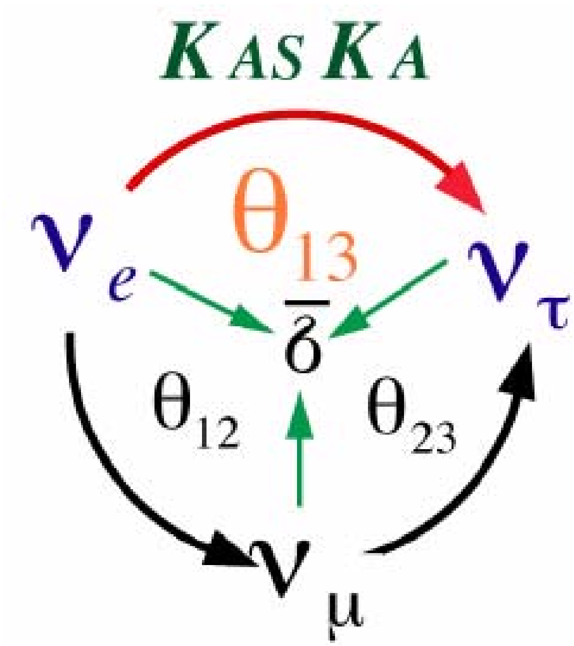
KASKA Experiment



US-Japan seminar on Double beta decay and Neutrino mass

on

Sep.17th ,2005@Hawaii

K.Nitta,

Tokyo Institute of Technology

For

KASKA Collaboration

Contents

- Introduction to reactor neutrino experiment
- KASKA experiment
- Current R&D status
  - Boring test
  - Prototype detector
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- Summary

KASKA Collaboration

- Niigata Univ.
- Tohoku Univ.
- Tokyo Institute of Technology (TIT)
- Miyagi Univ. of Education
- KEK
- Kobe Univ.
- Tokyo Metropolitan Univ. (TMU)
- Hiroshima Institute of Technology

8 Institutes

~30 people

Neutrino Matrix

- Maki-Nakagawa-Sakata mixing matrix
  - If neutrinos are massive particles, it is possible that the mass eigenstates and the weak eigenstates are not the same:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \overbrace{\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}}^{U_{MNS}} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

ν_e, ν_μ, ν_τ : flavor eigenstate

ν_1, ν_2, ν_3 : mass eigenstate

$$= \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{\text{From SK(atm),K2K}} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{From Solar,KamLAND}} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Θ_{13} Limit: mixing matrix components

- Experimental upper limit by CHOOZ
  - $\sin^2 2\theta_{13} < 0.15$ @ $\Delta m^2_{13} = 2.5 \times 10^{-3} eV^2$

$$|U_{MNS}| \sim \begin{pmatrix} 0.7 & 0.7 & < 0.2 \\ 0.7 & 0.5 & 0.7 \\ 0.5 & 0.5 & 0.7 \end{pmatrix} \leftarrow \sin\theta_{13} e^{i\delta_l}$$

$\sin\theta_{13} < 0.2$,
δ_l: totally unknown CPV phase

$\Delta m^2_{13} = \Delta m^2_{12} + \Delta m^2_{23} \sim \Delta m^2_{23}$

- Last unknown lepton sector is Θ_{13}

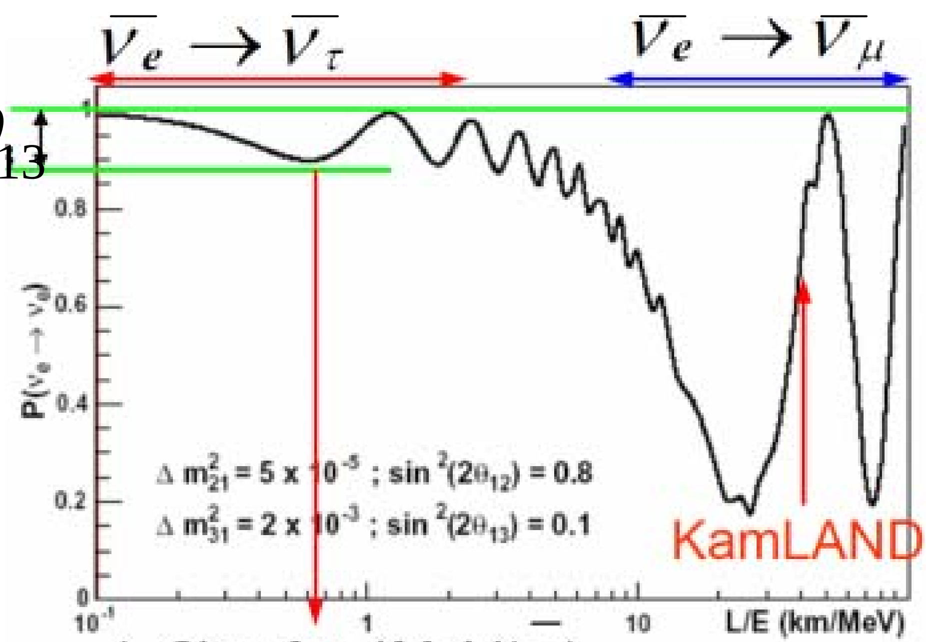
- Result of $\sin^2 2\theta_{13}$ measurement will indicate the possibility of CPV phase(δ_1) measurement

Measurement of θ$_{13}$ by reactor

- ν_e disappearance: survival probability (P_{ee})

$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}{}^2 L}{4E_\nu}\right) - \underbrace{\cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{21}{}^2 L}{4E_\nu}\right)}_{O(10^{-3})}$$

$\sin^2 2\theta_{13}$



1~2km for 4MeV($\bar{\nu}$)

$O(10^{-3})$

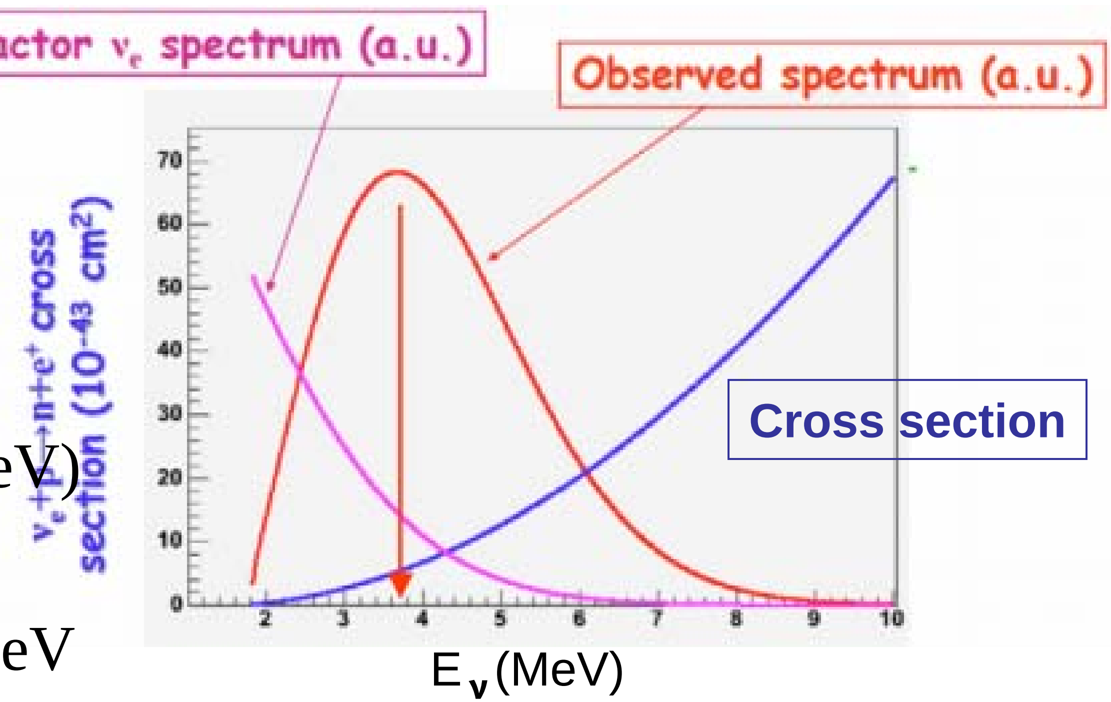
Measure this small deficit
→This is pure θ$_{13}$ measurement
($\Delta m^2_{12} << \Delta m^2_{23}, \Delta m^2_{13}$)

Baseline~O(1km)
→matter effect negligible

Need 1% accuracy for the measument

Neutrino spectrum from reactor

- ν s are produced by β-decay from the fission products
- One nuclear fission produces 6 $\bar{\nu}_e$ in average
- 1GW reactor emits ~6×10^{20} $\bar{\nu}_e$ /sec
- 2.5% accuracy of E_ν spectrum by β ray from fission products data



- Detection method

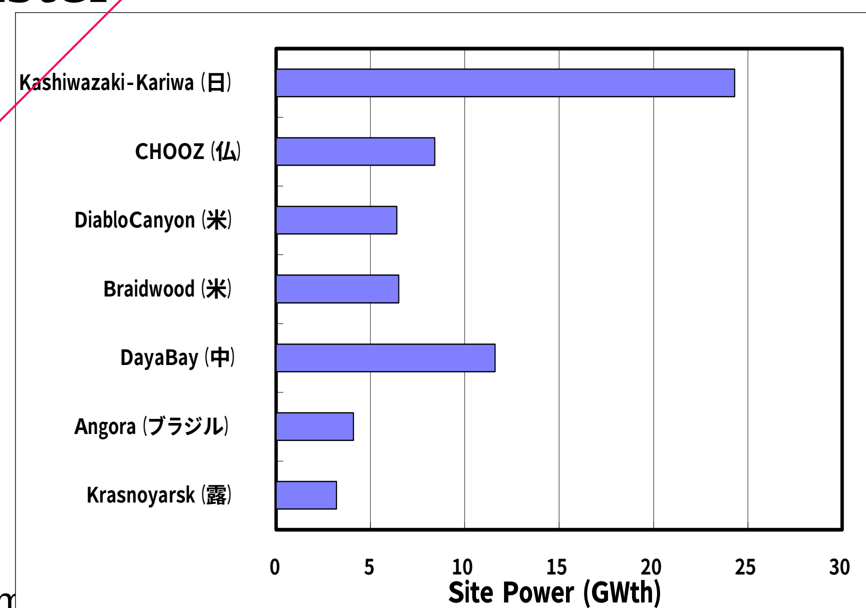
$\bar{\nu}_e + p \to e^+ + n$ ($E_e = E_\nu - 1.8$MeV)

