Neutron background and possibility for shallow experiments

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- Neutron simulations for 2700 and 300 m.w.e.
- A "naïve" estimation for geo-ν at 300 m.w.e.
- What to do for the "next-to-next" step

(Thank you very much John and Steve for squeezing time for me)

Cosmic ray: serious backgrounds for neutrino observations

- Fortunately, delayed coincidence can be utilized for electron anti neutrinos, $\bar{\nu}_e + p \rightarrow e^+ + n$
- Even though, correlated (not random coinc.) b.g. are …
  - neutron-neutron:

    2 neutrons from the same muon
  - fast neutron:

    proton recoil is "prompt", neutron capture is "delayed"
  - Spallation products, especially, ^{9}Li:

    ^{9}Li (τ=257ms) $\rightarrow$ β^- n (51%)
- Experimental sites are:

  several 1000 meters water equivalent (m.w.e)

Cost against cosmic ray is also serious

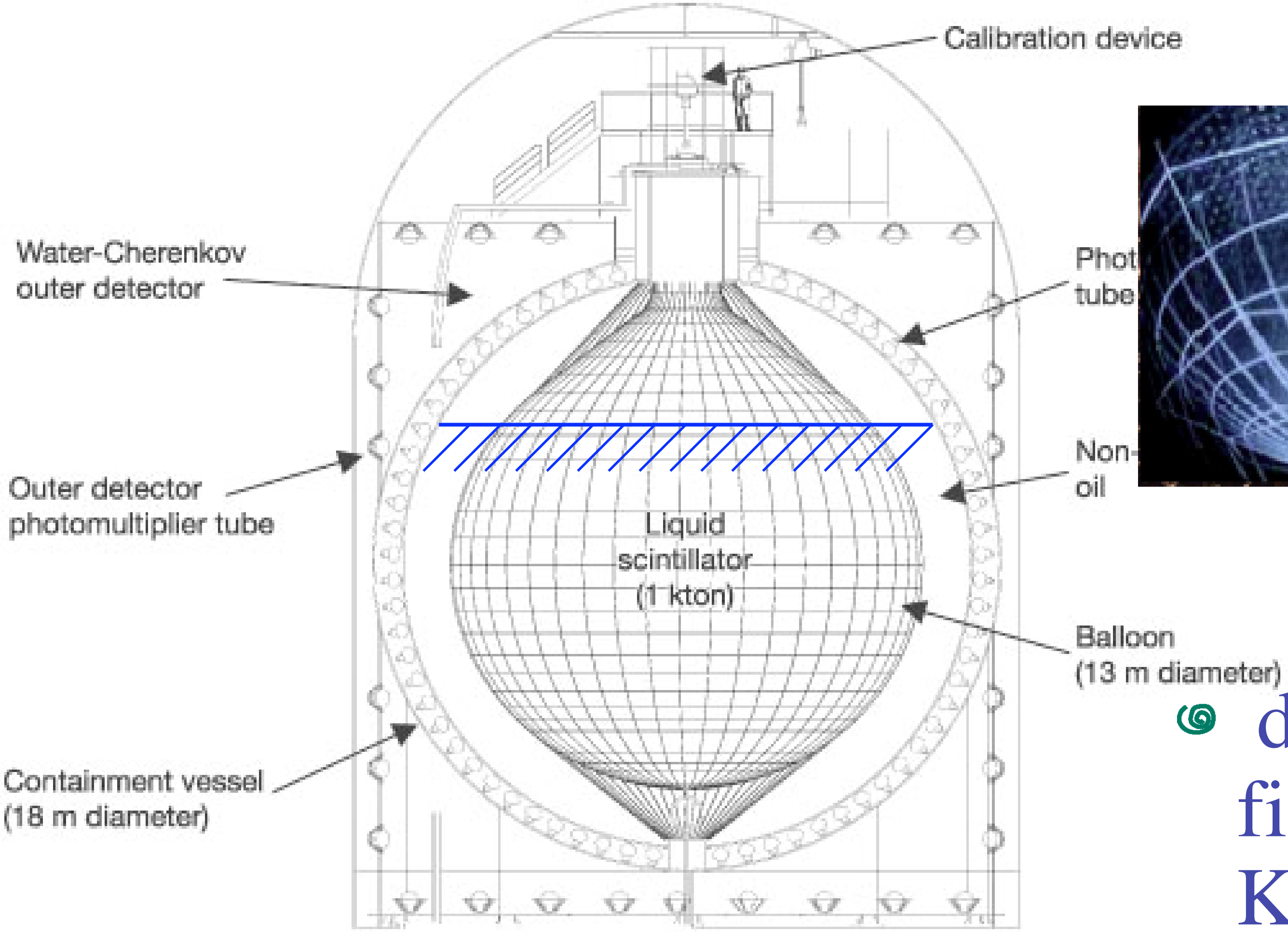
- Existing mines or other tunnels … main sites so far, (physics was the main objective)
- For the next generation of geophysics, *a lot of neutrino detectors all over the surface of the Earth, like seismographs!* (A. Suzuki, July, 2005) for a full-dress measurement of the Earth's power.
- Diagnoses of reactors or other applied physics
- Sites will not always be in the existing mines or other existing tunnels.
- Save the cost of civil engineering …

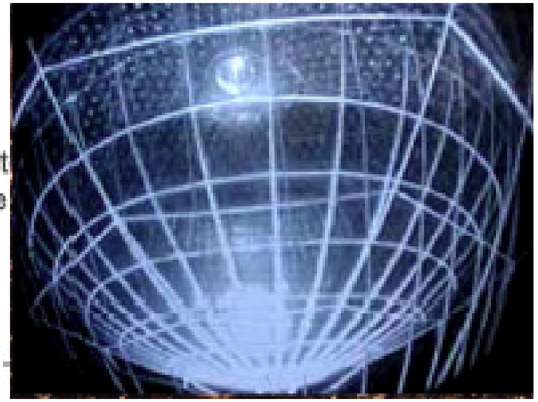
Deep-sea experiments

- Very few people has techniques and experiences (e.g. U. Hawaii)
- High pressure
- PMT (chain reaction)
- Scintillator container

  (balloon? or acrylic vessel?)

