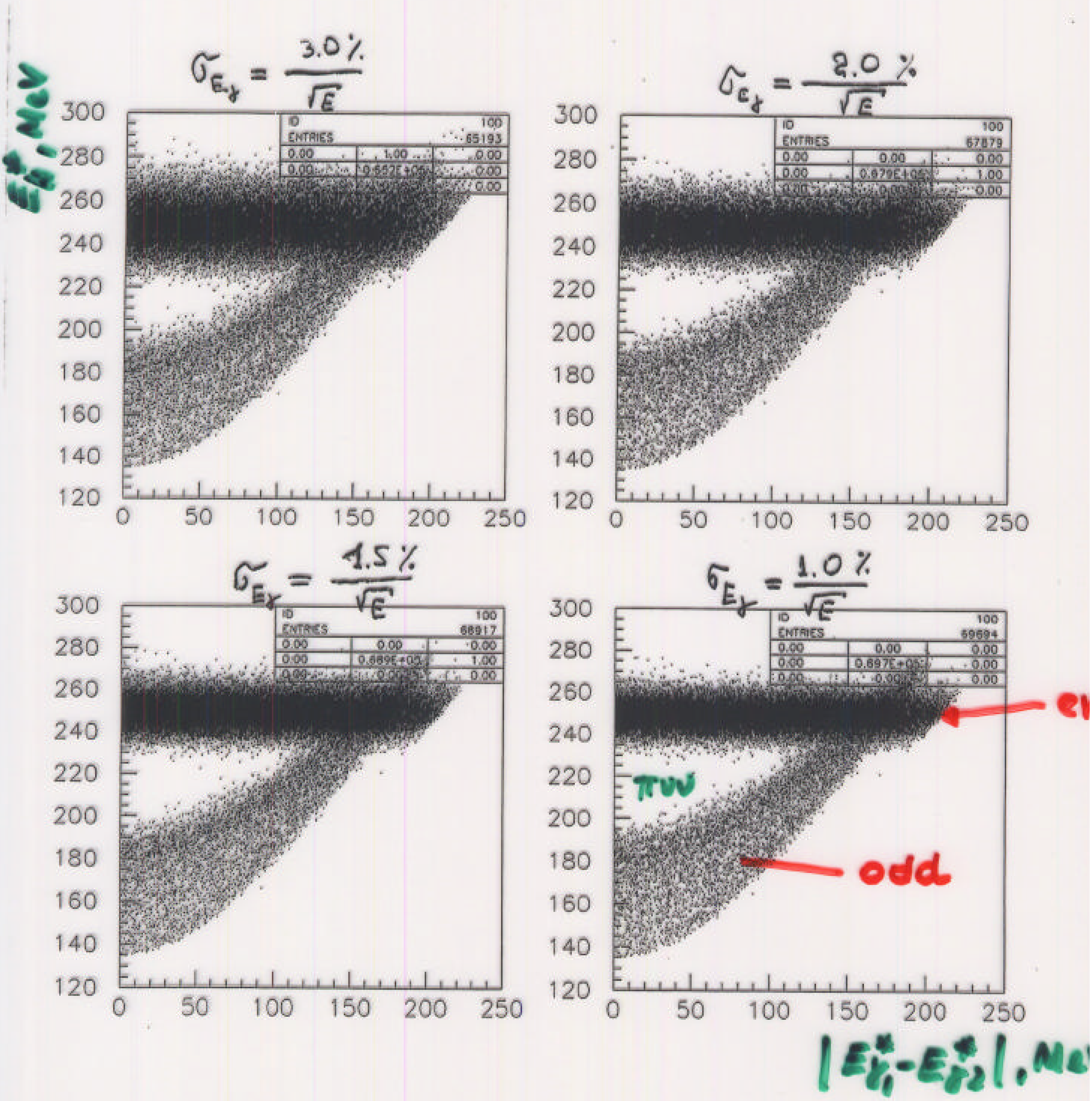
(γ) ε= 89% E_γ=100
ε= 95% E_γ=200
ε= 98.5% E_γ=500

Vacuum vessel

high vacuum $\sim 10^{-7}$ torr
Graphite/epoxy laminate 1.3 cm thick $\sim 0.05X_0$
diameter ~ 2.5 m




KOPIO
Veto
K_L Beam
Calorimeter
Downstream
Vacuum &
Veto System
Evacuated
Decay
Region
Pre-radiator
Beam Catcher Veto