$e^+ + e^- \to 2\gamma$ (0.511MeV)

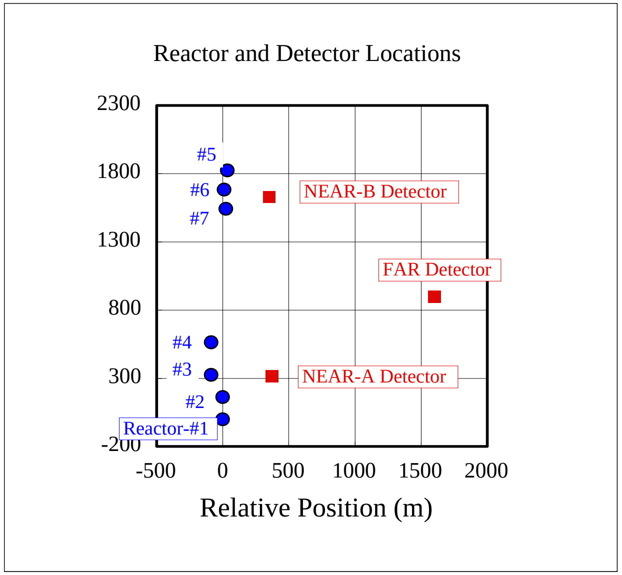
$E_{signal} = E_\nu - 0.8\text{MeV} > 1.0\text{MeV}$

KASKA experiment

- **Ka**shiwazaki –**Ka**riwa nuclear power station
  - Largest power in the world (24.3GW)
  - 7 reactors in two cluster (3+4)

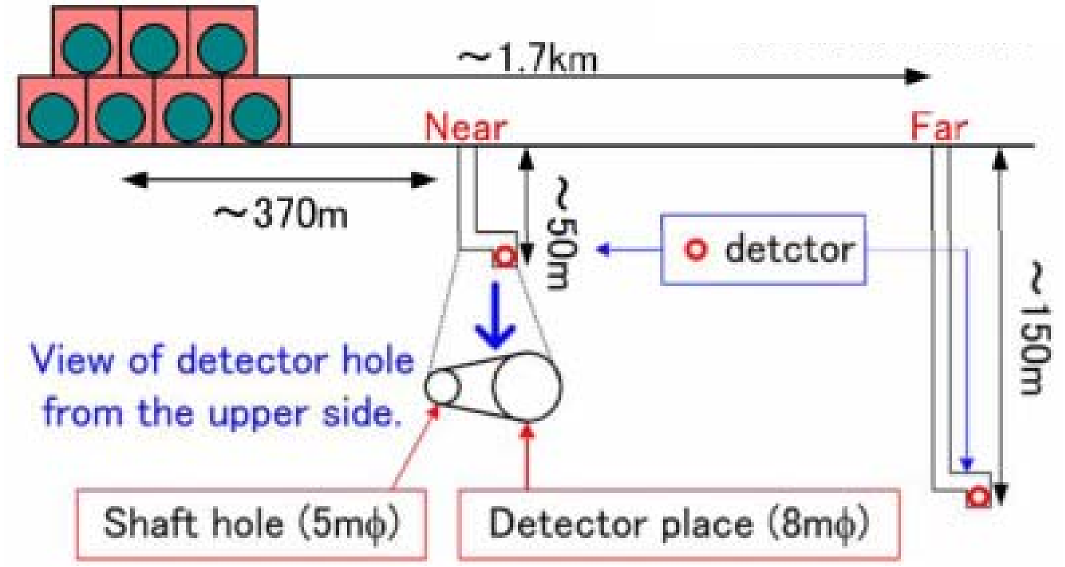


Geometry of KASKA experiment



- Two near detectors: ~400m (~50m depth)
- One far-detector:1.7km (~150m depth)

Location of far-detector is optimized by full oscillation



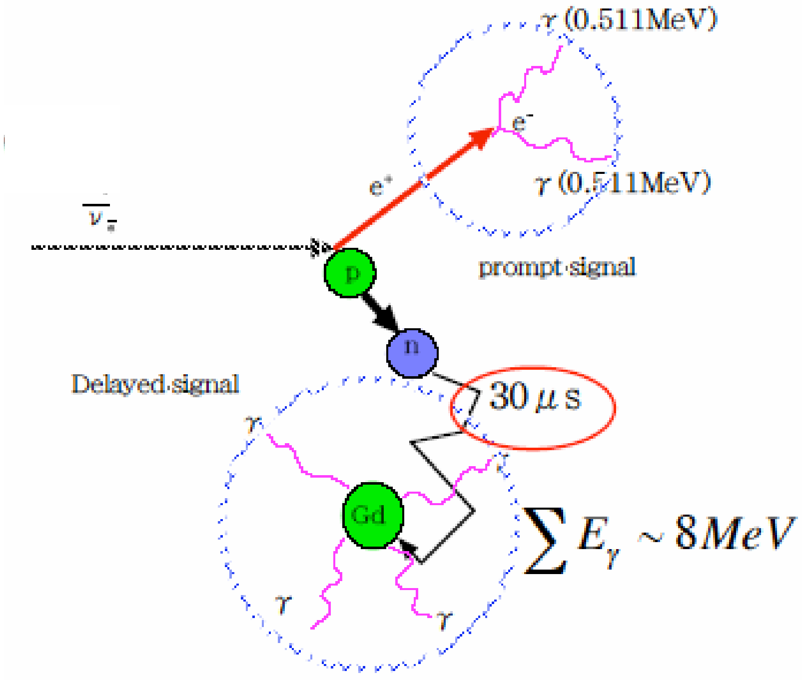
Detection method of anti-neutrino

- Absorption by proton via inverse β-decay

$$\bar{\nu}_e + p \rightarrow n + e^+$$

$$e^+ + e^- \rightarrow 2\gamma \quad (E = E\nu - 0.8\text{MeV})$$

$$n + Gd \rightarrow Gd' + \gamma s \; (\Sigma E_\gamma \sim 8\text{MeV})$$

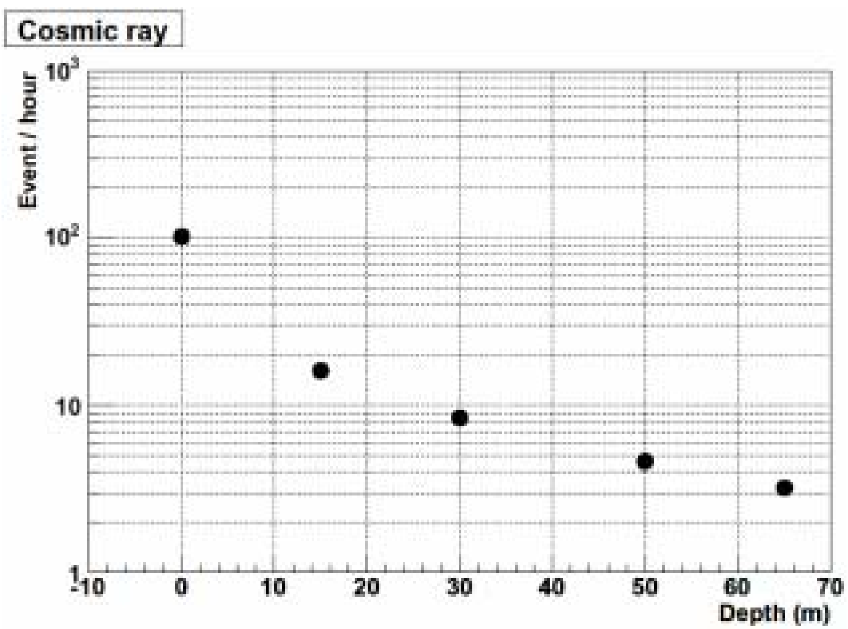


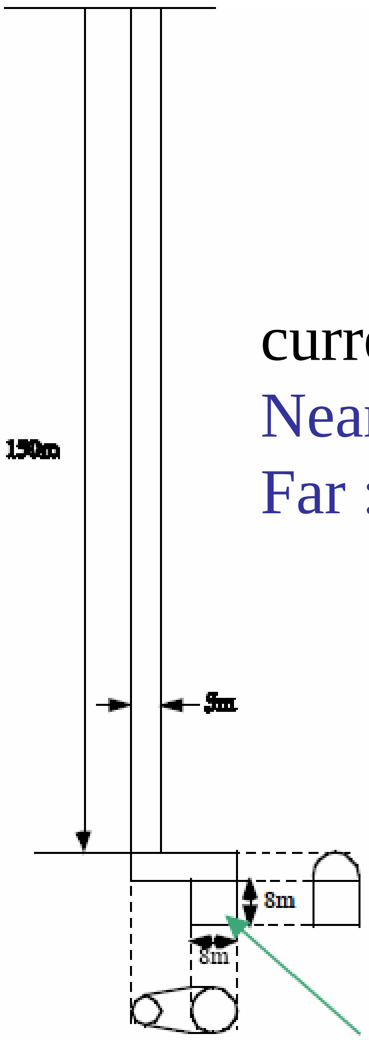
Delayed gammas emit after ~30 μ sec
→ ν can detected using delayed coincidence

Delayed coincidence can drastically reduce the background

Detector under the ground

- Shaft hole is designed
  - To reduce cosmic ray backgrounds
  - Already measured by boring test
  - Shaft hole has horizontal tunnel