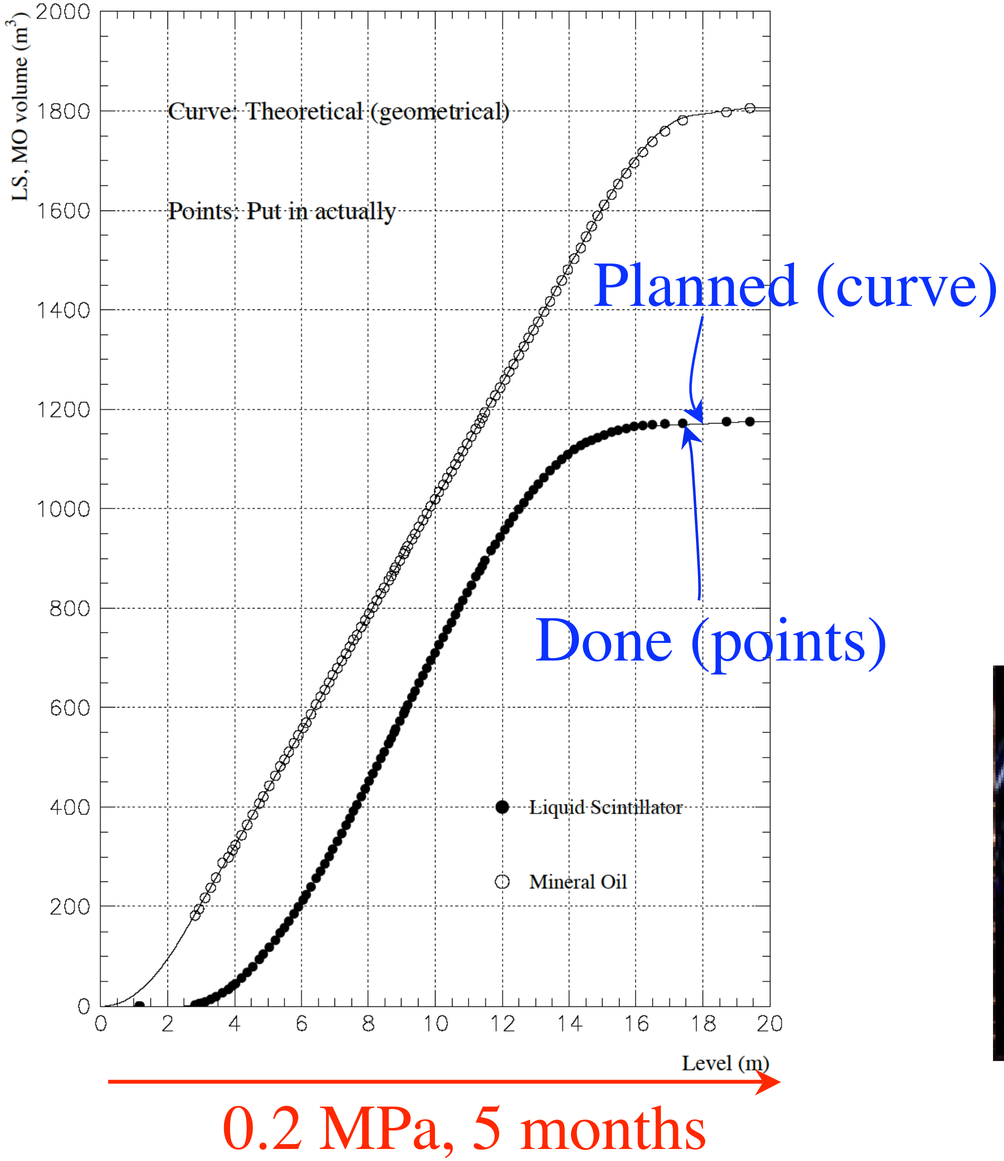
Pressure difference on the balloon etc





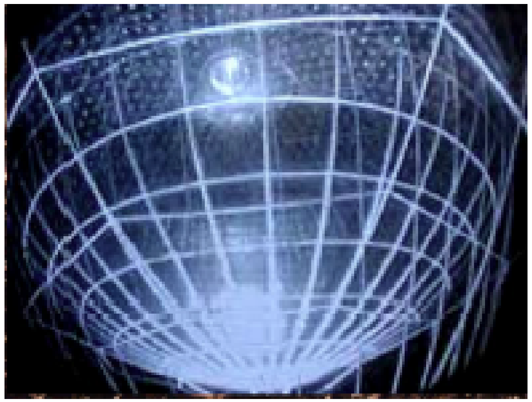
- detector filling of KamLAND

Pressure control: 10^{-3} precision

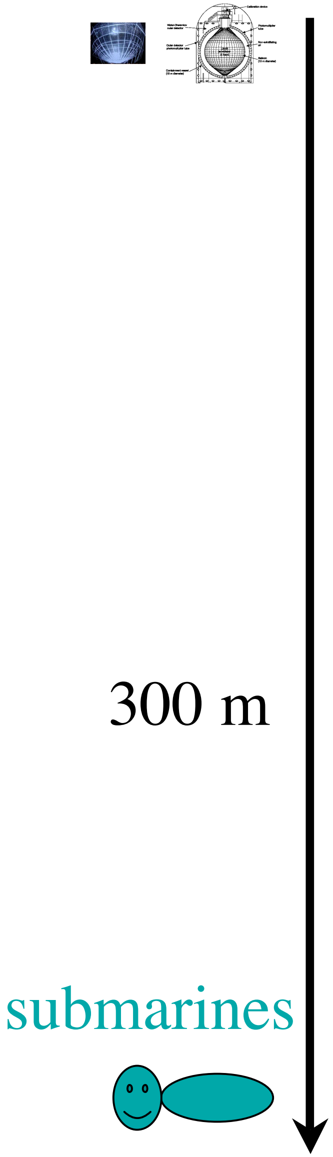


- 0.2 MPa for 5 months
- Pressure difference:

+50 < ΔP < +100 Pa



When it dives to 300 m (3 MPa)…



- Slightly positive pressure between +50 and +100 Pa

→ 10^{-4} precision of total pressure change of 3 MPa

- Shrink: ~ $\mathrm{GPa}^{-1} \times 3$ MPa

  ~ 0.3% (3 m^3 out of 1000 m^3)

- Hanohano dives 10 times deeper, but it takes acrylic vessel with more pressure difference tolerated, not an easy technique anyway

Cheap, fast, shallow detectors

"mass production"

for geophysics and applied physics

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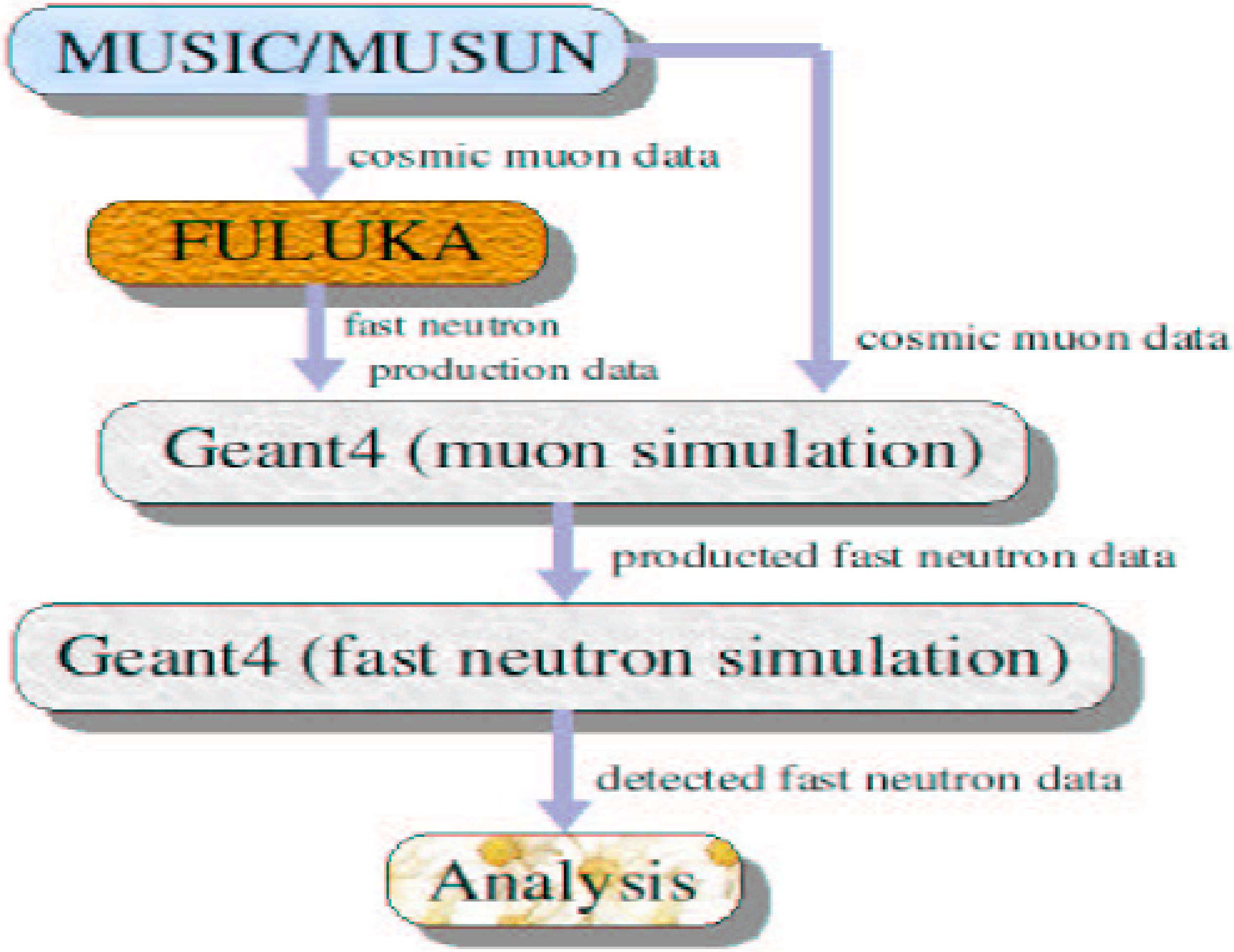
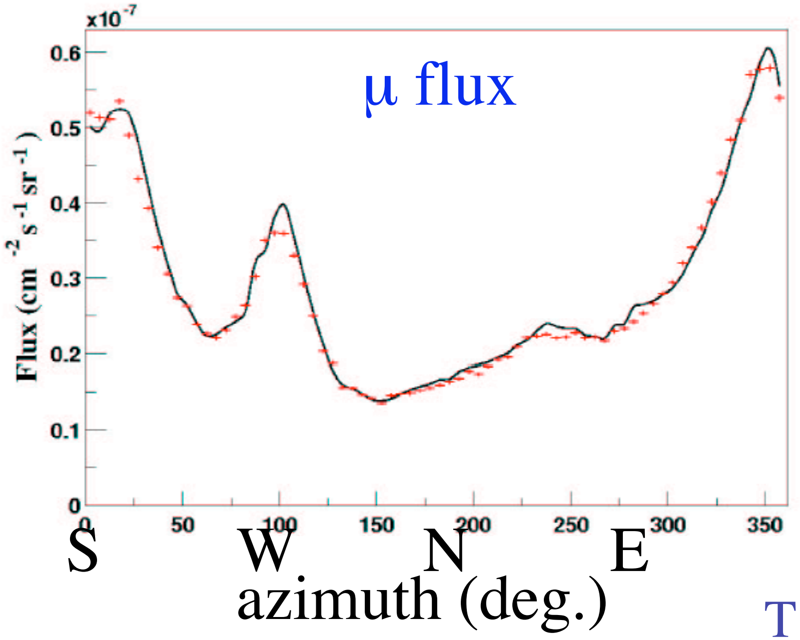
Hybrid Monte Carlo for neutrons