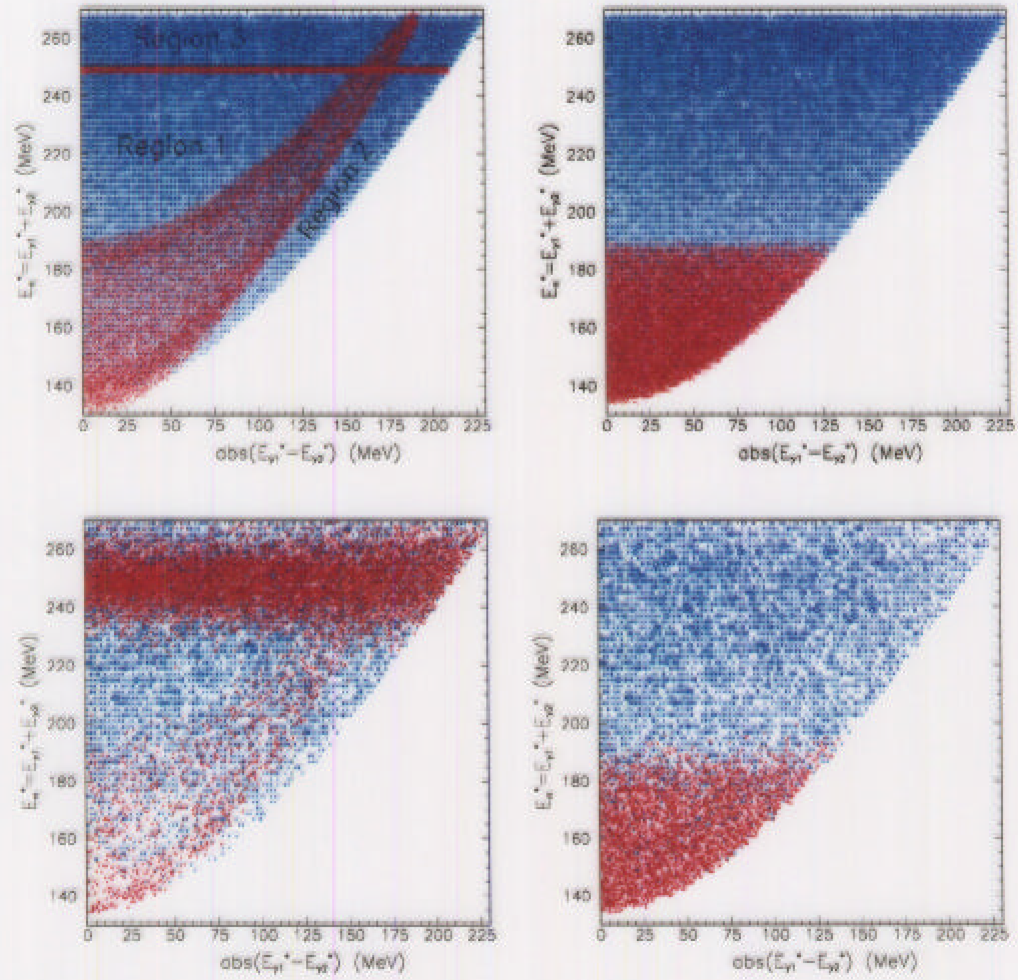


E^*_γ, MeV
$\sigma_{E_\gamma} = \frac{3.0\%}{\sqrt{E}}$
$\sigma_{E_\gamma} = \frac{2.0\%}{\sqrt{E}}$
$\sigma_{E_\gamma} = \frac{1.5\%}{\sqrt{E}}$
$\sigma_{E_\gamma} = \frac{1.0\%}{\sqrt{E}}$
ID 100
ENTRIES 65193
ENTRIES 67879
ENTRIES 68917
ENTRIES 69694
πνν
odd
ev
$|E^*_{\gamma 1} - E^*_{\gamma 2}|$, MeV

Background suppression

K_L **center of mass**

$\pi^0\nu\nu$ **and** $\pi^0\pi^0$ $\qquad$ $\pi^0\nu\nu$ **and** $\pi^+\pi^-\pi^0$