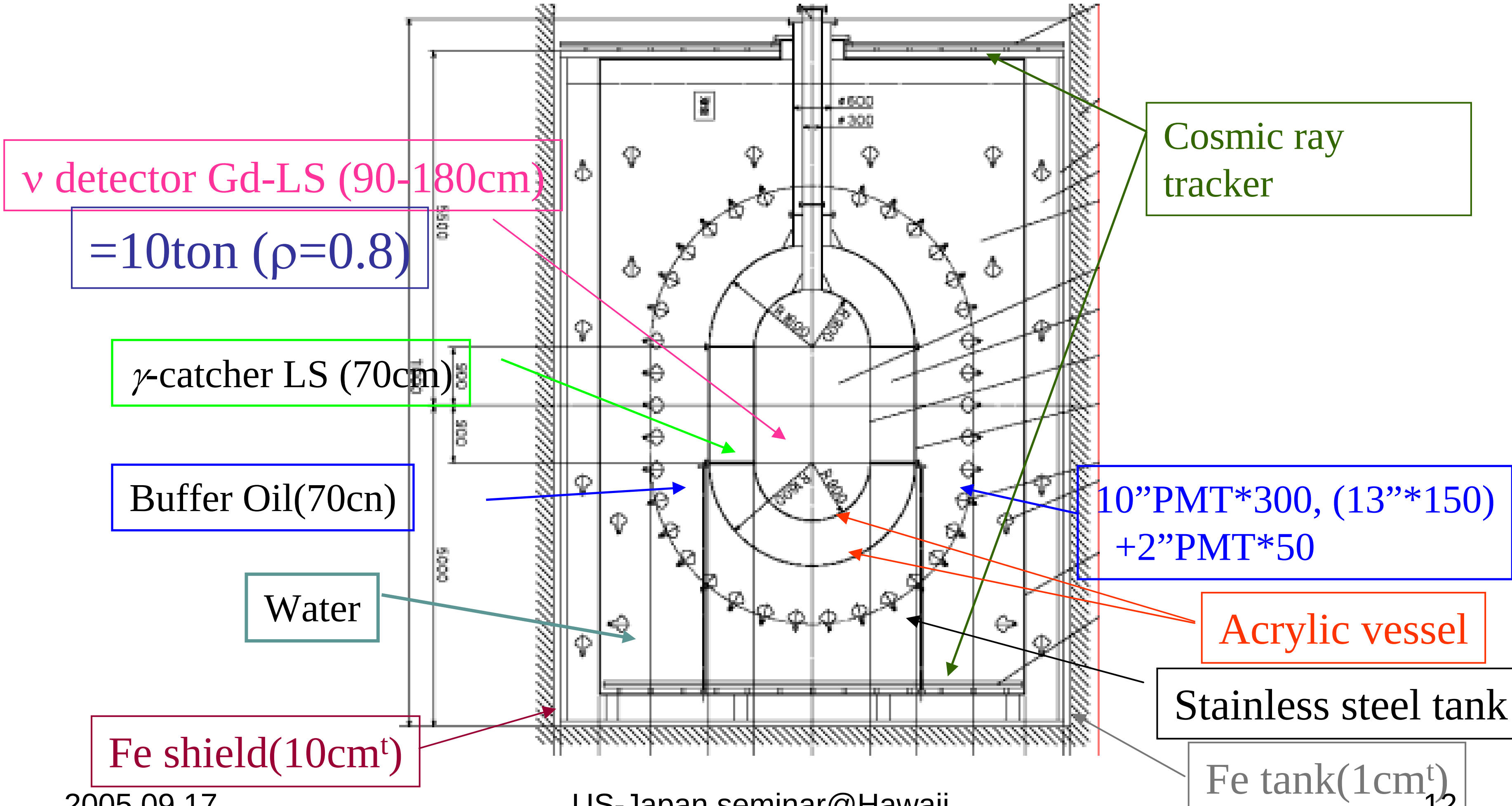




current design
Near : ~100Hz
Far : ~10Hz

KASKA Detector

- Cylindrical detector



Systematic errors

efficiency related

selection	CHOOZ	KASKA
positron energy	0.8%	<0.1%
positron position	0.1%	-
neutron capture	1.0%	<0.5%
capure energy containment	0.4%	<0.4%
neutron position	0.4%	-
neutron delay	0.4%	<0.2%
positron-neutron distance	0.3%	-
neutron multiplicity	0.5%	-
number of protons	0.8%	<0.5%
Combined	1.76%	<0.85%

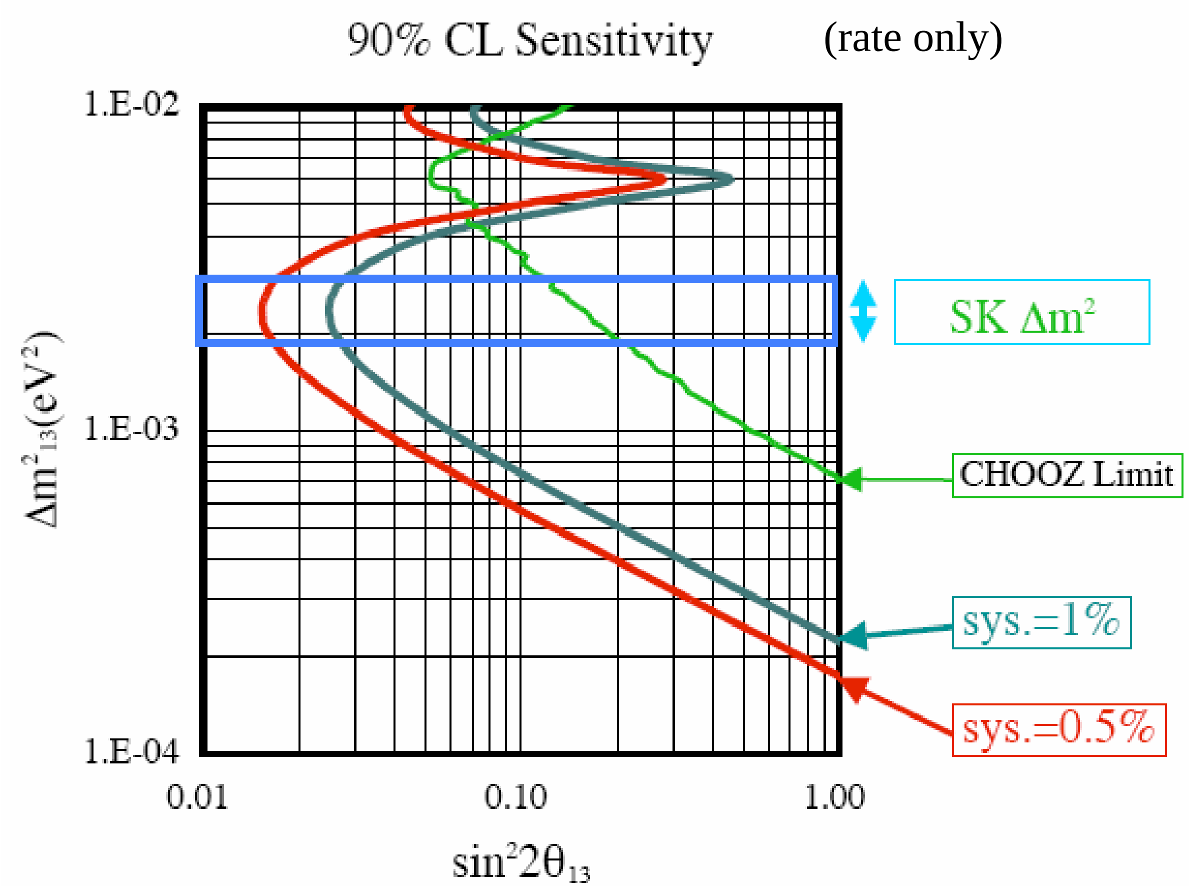
+ ν flux + BKG

parameter	CHOOZ	KASKA
Reaction Cross section	1.9%	-
detection efficiency	1.76%	<0.85%
reactor power	0.7%	-
energy released per fission	0.6%	-
baseline difference	-	<0.2%
background	0%	<0.5%
combined	2.7%	<1.0%

Sensitivity

Expected event rate @ far detector : 50,000/3years

1,200,000events/3years @ near detector



σ_{stat} ~ 0.5%

2.8% for CHOOZ

σ_{sys}<1%

2.7% for CHOOZ

σ sys: 0.5%,

→ $Sin^2 2\theta_{13}$~0.015

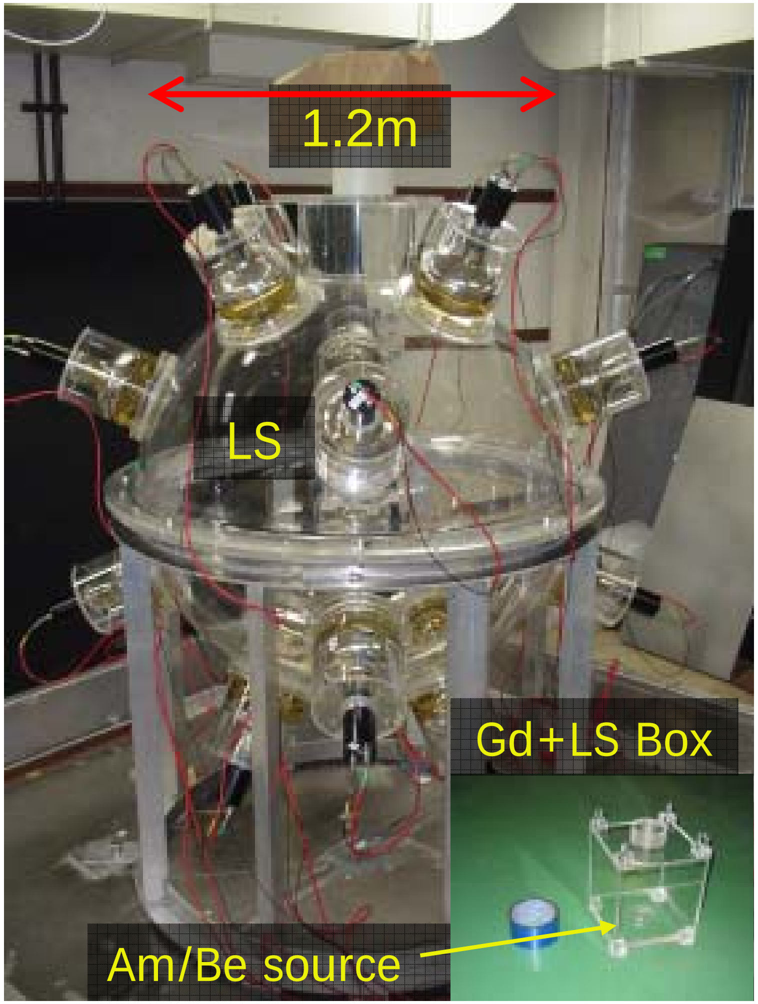
Present status of KASKA R&D

- R&D budgets have been approved in JFY2004~2005
  - Prototype detector
  - Boring study at near-B site
  - Electronics development
  - LS developments (another budget 2005-2006)
  - Detector and Shaft hole design study
  - Cosmic-ray detector development (2005-2006)