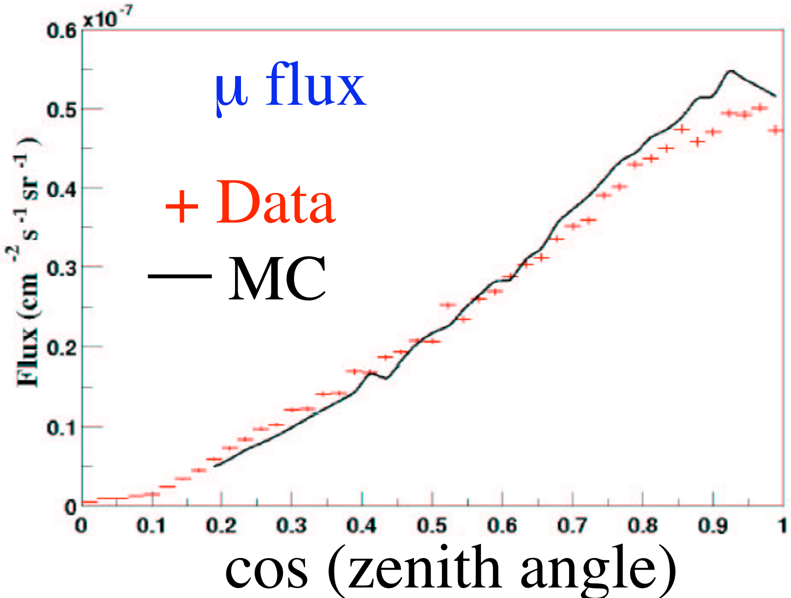


T. Araki, master thesis, Tohoku U., 2005

Mt. Ikenoyama shape and μ flux

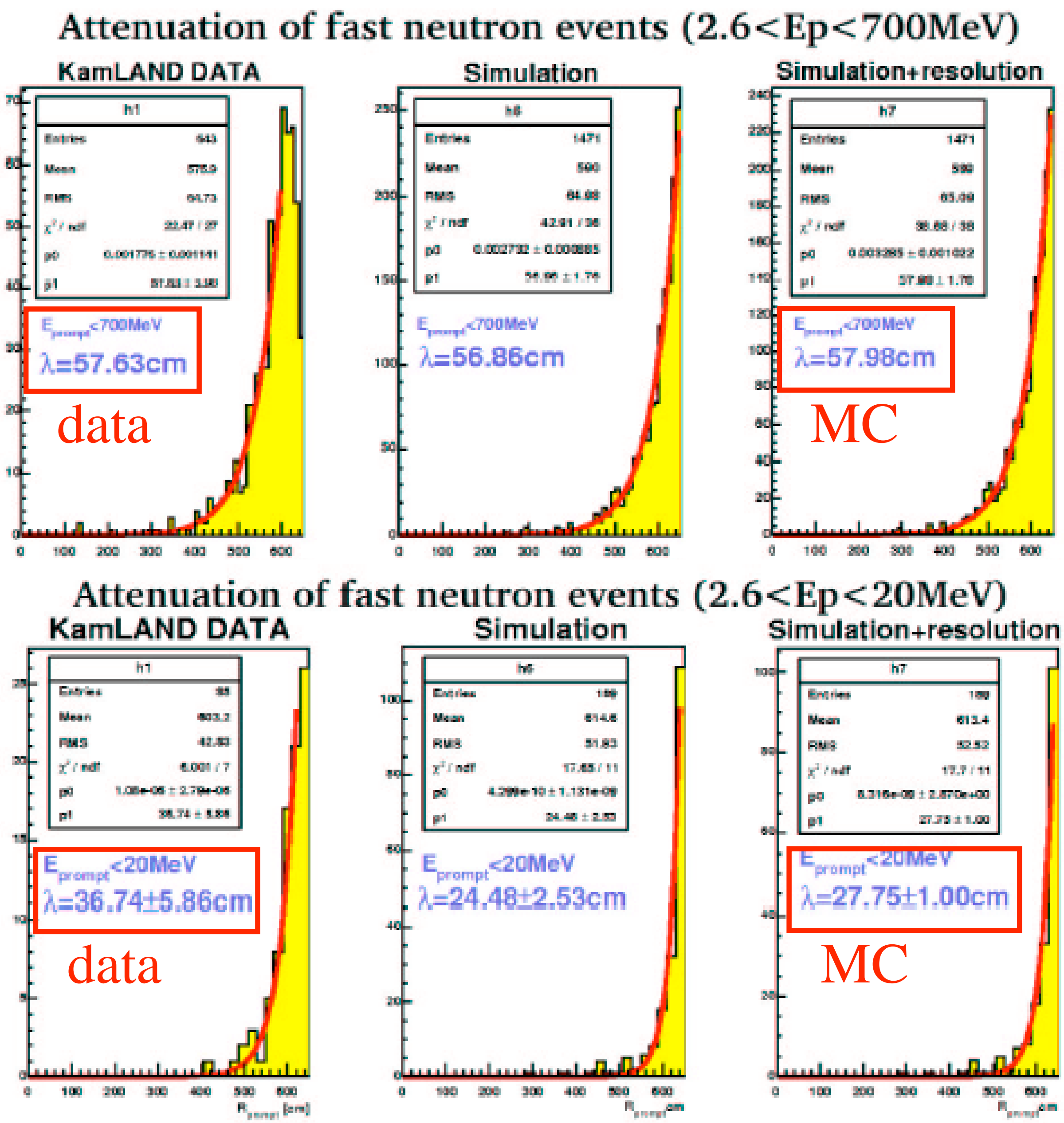
- Only one parameter, rock density tuned to be 2.675 g/cm^{-3}
- Then good agreement in zenith and azimuth distributions





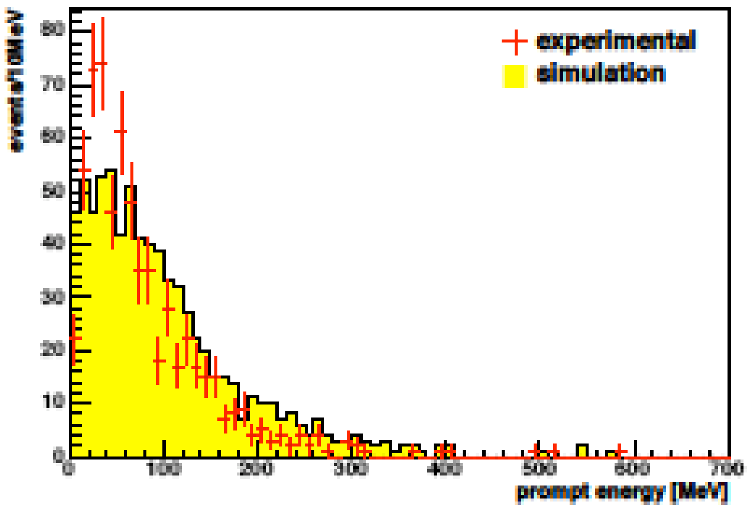
T. Araki, master thesis, Tohoku U., 2005

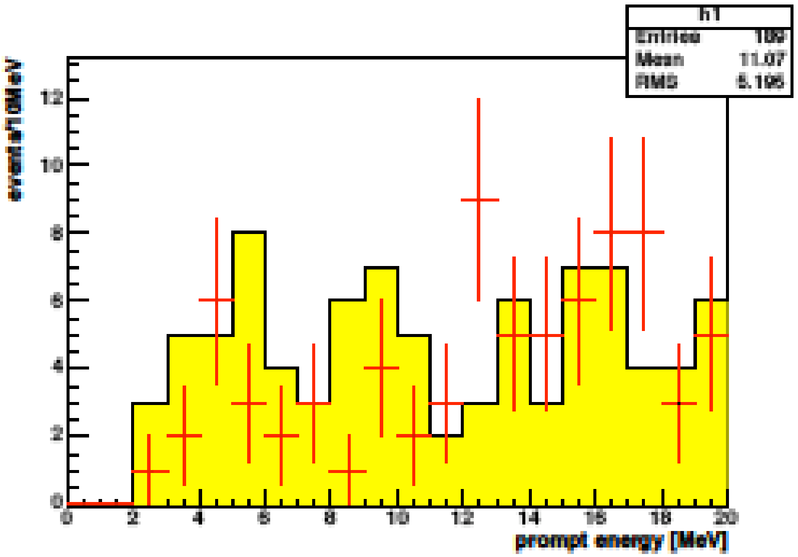
Neutron attenuation length: data v.s. MC