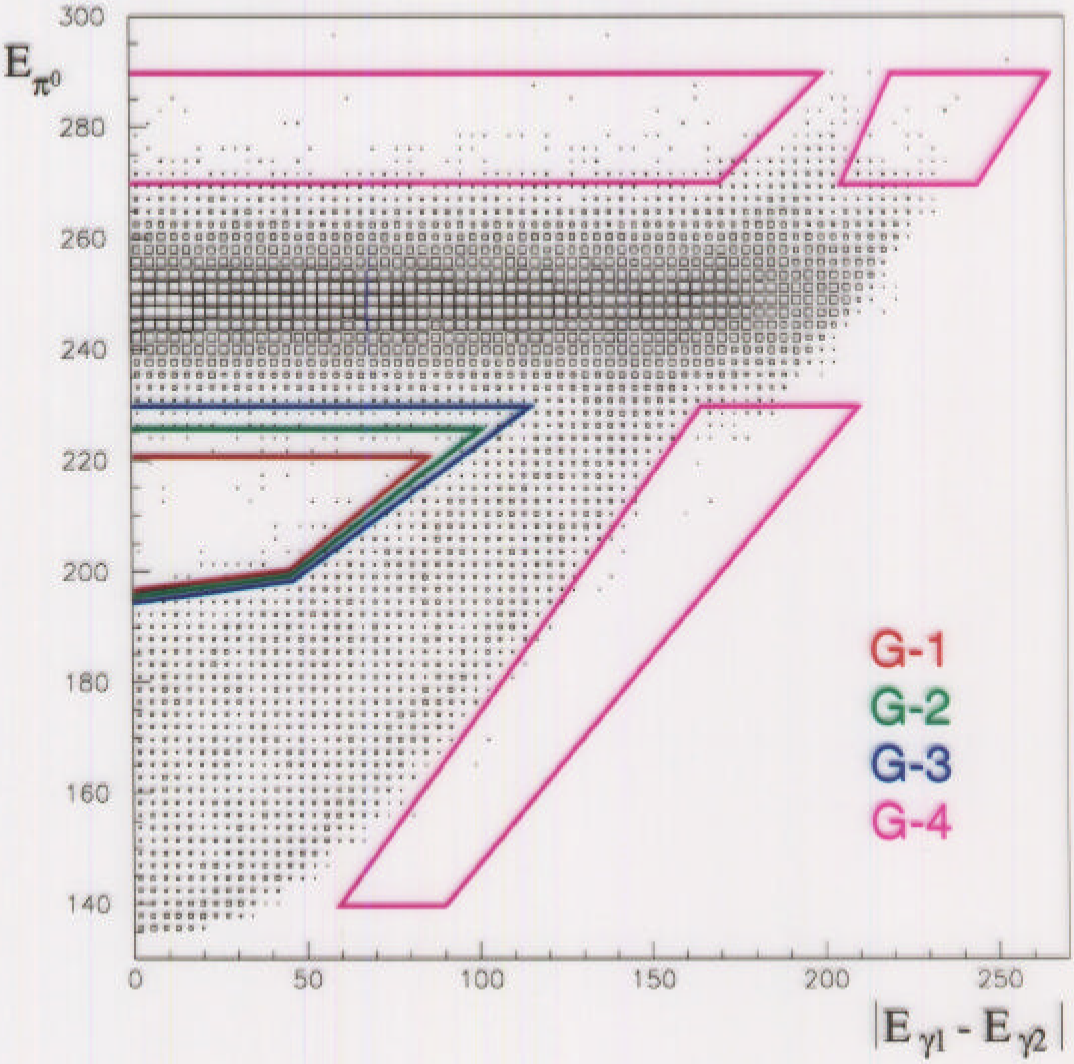


⇑

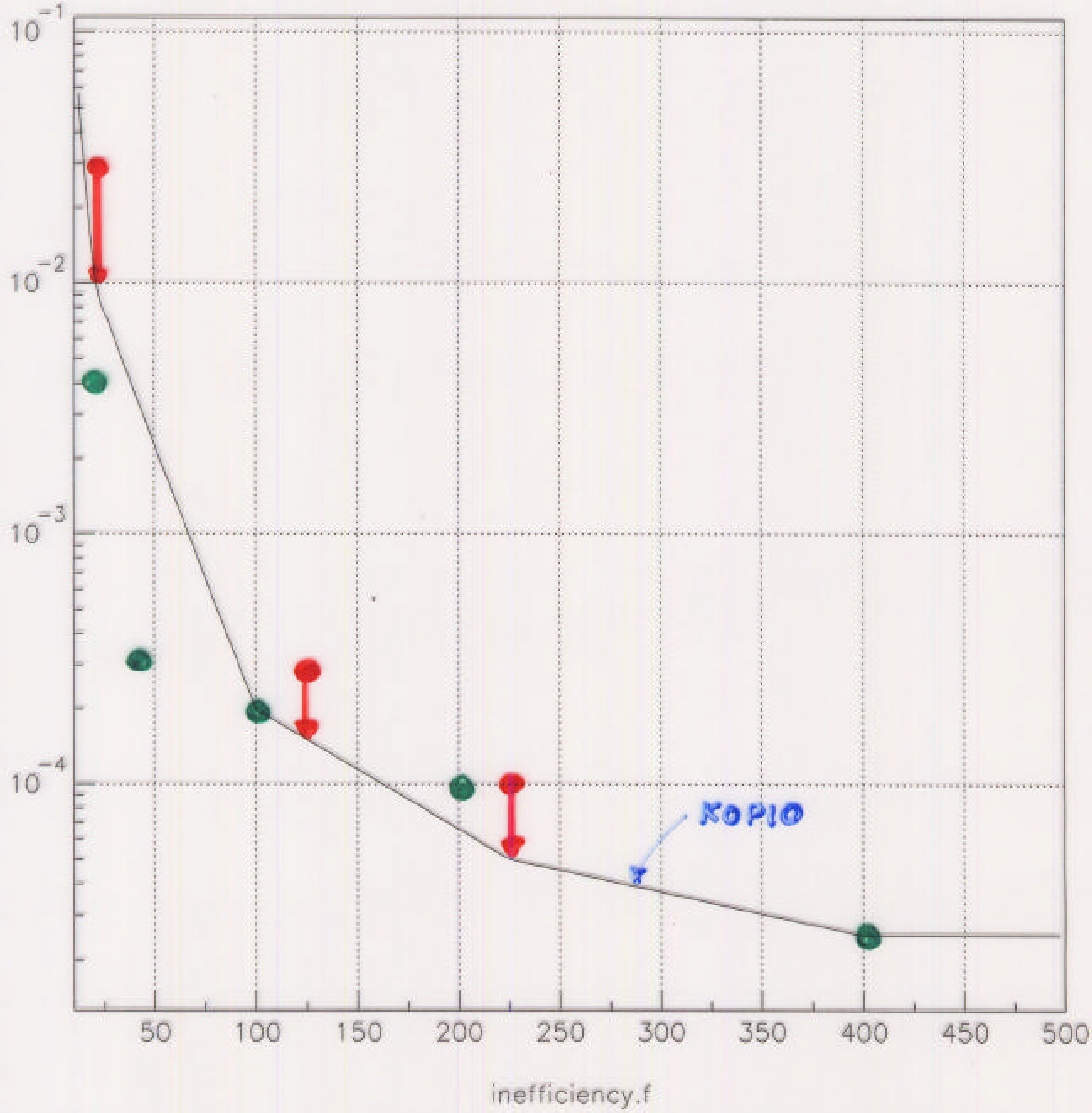
photon energy resolution = $3.5\%/\sqrt{E}$

Background suppression

even and odd $K_{\pi 2}$ backgrounds
$\pi^0, \gamma_1, \gamma_2$ energies in K_L center of mass system