Prototype Detector

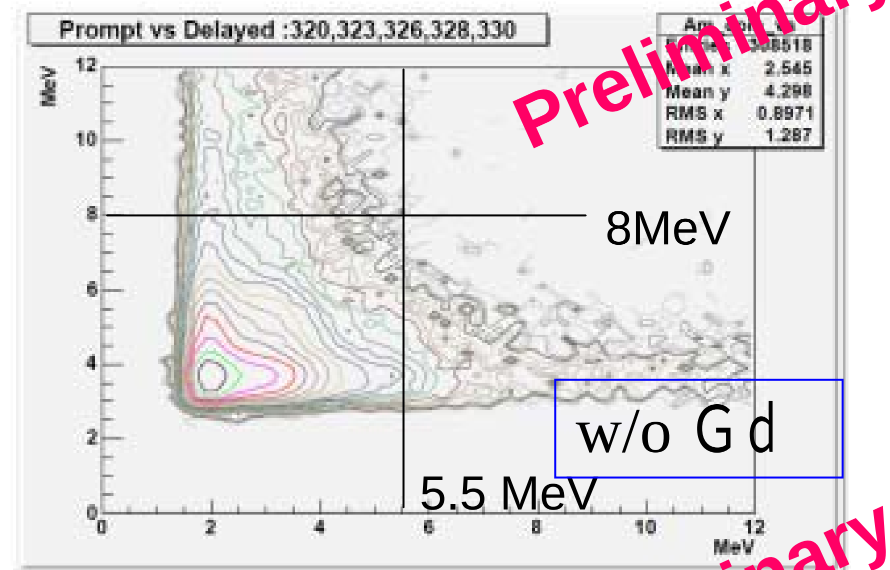
- Detection of Gd- γ
  - Efficiency of γ -cather
- Background estimation from cosmic-ray spallation
- Reactor neutrino detection
  - At JOYO: experimental fast reactor

- Am/Be neutrino like signal
  - Prompt $E_{p+\gamma}$(visible)~5.5MeV
  - Emit neutron: captured after 30us
- LS contents
  - Pseudocumene(13.5%)+Iosparaffin(86.5%)+PPO,BisMSB
  - Gd: 0.1%

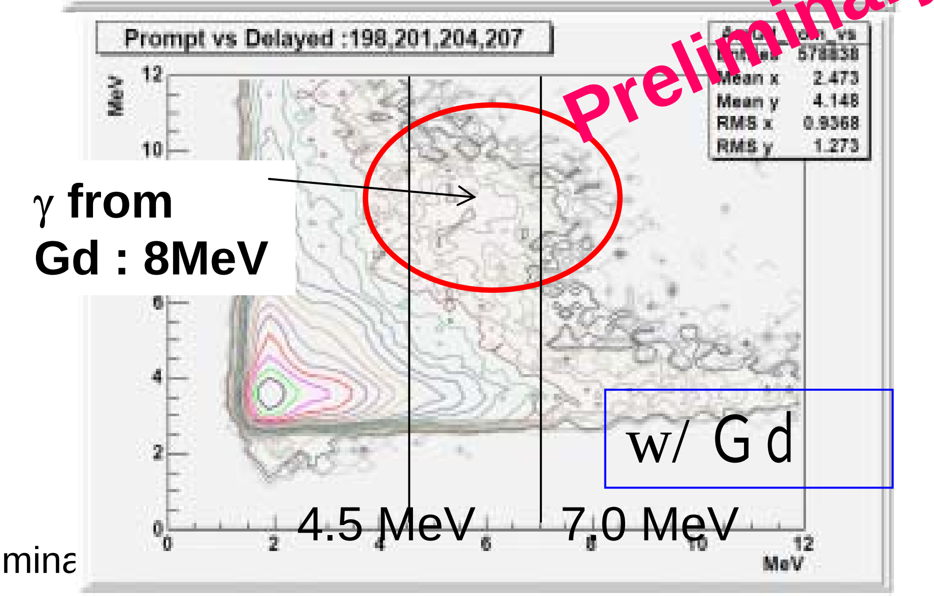


Am/Be source w/o and w/ Gd

- Observation of γ spectrum from w/ Gd
  - No cut
  - Low S/N



- Possible S/N improvement
  - Shield around the detector
  - Larger volume of Gd



Cosmic background - spallation

- Spallation event

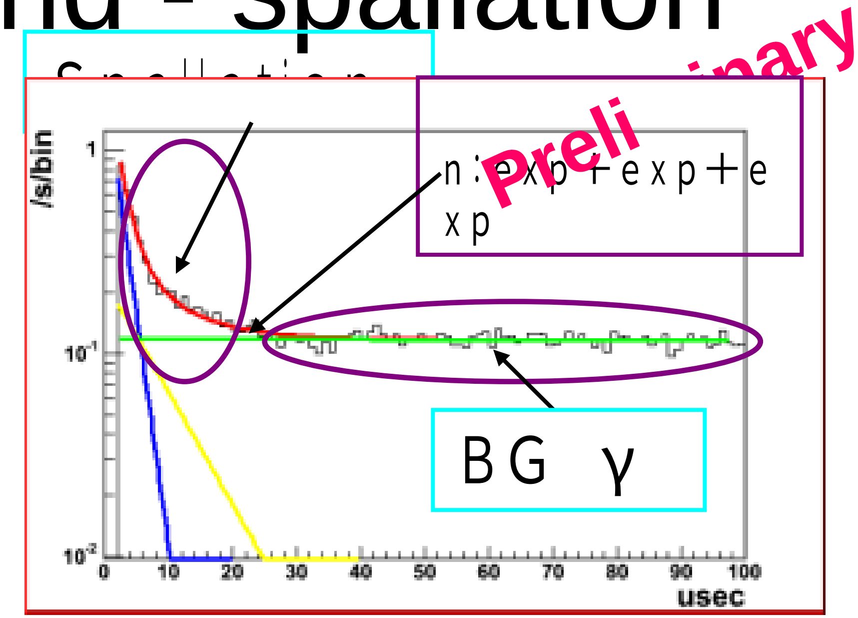
$$\mu + {}^{12}C \rightarrow X^{*} \rightarrow Decay$$

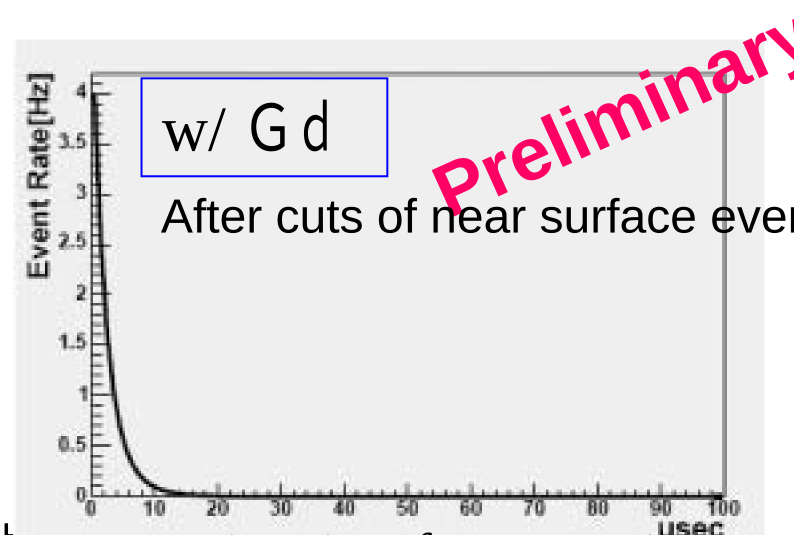
  - Single rate must be <1Hz
    - <10Hz @ Prototype

      detector size: 1/30

      Cosmic ray rate: x300
  - Time from Cosmic trigger
  - >100usec: low rate
  - Full detector:

    200usec deadtime





Passing time from cosmic

Cosmic background – correlated

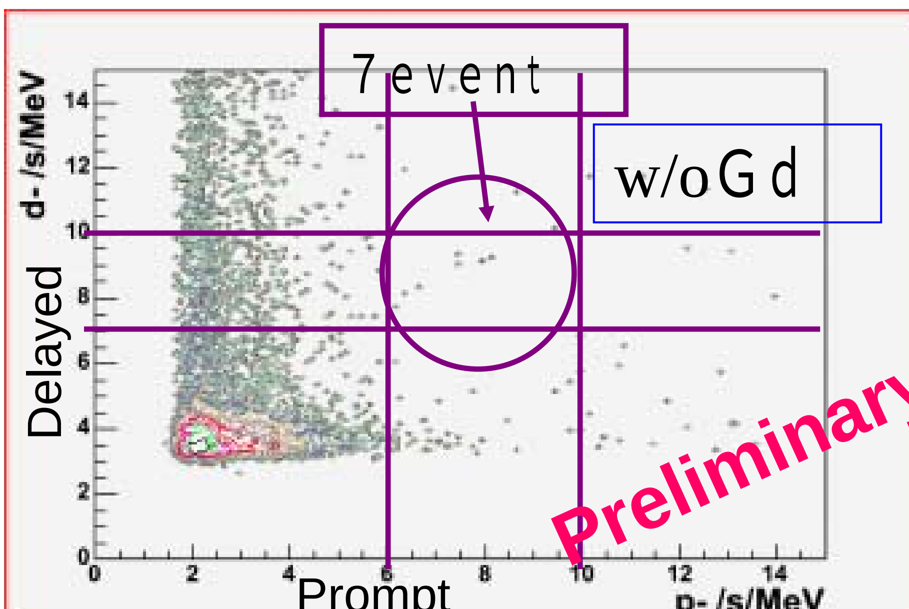
- Correlated background

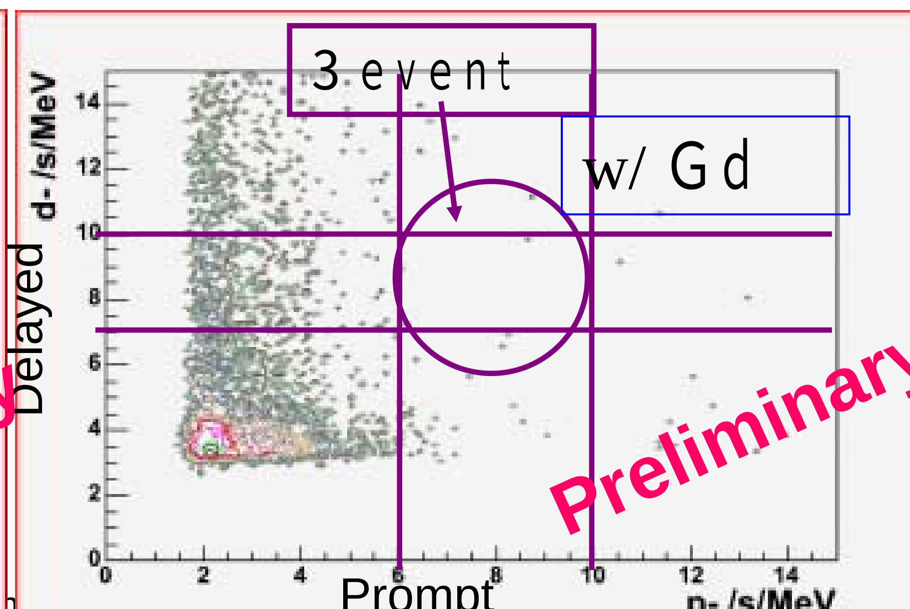
  $^{9}Li \rightarrow {}^{8}Be + e^{+}(13MeV) + n, (\tau = 0.26s, Br = 48\%)$

  – BG must be <1 event/day → 10 event/day@prototype

  – Li window: Prompt(6~10MeV) Delayed(7~10MeV)