Fast neutron event: data v.s. MC

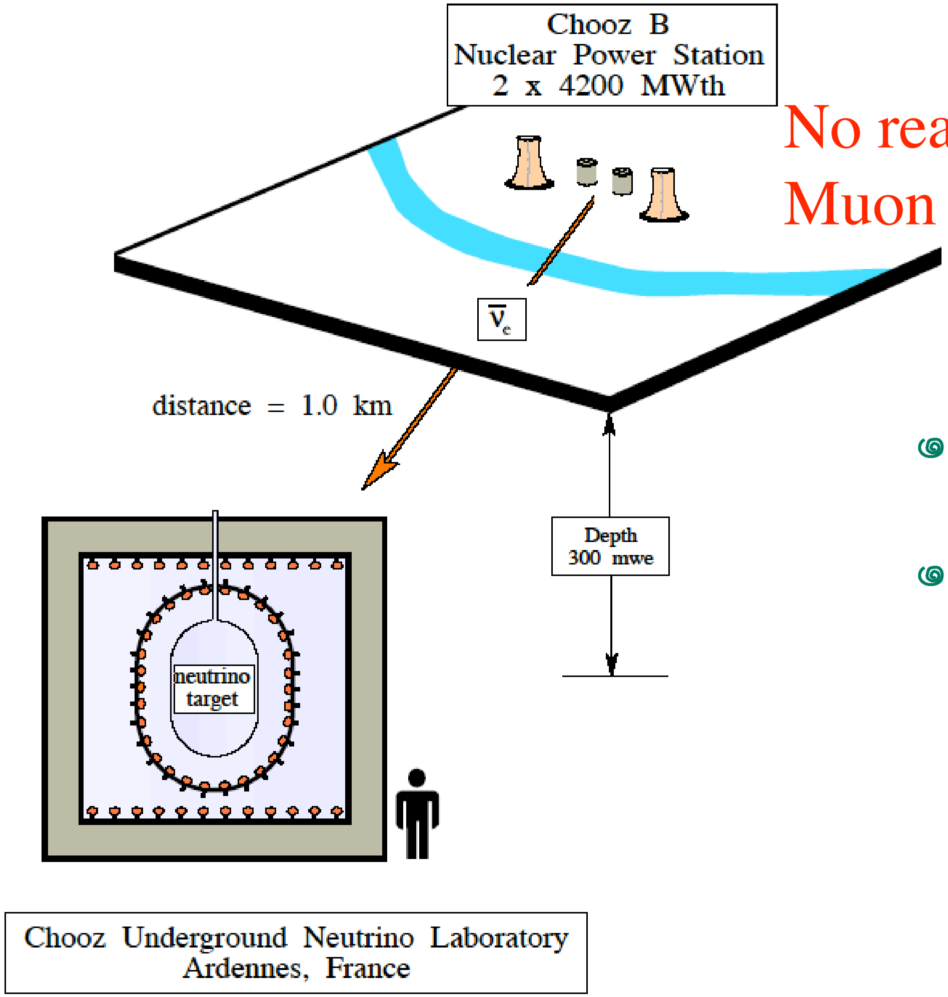
- Fast neutron event with OD hit (by muon) and delayed coincidence (proton recoil - neutron capture coincidence)
- Good agreement: data and MC





T. Araki, master thesis 2005

CHOOZ (300 m.w.e.)



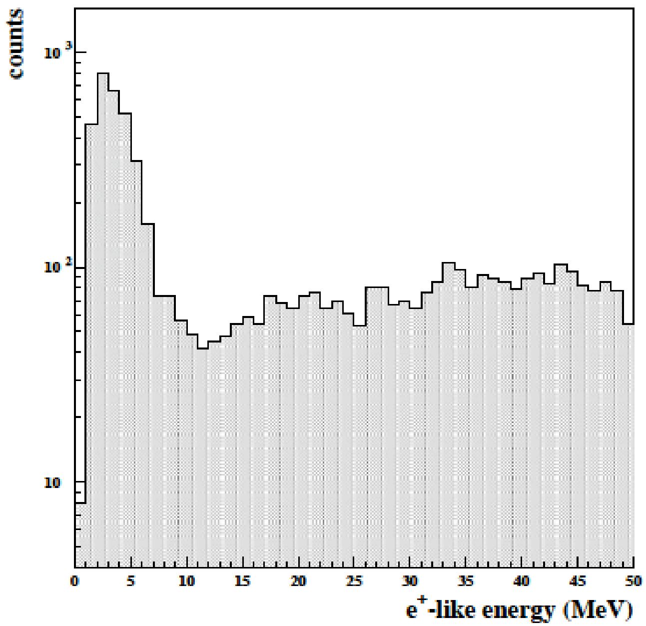
No reactor in simulation
Muon flux only

- Depth and detector of CHOOZ input
- Muon
  → neutron production
  → neutron propagation simulation in the same way as KamLAND

arXiv:hep-ex031017

CHOOZ (300 m.w.e.)

data



MC

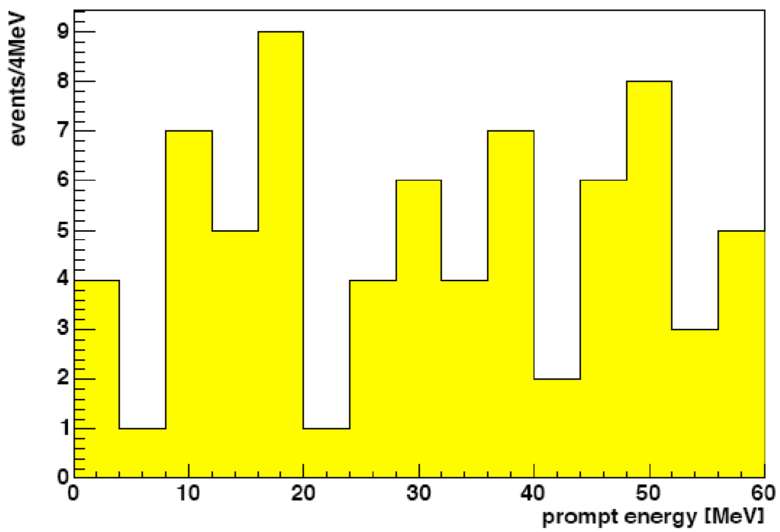


Fig. 48. Energy distribution of e^+-like signals associated with the correlated background.

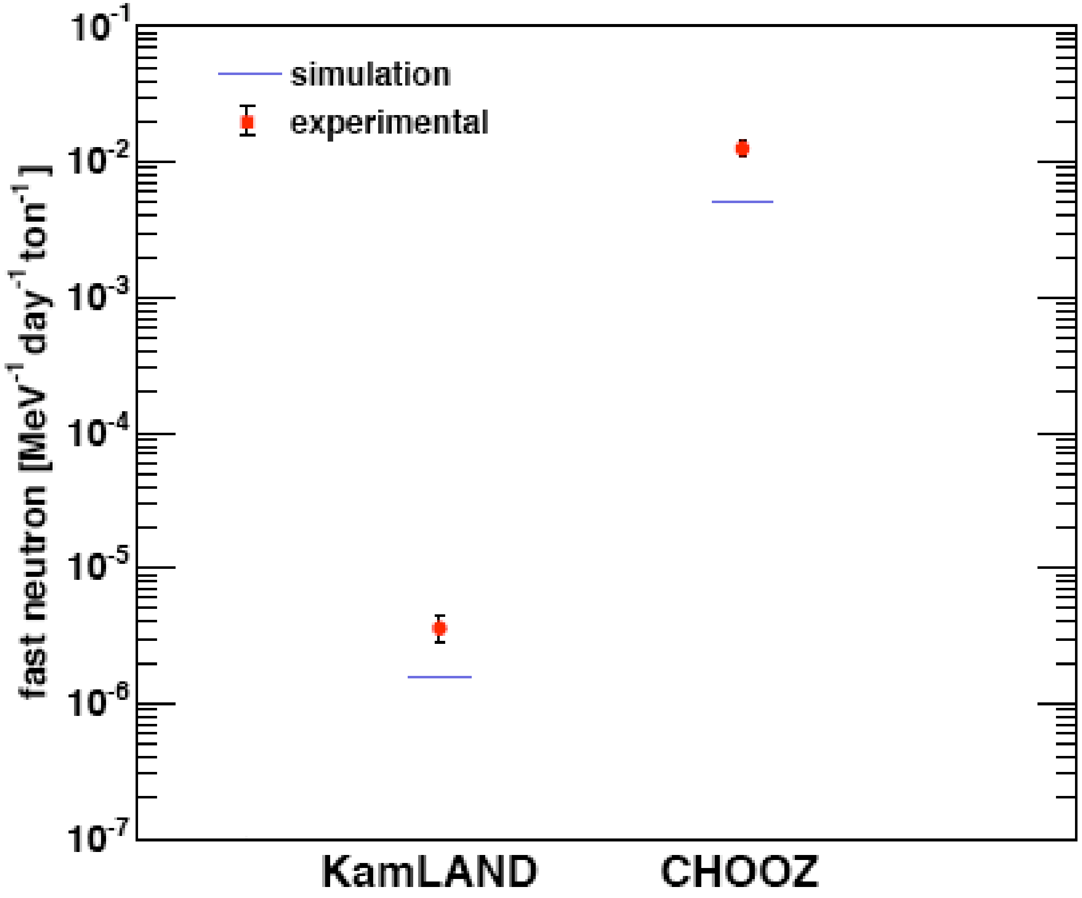
$$B_{corr} = \begin{cases} (0.156 \pm 0.01)\,\mathrm{MeV}^{-1}\,\mathrm{d}^{-1} & \text{for the 1st period,} \\ (0.158 \pm 0.01)\,\mathrm{MeV}^{-1}\,\mathrm{d}^{-1} & \text{for the 2nd period,} \\ (0.151 \pm 0.01)\,\mathrm{MeV}^{-1}\,\mathrm{d}^{-1} & \text{for the 3rd period,} \end{cases}$$