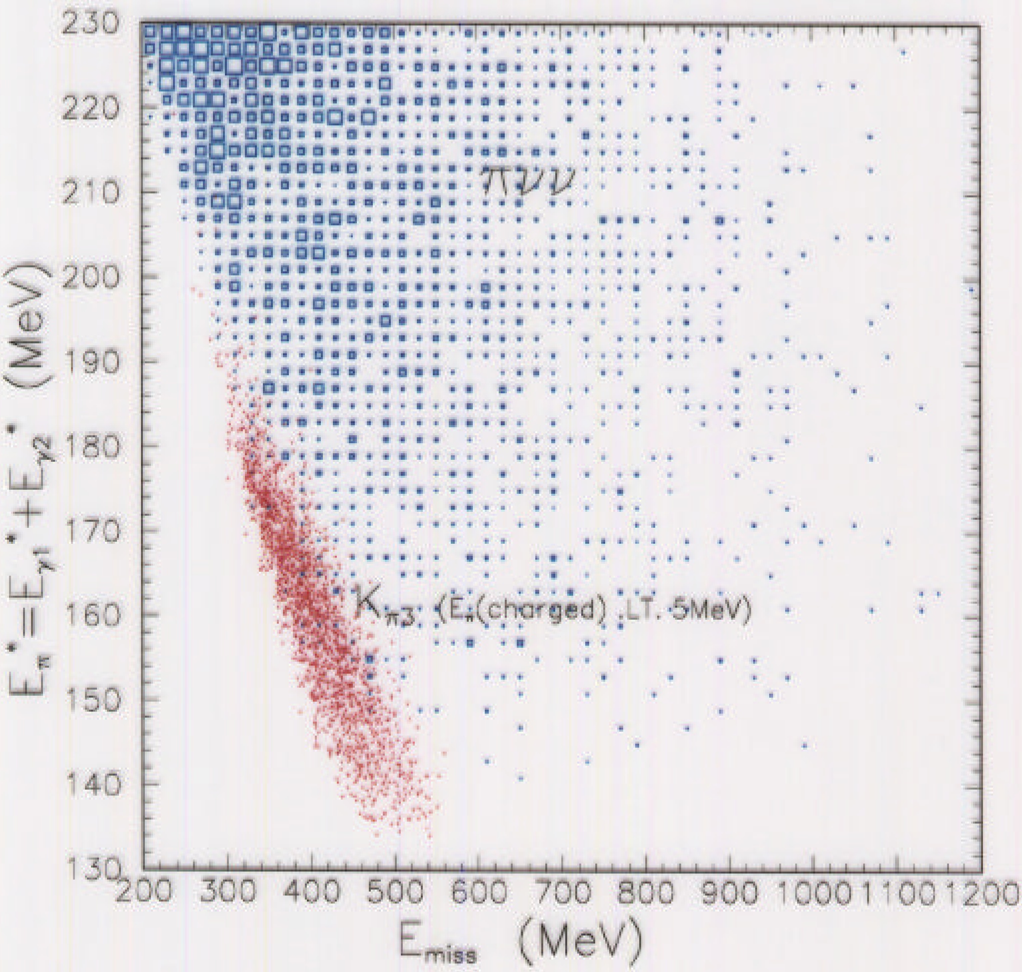


Photon detection inefficiency



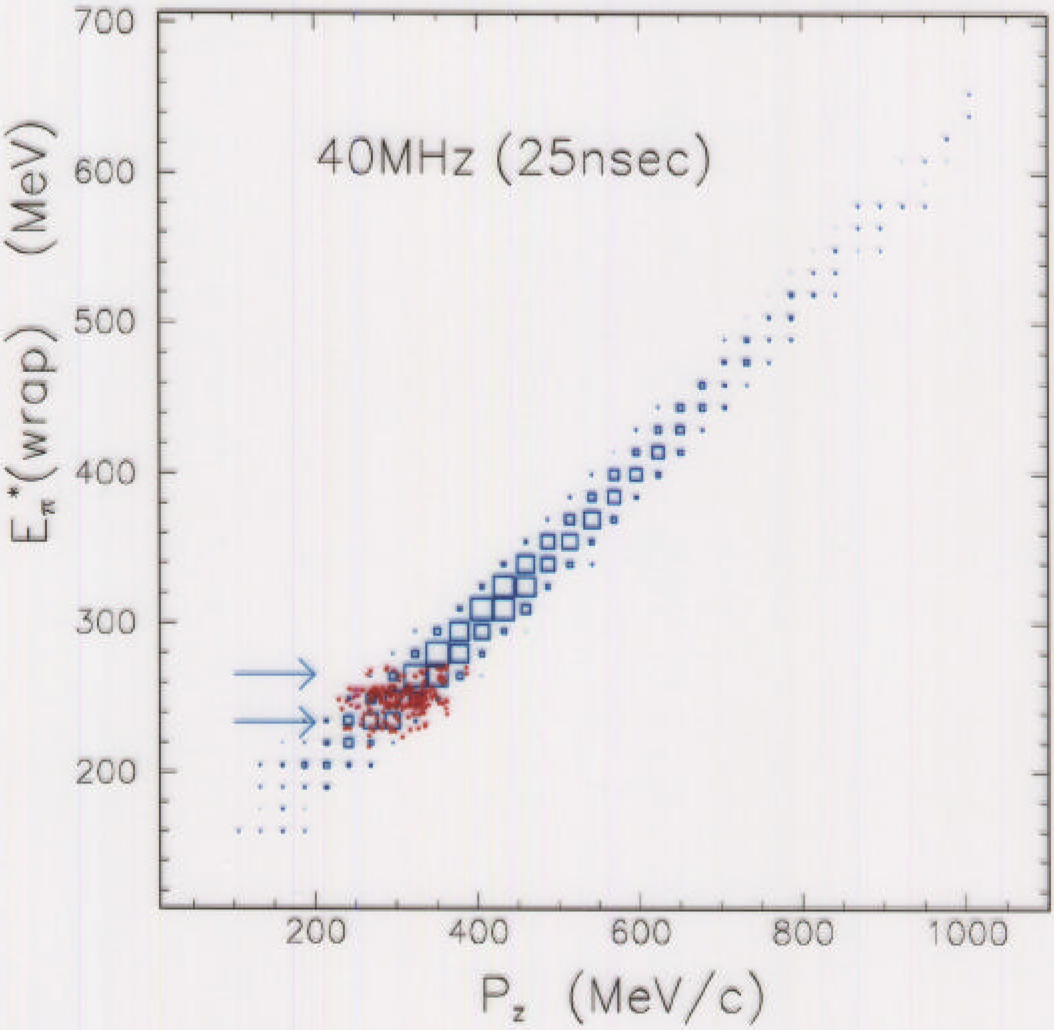
$K_{\pi3}$ background

$K_{\pi3}$ background when E_{π^+} less than 5MeV

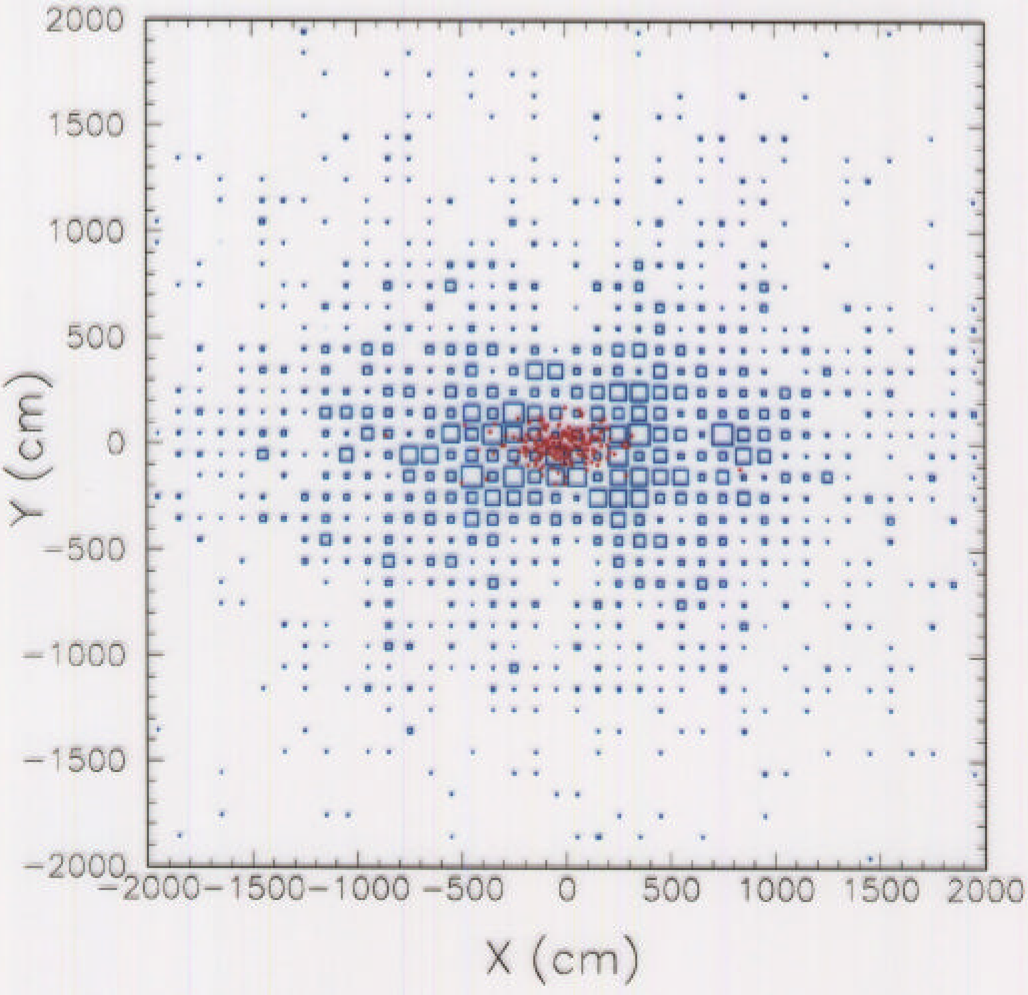


Wrap-around

Background from $K_{\pi 2}$ of slow K_L's
$K_{\pi 2}$ decays from previous microbunch
$E^*_\pi \simeq 240 - 250$ MeV
$K_{\pi\nu\nu}$ decays $E^*_\pi \geq 250$ MeV



$K_{\pi2}$ in catcher



Open beam hole (no catcher) $\rightarrow$ $\pi\nu\nu$ *acceptance* $\searrow$ *20%(30%)*

factor 25(50) $K_{\pi2}$ *rejection*

Acceptance for $K_L^0 \to \pi^0 \nu\nu$

Requirement	Acceptance
Z fiducial region and P_K	0.58
Solid angle	0.33
Photon conversion probability	0.50
Invariant mass of π^0	0.73
Wrap-around/$K_{\pi 3}$ low energy	0.73
E_π^*	0.31
Photon veto	1.0
Missing energy	0.91
E_π^* vs $\lvert E_{\gamma 1}^* - E_{\gamma 2}^* \rvert$	0.9
Acceptance	**0.012**