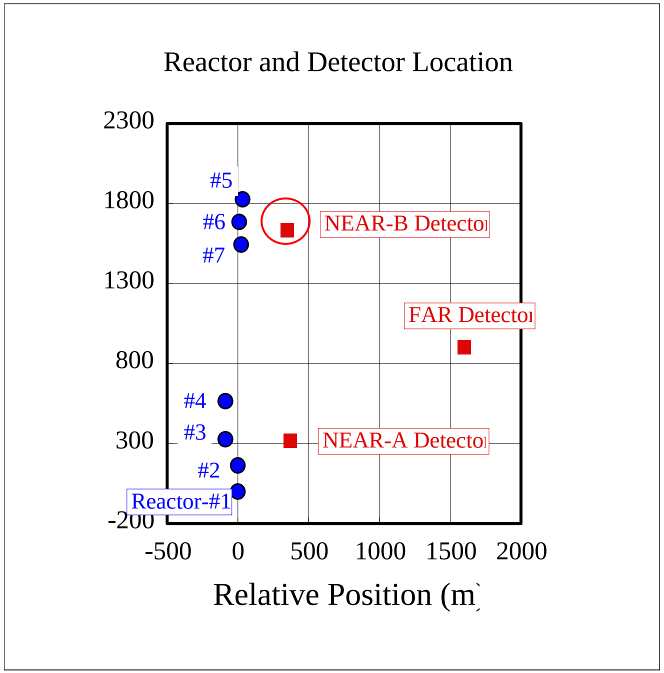
  – Larger volume of Gd

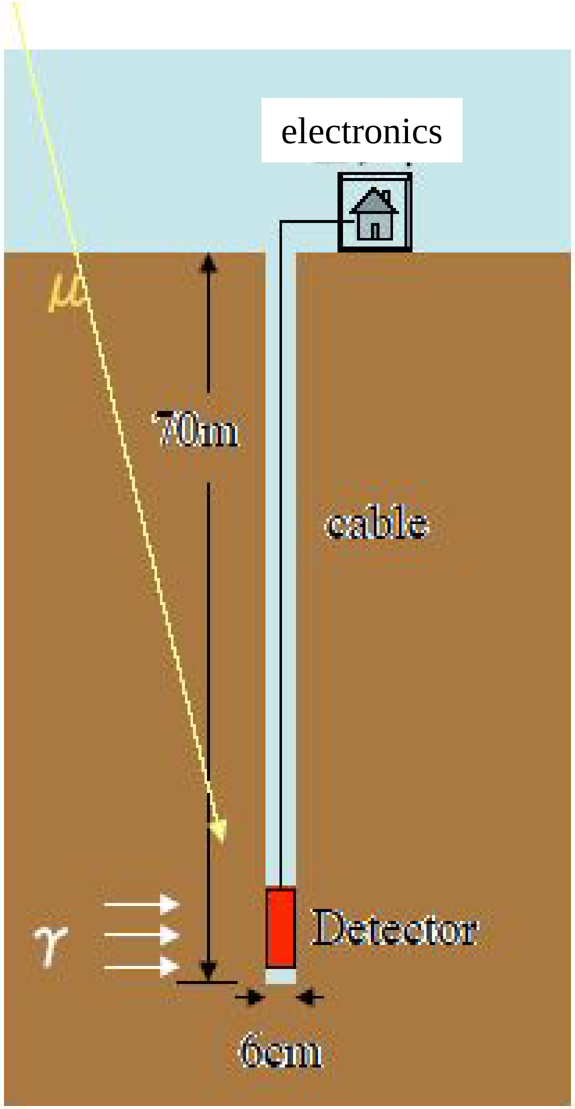


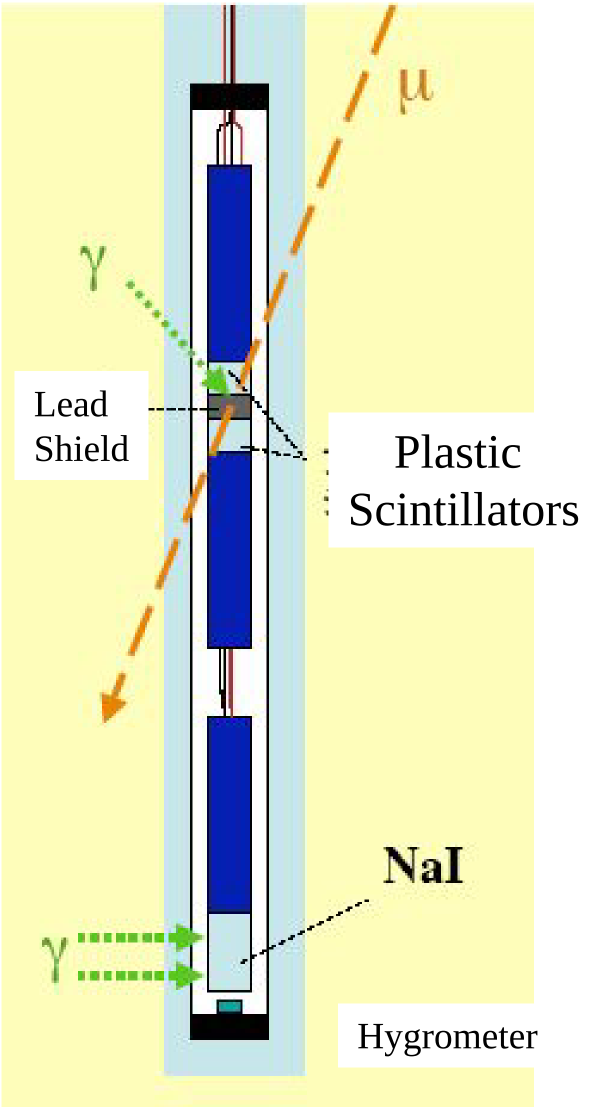


BG study of cosmic ray and γ ray

- Boring Study
  @ near-B site
- 2004.10~11

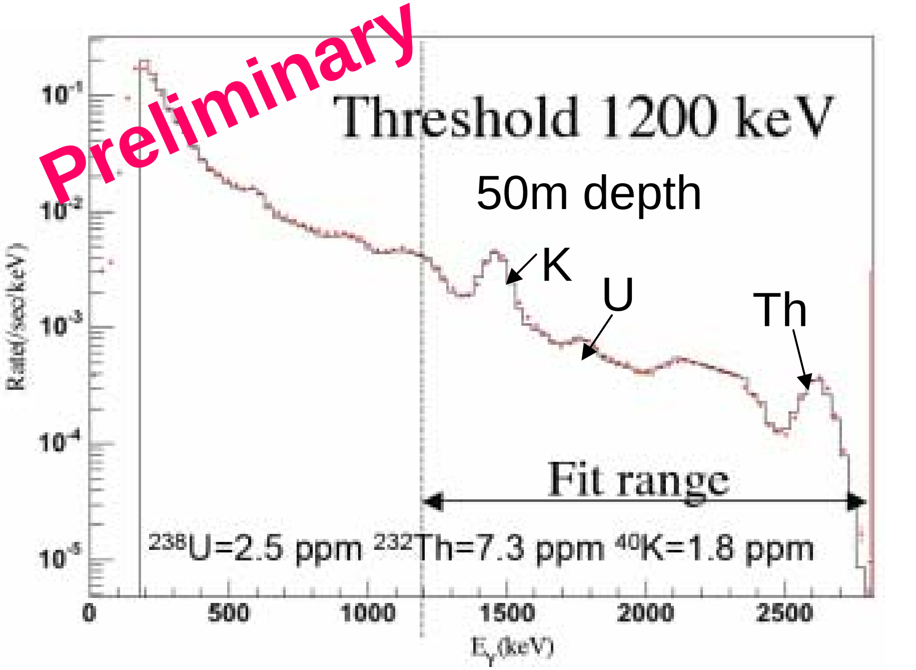


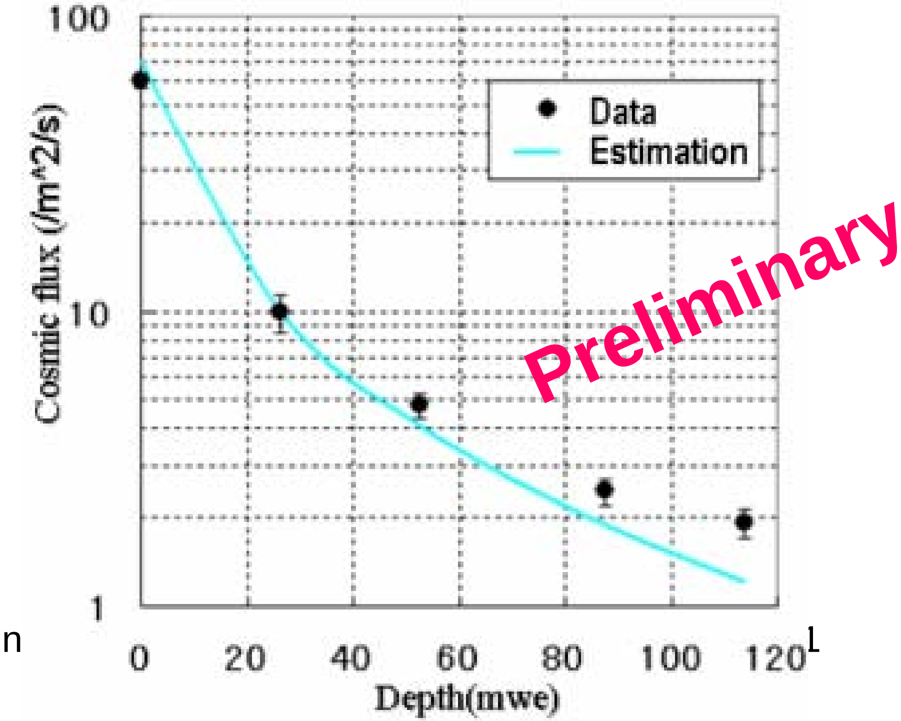




Results of BG

- γ ray background
  - The γ spectrum is well produced by Geant4 with ~60 γ-ray enegies
  - γ background rate
    - PMT<4Hz,
    - soil+concreate<1Hz
- Cosmic rate
  - Consistent with the estimation





Electronics & DAQ

- CAMAC based DAQ prototype
- VME bus or Compact PCI bus system for the full spec detector

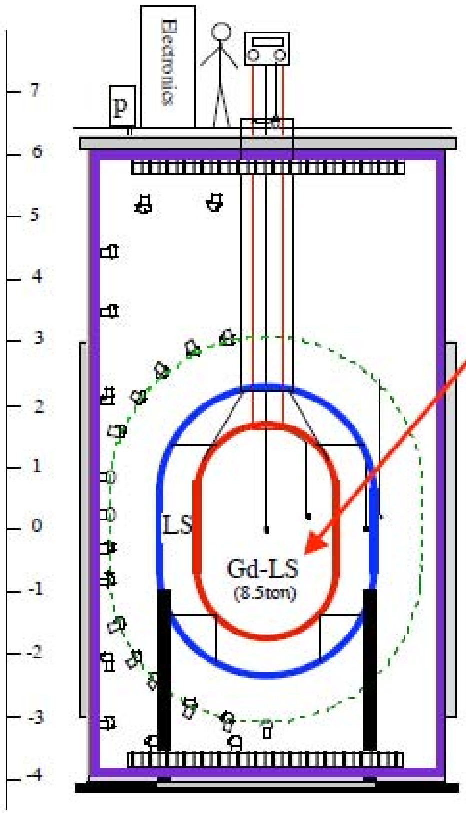
- Now we develop new 1GHz FADC board

Summary

- KASKA is the θ_{13} experiment from reactor neutrinos.
  - Most powerful reactor: Kashiwazaki-kariwa
  - Sensitivity: θ_{13} ~0.015 at σ_{sys}<0.5%
- Now we study many tests using R&D budgets
  - Boring test : γ BG, cosmic rate and neutron BG
  - Make and test: Prototype detector, Cosmic-ray tracker, Liquid scintillator, FADC and others
- We now apply for full budget
  - Construction from 2006 and data taking from end of 2008 if we can get!

Backup Slides

The Detector



Neutrino Target [Region-I]

Gd Loaded Liquid Scintillator
Gd (0.1%)+ Pseudocumene(~30%) + Tetradecane (~70%)
M=8ton
Contained in Acrylic Vessel

- Anti-ν_e detection by inverse-β reaction

$$\overline{\nu}_e + p \rightarrow n + e^+$$

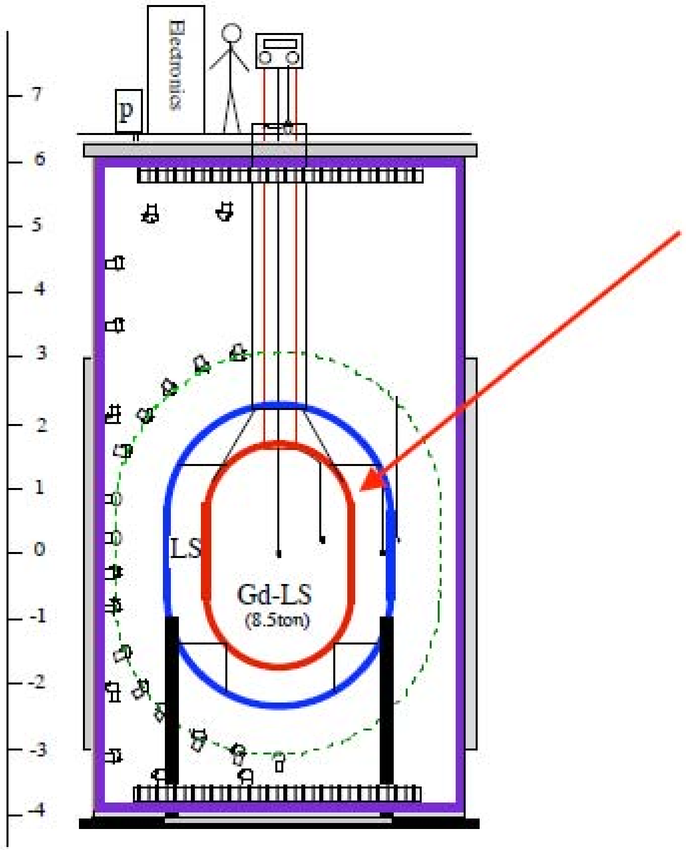
$$e^+ + e^- \rightarrow 2\gamma$$ Prompt signal

$$(E_\nu - 0.8MeV)$$ $\langle E_\nu \rangle \sim 4MeV$

$$n + Gd \rightarrow Gd' + \gamma s\left(\sum E = 8MeV\right)$$

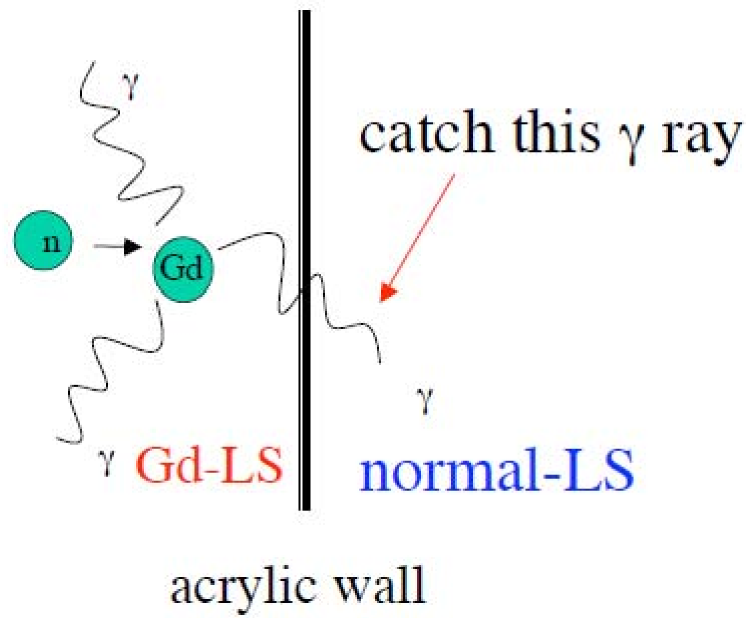
~30μs delayed coincidence

The Detector (2)

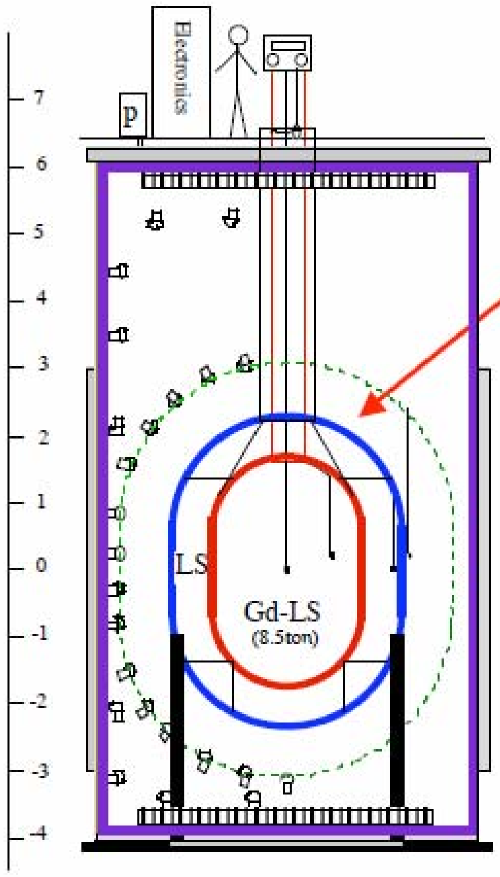


γ catcher [Region-II]