$0.062 \pm 0.008\ \mathrm{MeV}^{-1}\ \mathrm{d}^{-1}$

arXiv:hep-ex031017

Factor ~2 agreement

Hybrid Monte Carlo for neutrons



- Tolerable agreement from 300 to 2700 m.w.e. without any individual tuning
- Muon flux range: ~ 200
- Fast neutron rate: > 1000

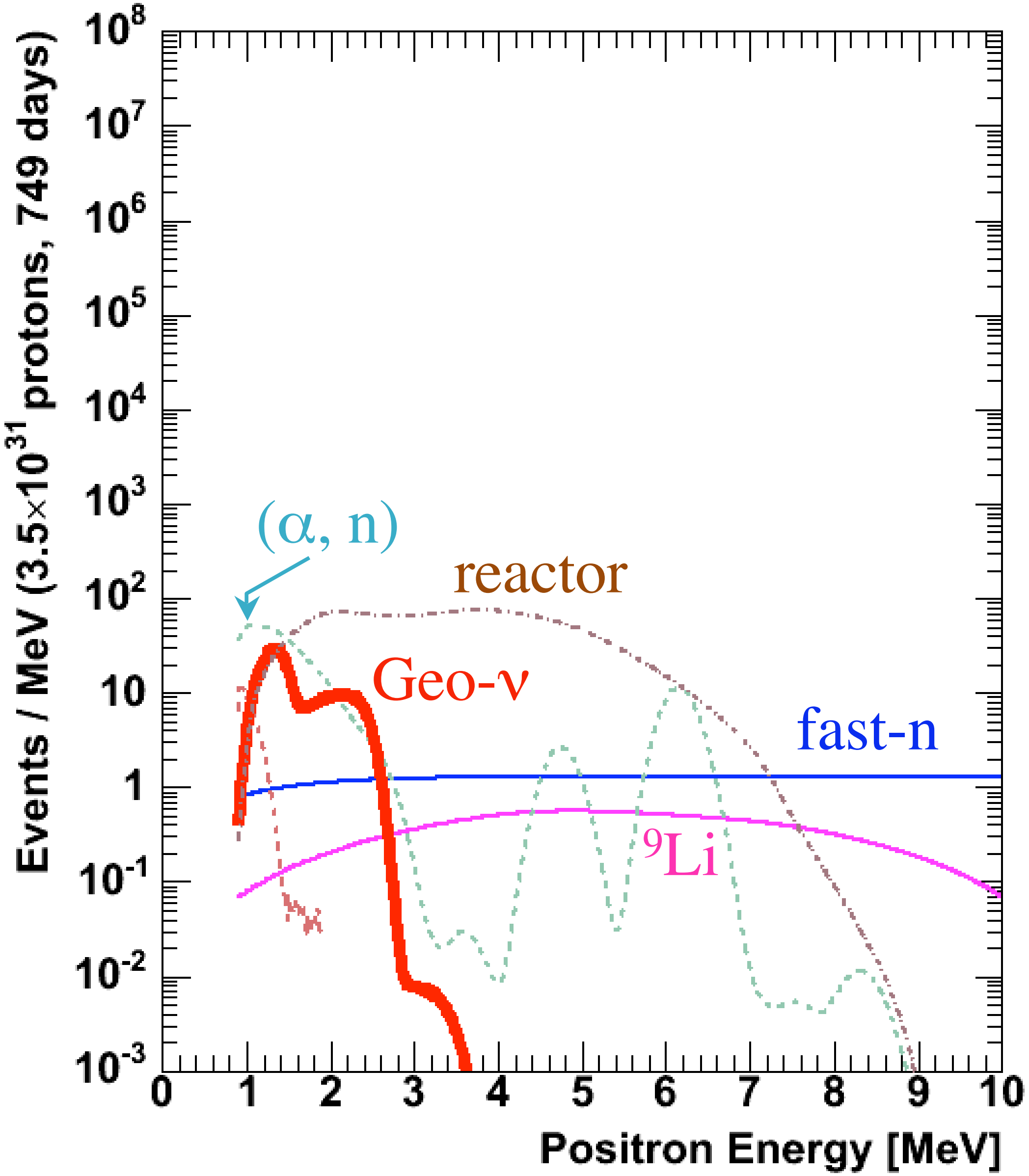
T. Araki, master thesis 2005

KamLAND at 300 m.w.e.

geo-ν and background

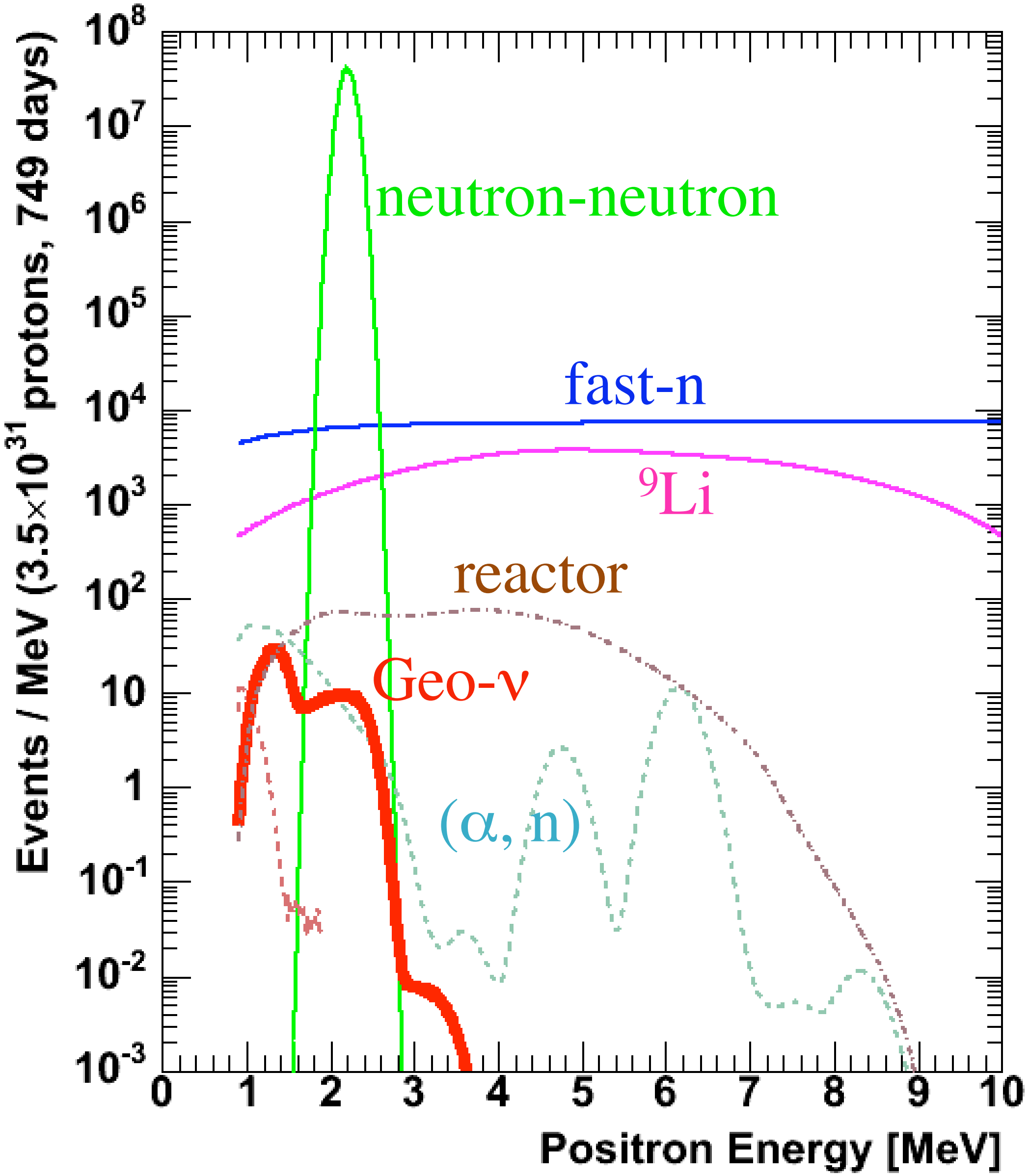
- A full simulation is being developed
- “scaling result” (using neutron rate, neutron attenuation length, …) are shown here (should not be so seriously different from the full simulation … I hope)

KamLAND (2700 m.w.e, 400 ton, 750 days)