$N_K =$
$(4.2 \times 10^{-7} K_L$ **decays/spill**$) \cdot 0.57($**1 decay** $) \cdot (6.1 \times 10^6$ **spills**$)$
$\sim 1.5 \times 10^{14}$ **decays**

$N_{\pi\nu\nu} = N_K \cdot$ (**Acceptance**)$\cdot B$
$= (1.5 \times 10^{14}) \cdot (0.013) \cdot (3 \times 10^{11} \simeq$ **65 events**

$K_L^0 \to \pi^0\pi^0$ background

Requirement	Even pairing	Odd pairing
γ combinations	2	4
Z fiducial region and P_K	0.57	0.59
Solid angle	0.34	0.29
Photon conversion probability	0.50	0.50
Invariant mass of π^0	0.73	0.09
Wrap-around/$K_{\pi3}$ low energy	0.68	0.78
E_π^*	0.016	0.27
Photon veto	8.3×10^{-8}	2.9×10^{-8}
Missing energy	0.57	0.84
E_π^* vs $\lvert E_{\gamma1}^* - E_{\gamma2}^* \rvert$	0.82	0.52
Acceptance	5.8×10^{-11}	8.1×10^{-11}

Total $K_{\pi2}$ acceptance 1.4×10^{-10}

$\Downarrow$

$N_{K_{\pi2}} = 24$ **events**

Signal and backgrounds

Process	Events	
$K_L^0 \to \pi^0 \nu \nu$	65	
$\underline{\pi^0 \pi^0}, \pi^0 \pi^0 \pi^0, \pi^0 \gamma\gamma$	24	
$\pi^+ \pi^- \pi^0$	9	•
$\underline{\pi^\pm e^\mp \nu}, \pi^\pm \mu^\mp \nu$	0.1	•
$\pi^\pm l^\mp \nu \gamma$	1	•
$\Lambda \to \pi^0 n$	0.03	
Interactions $n \to \pi^0$	0.5	
Accidentals K_L, γ, n	1.5	
Total background	$\sim$37	

Status and Plan

R & D 2001-2002

- Beam test of calorimeter prototype
  "shashlyk" and PbWO crystals
- Beam test of veto prototype
- Beam test of preshower segment
- Catcher study
- Test of vacumm vessel scale model
- Further beam bunching study

Beginning of beam line construction 2002

Beginning of detector construction 2002 - 2003

Engineering run 2004 - 2005

Conclusion

$K_L^0 \to \pi^0 \nu\nu$ *best way to measure* η

Comlementary to B system

KOPIO virtues

- **low energy K_L's**
- **time of flight**
- **kinematic reconstruction**

KOPIO goal: about **60** events with $S/B \sim 2$