Liquid Scintillator (w/o Gd)
Thickness 50~60cm
Contained in Acrylic Vessel

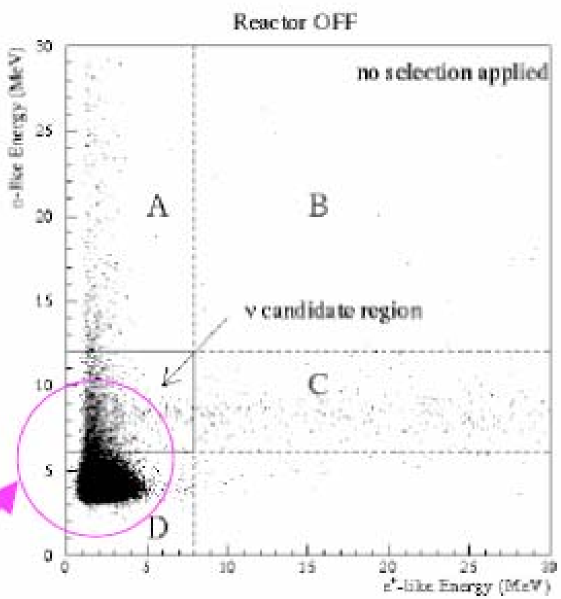


The Detector (3)



Inner Buffer (γ-shield) [Region-III]

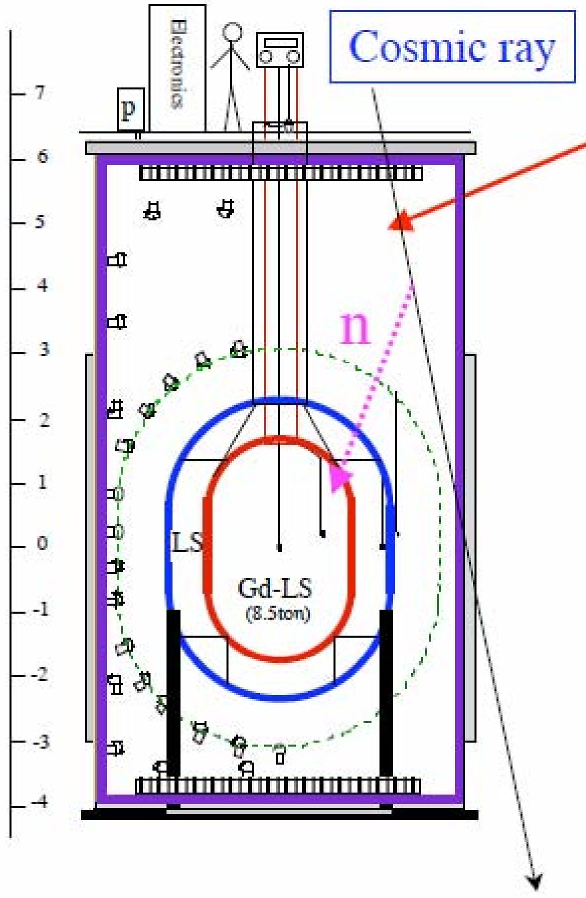
Buffer Oil (weak scintillation)
Thickness 80~90cm
To shield γ rays from PMT glass



CHOOZ hep-ex/0301017 v1

Reduce this BKG significantly

The Detector (4)



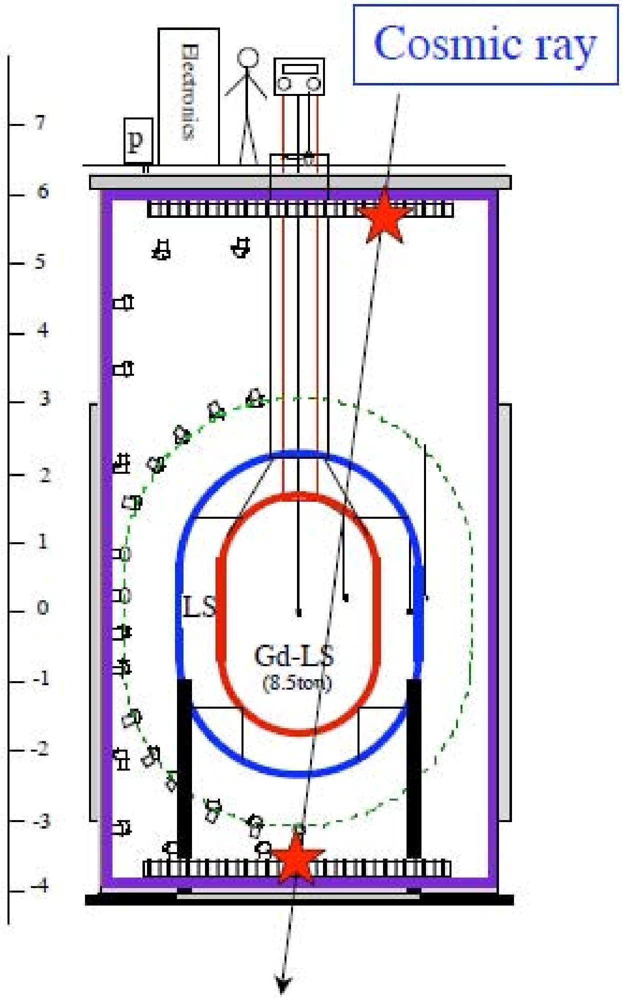
Outer Buffer (cosmic anti) [Region-IV]

Buffer Oil (weak scintillation)
$V \sim 150 m^3$
To veto cosmic rays

~10Hz for far detector

~100Hz for near detectors

The Detector (5)



Cosmic-ray tracking device

σ~10cm

To *measure* spallation BKG

$\mu + {}^{12}C \Rightarrow \mu + {}^{9}Li + 3p$

${}^{9}Li$ (260ms) $\Rightarrow {}^{8}Be + e^{-} + n$

Correlated BKG

(delayed coincidence)

Lifetime too long to make a veto gate

Accidental BG

(E > 0.7MeV)

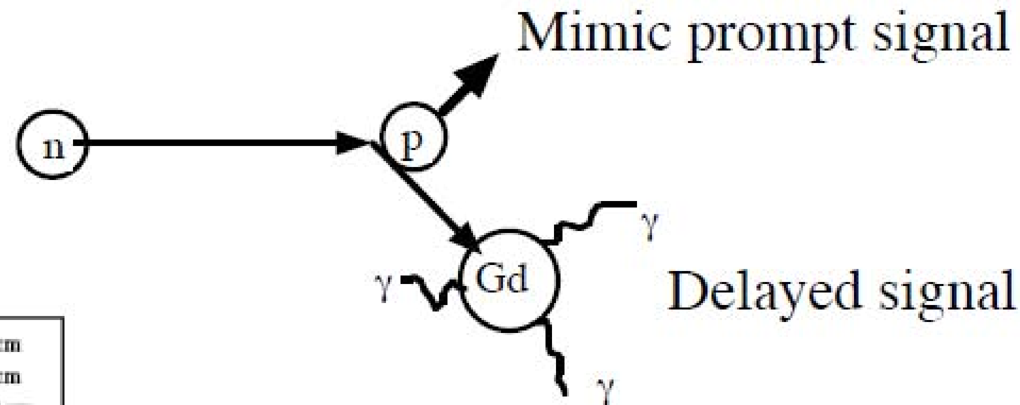
Soil:	< 1Hz	with >100cm oil+15cm Fe
PMT:	~5Hz	with 80cm shield
Gd-LS	~1Hz	(CHOOZ Gd)
Acrylic	~1Hz	

==================================

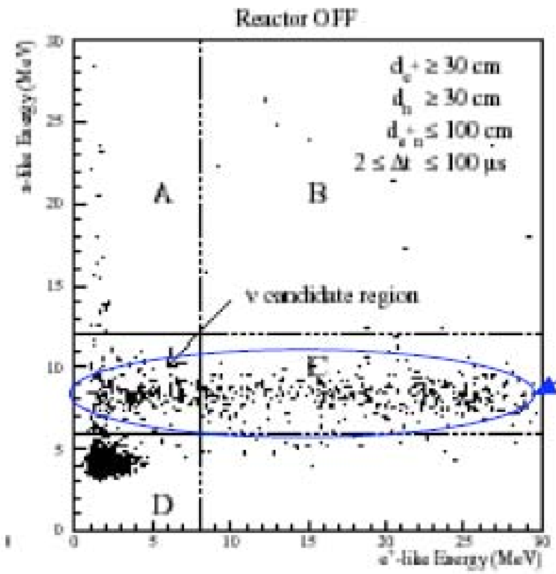
Total	< 8Hz	γ/β single rate
	$< 2*10^{-3}$Hz	neutron rate

⇒ Accidental BG < 1%

Fast Neutron



CHOOZ
hep-ex/0301017v1



n backgrounds
have flat distribution

Interpolate events rate
@>13MeV &<1MeV

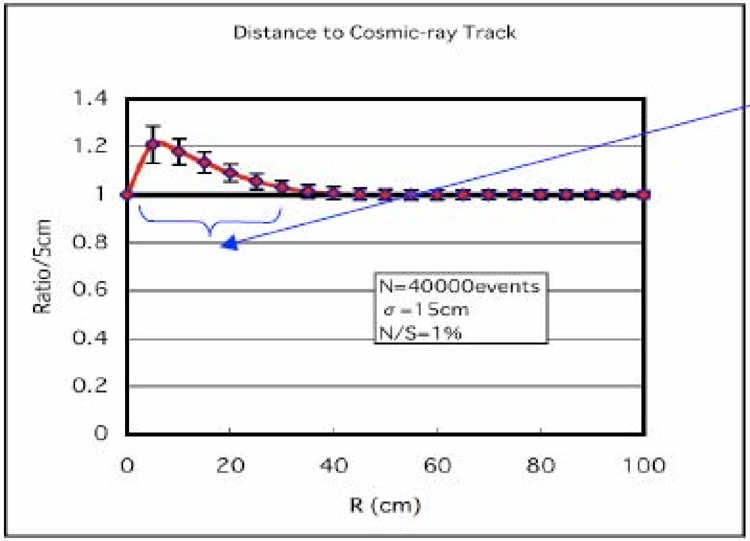
$$\boxed{\text{n BKG} \sim (1 \pm 0.2)\%}$$