- (α, n) and reactor are main background.
- Upper peak (^{238}U contribution only) is almost unseen, because of reactor background.
- Background from cosmic-rays (fast-n and ^{9}Li) are small

“KamLAND” at 300 m.w.e



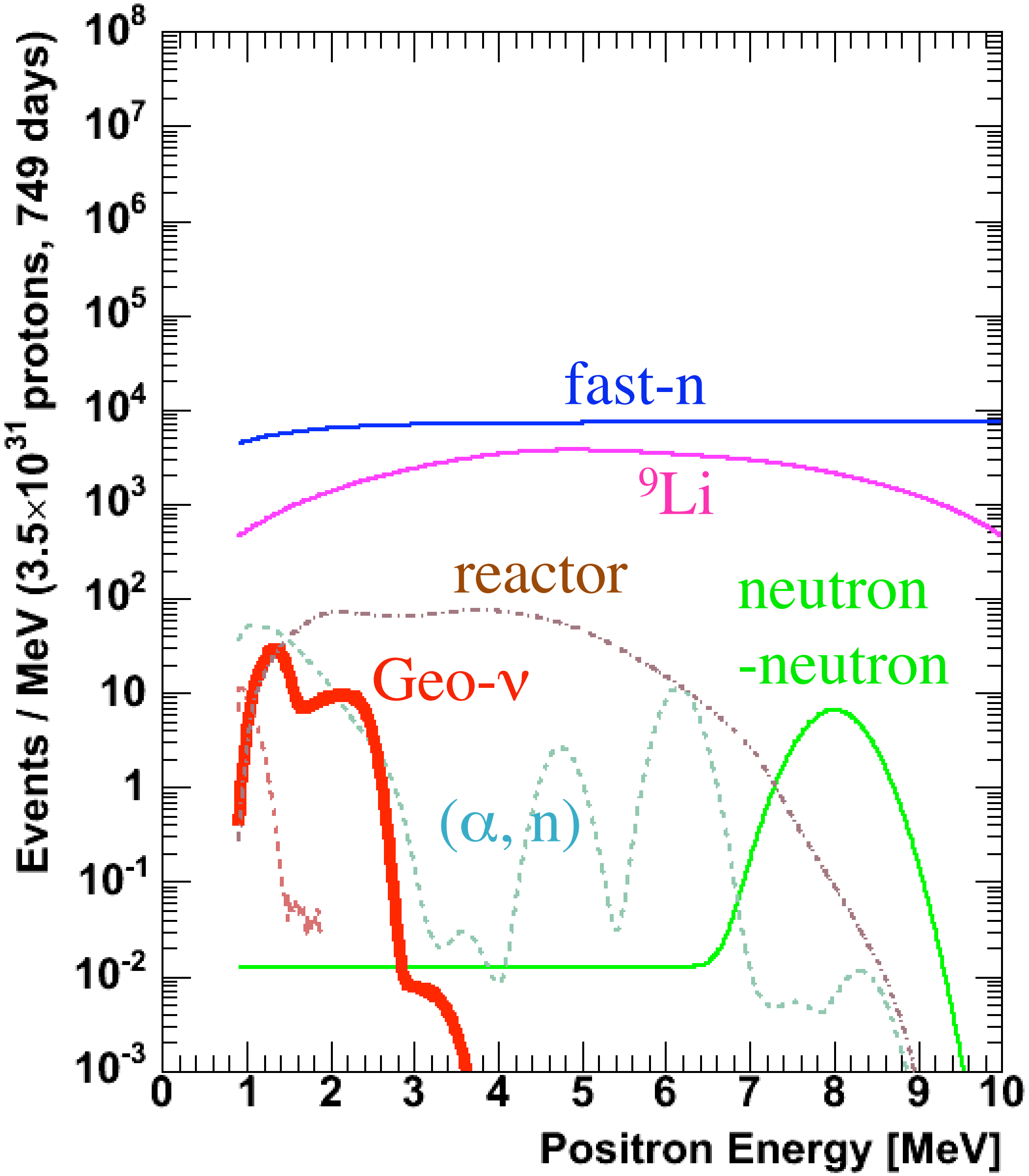
- Large background from ~10^3 times higher muon flux compared with 2700 m.w.e …
- neutron-neutron:

  2 neutrons from the same muon
- fast neutron:

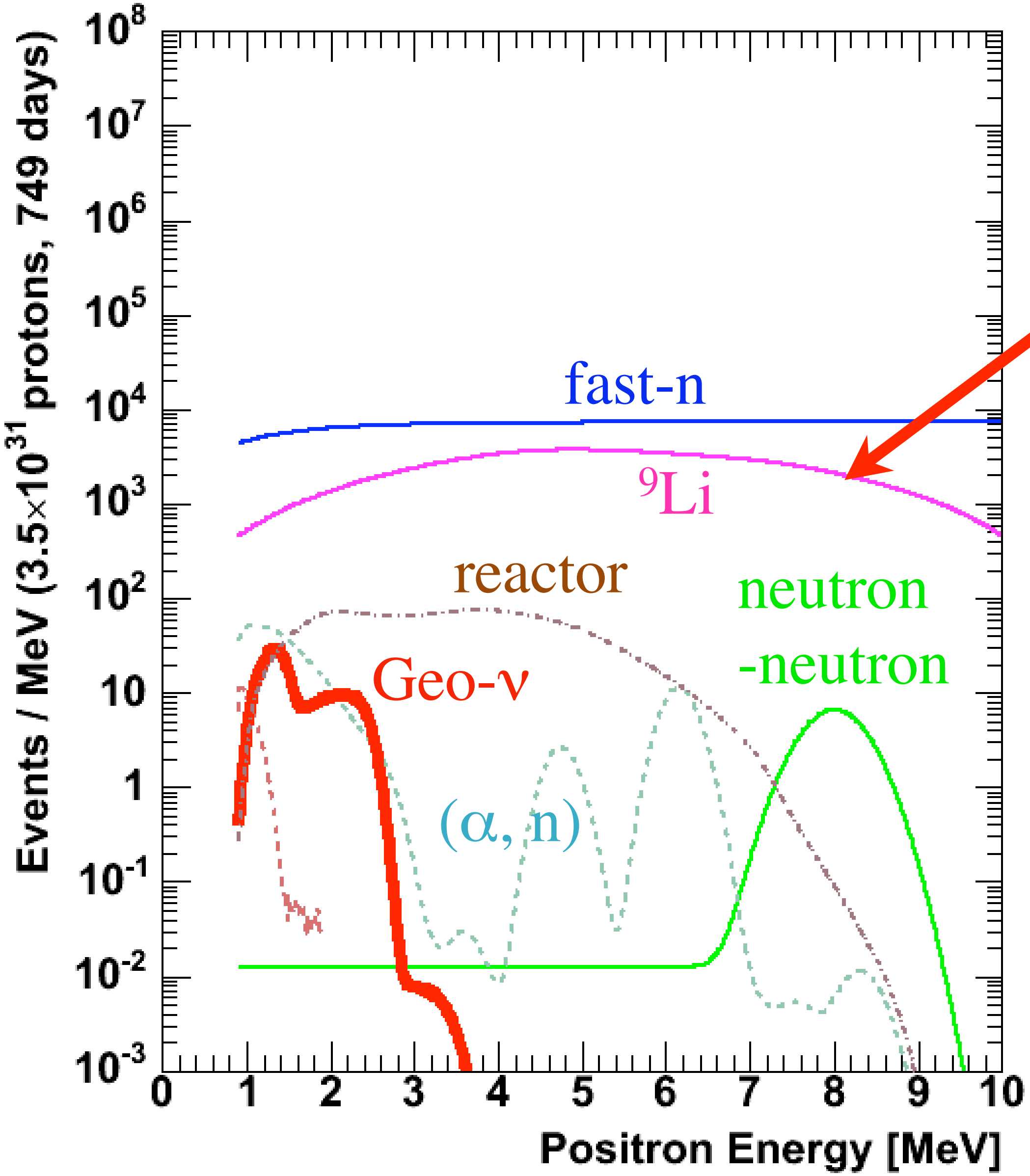
  proton recoil is “prompt”, neutron capture is “delayed”
- ^{9}Li:

  ^{9}Li (τ=257ms) → β^- n (51%)

“Gd ~ 0.1 %” to reject neutron-neutron b.g.



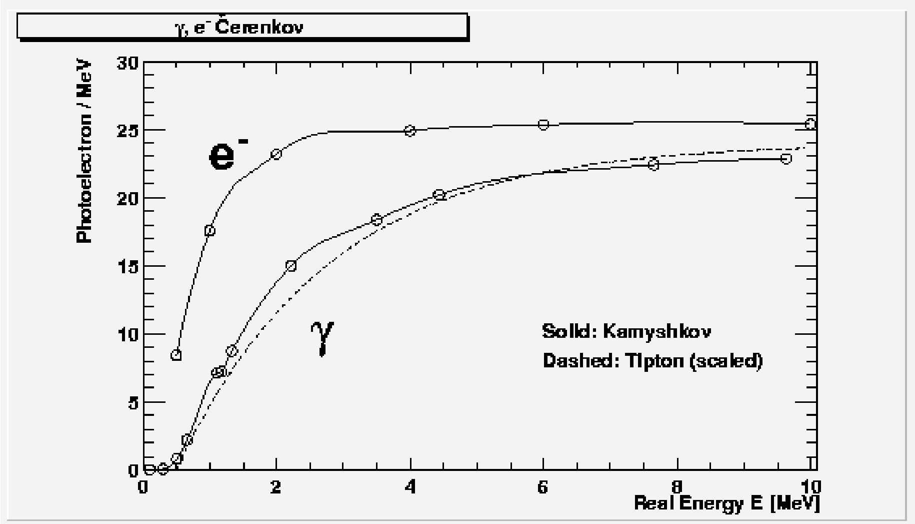
- Assumptions:
  - Muon flux ~200 Hz
  - Veto: 500 μs
  - Neutron life time:
    - 30 μs (Gd ~ 0.1%)
    - 200 μs (KamLAND)
  - 10% tail assumed from Gd (~8 MeV) signal

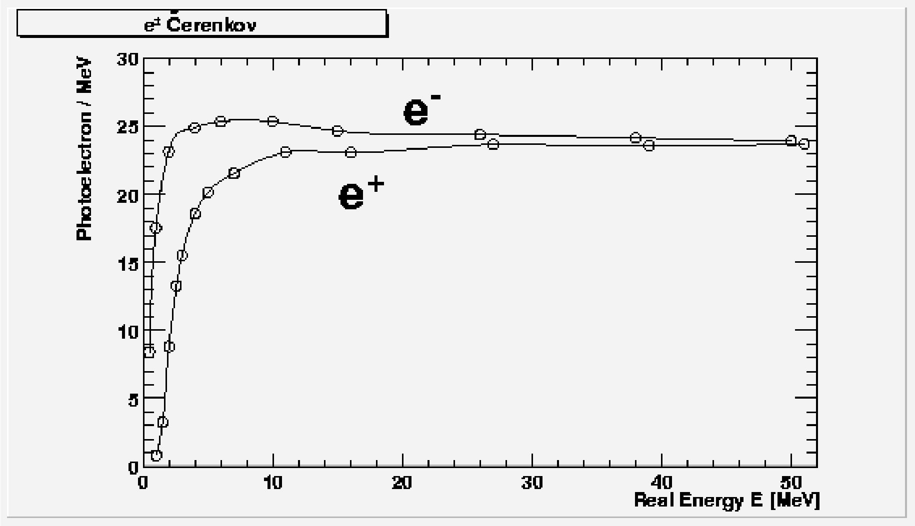


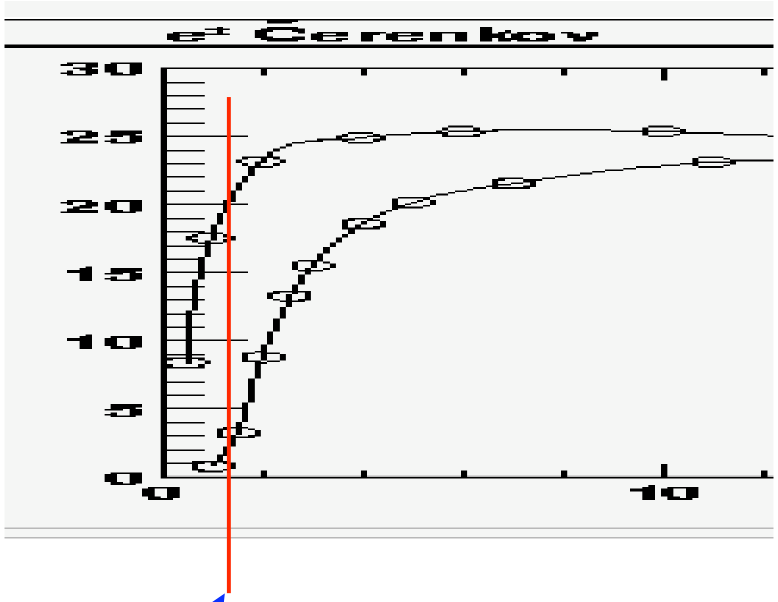
Delayed neutron emitting spallation products

Particle ID (e^+/e^-) using cherenkov lights

Calculated cherenkov light contribution in KamLAND





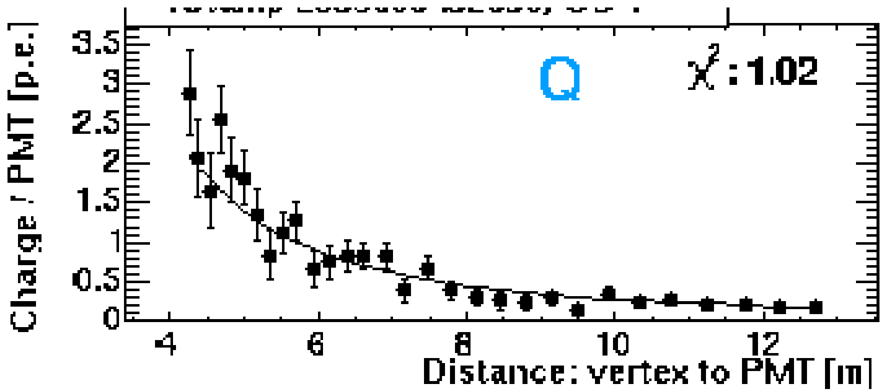


- geo-ν lower peak region
- e^+ (neutrino): 3 p.e./MeV
- e^- (^{9}Li b.g.): 20 p.e./MeV

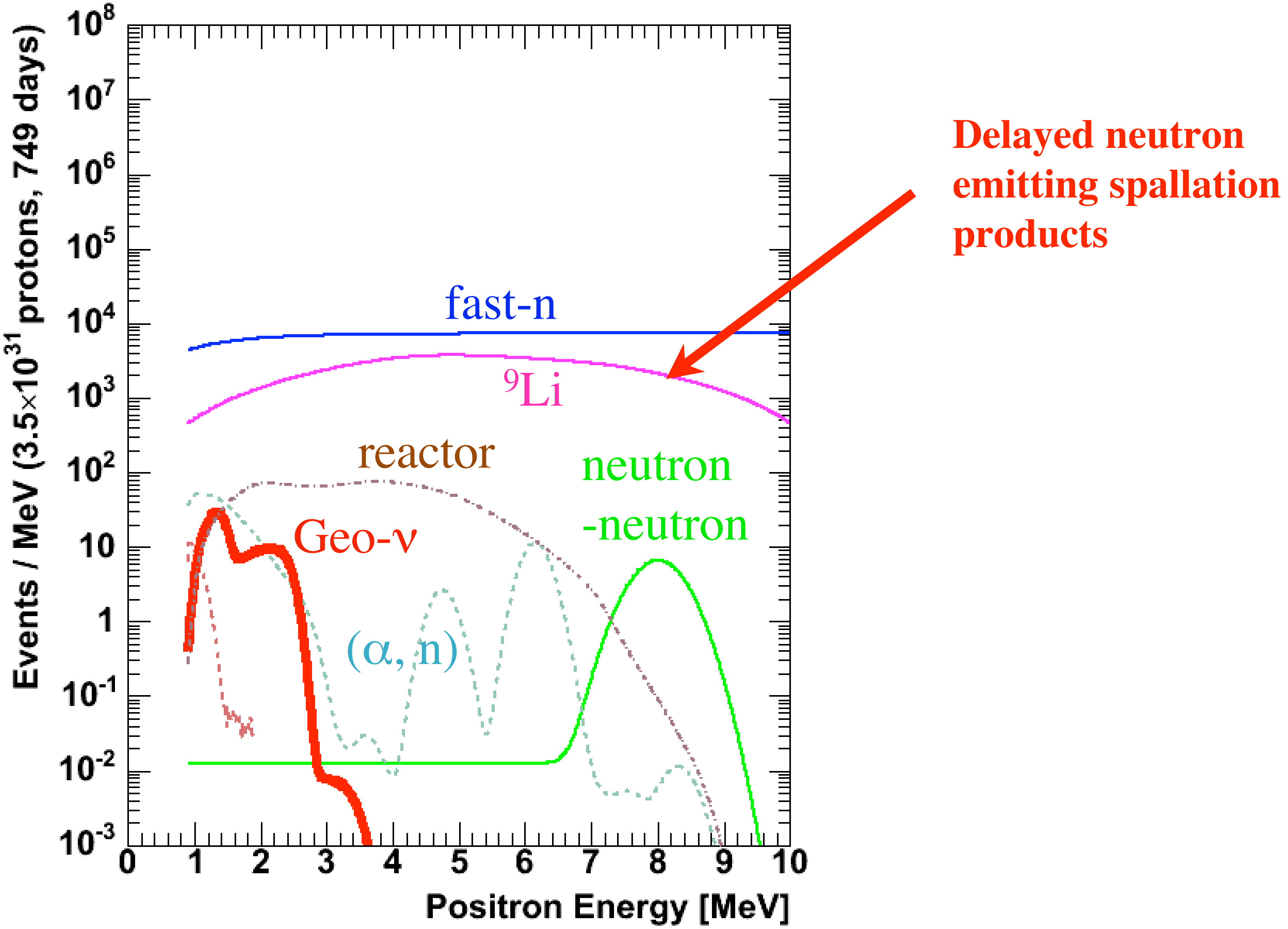
Particle ID (e^+/e^-) using cherenkov lights