(CHOOZ Case $(5 \pm 0.5)\%$)

Spallation

$\mu + {}^{12}C \rightarrow {}^{9}Li + X$

${}^{9}Li \rightarrow {}^{8}Be + e(13MeV) + n$, (τ=0.26s, Br=48%)



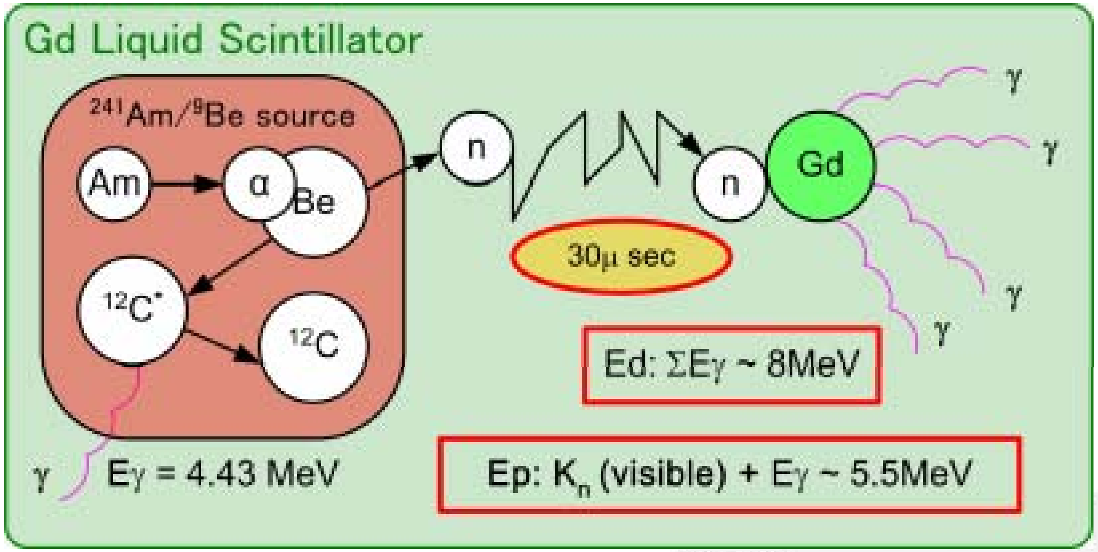
Estimation can be done by using event rate at 8MeV<E<11MeV & Δt-Δx distribution from the last muon.

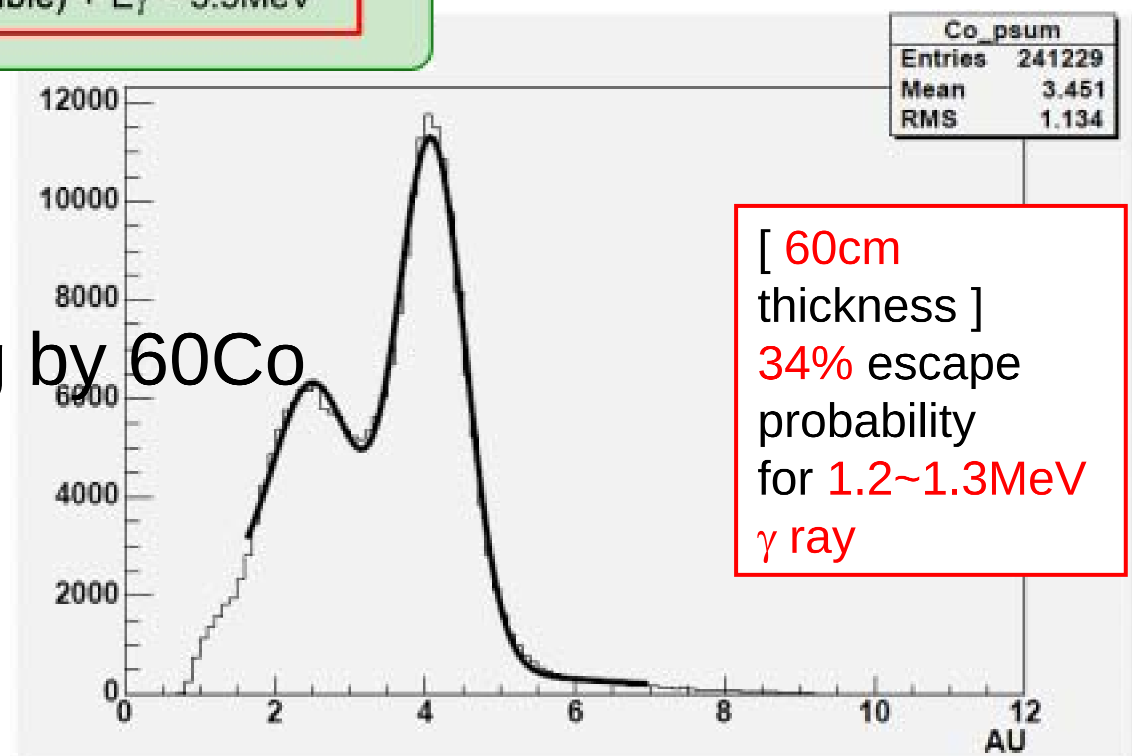
Error of estimation ~ 50%

$\Downarrow$

Spallation BKG ~ $(0.4 \pm 0.2)\%$

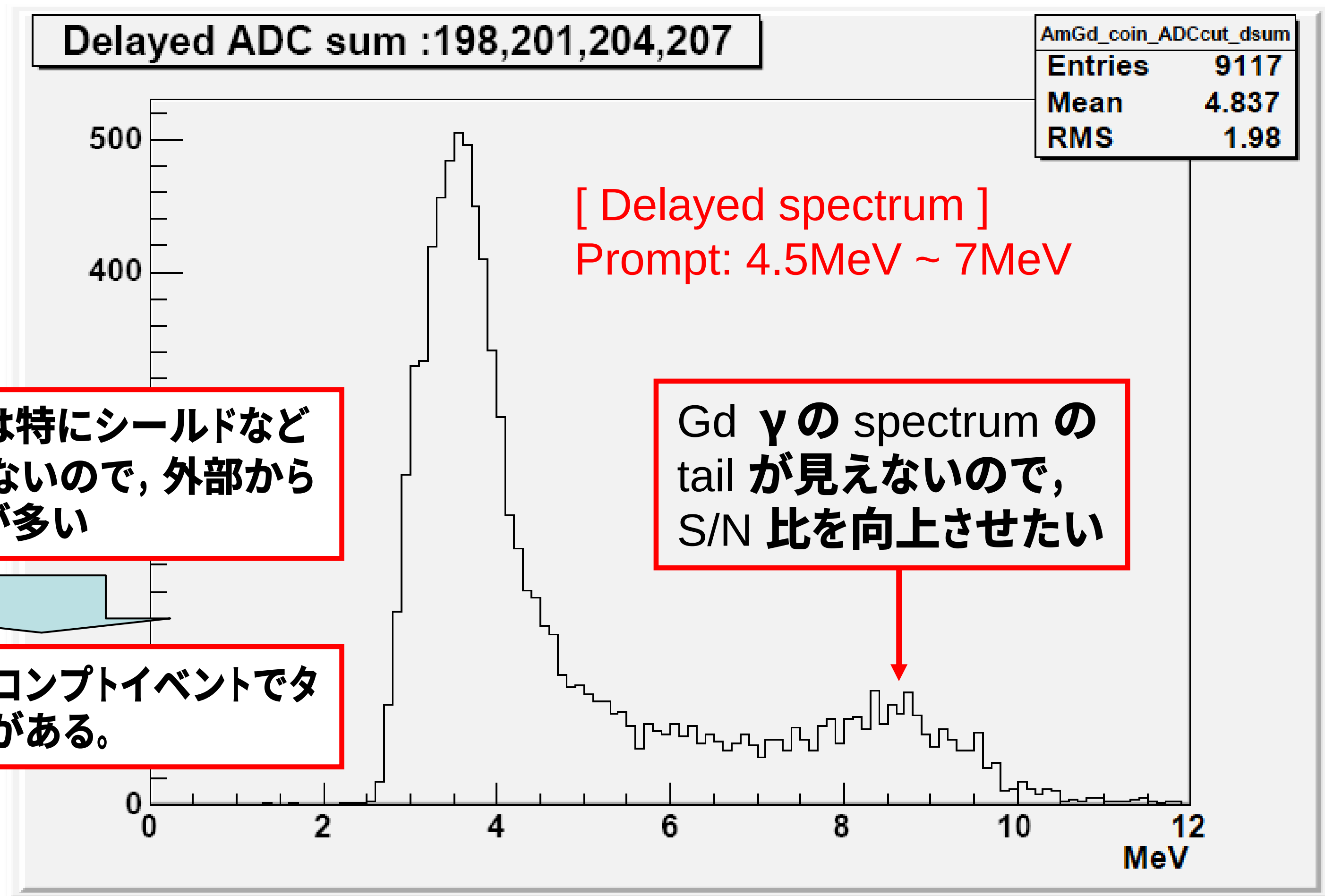
Energy Scaling by 60Co





[60cm thickness]
34% escape probability for 1.2~1.3MeV γ ray

Am/Be source + Gd (Ep = 4.5-7 MeV)



Prototype **は特にシールドなどは設けていないので，外部からのγ線**BG**が多い**

中心部のプロンプトイベントでタグする必要がある。

Gd **γの** spectrum **の** tail **が見えないので，** S/N **比を向上させたい**