- By developing a new scintillator with less light yield, extract cherenkov ring out of the uniformly emitted scintillation light.
- Actually, no need to extract the "ring", deviation from uniform light emission implies cherenkov contribution
- Scintillation 30 p.e./MeV, cherenkov 30 p.e./MeV (asymptotic) $\rightarrow$ rejection power > 100 (e^+/e^- at visible energy 1.4 MeV (geo-ν lower peak))

A geo-ν candidate 1.88 MeV

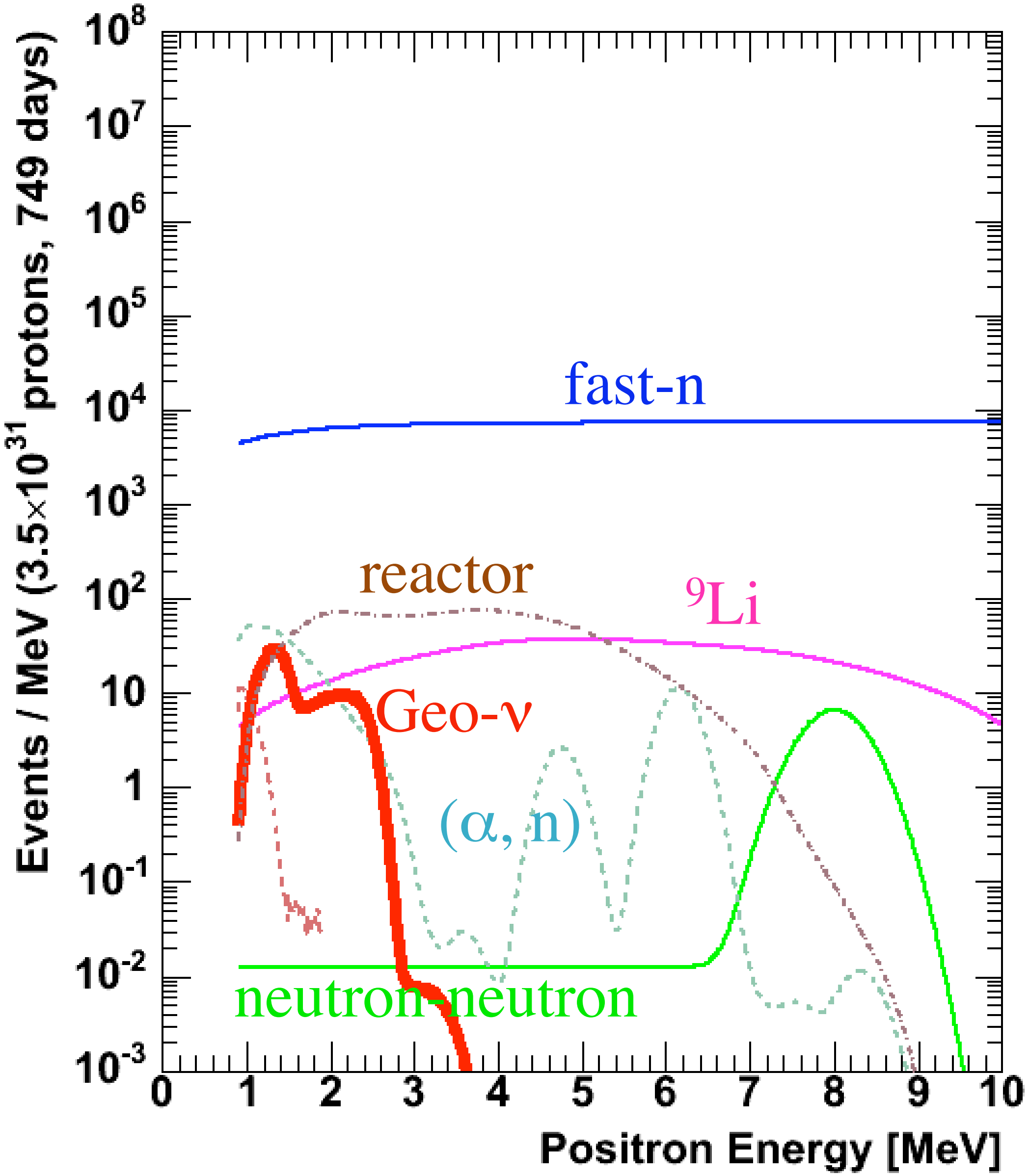


Charge distribution is very well fitted with an assumption of uniform light emission (KamLAND)



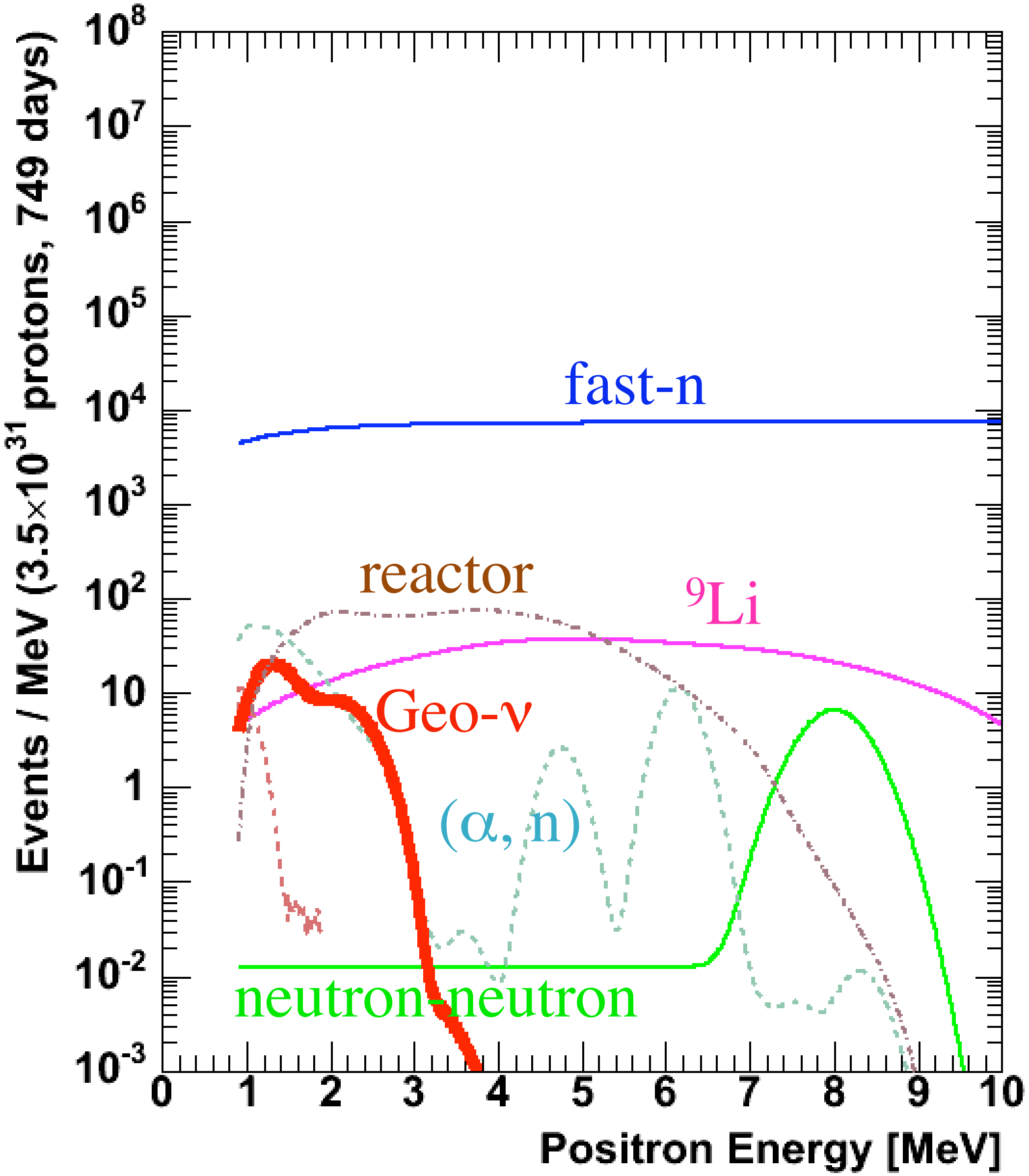
Events / MeV (3.5×10^31 protons, 749 days)
Positron Energy [MeV]
fast-n
9Li
reactor
neutron
-neutron
Geo-ν
(α, n)
Delayed neutron
emitting spallation
products

“Cherenkov/Sintillation detector” to identify e+/e-

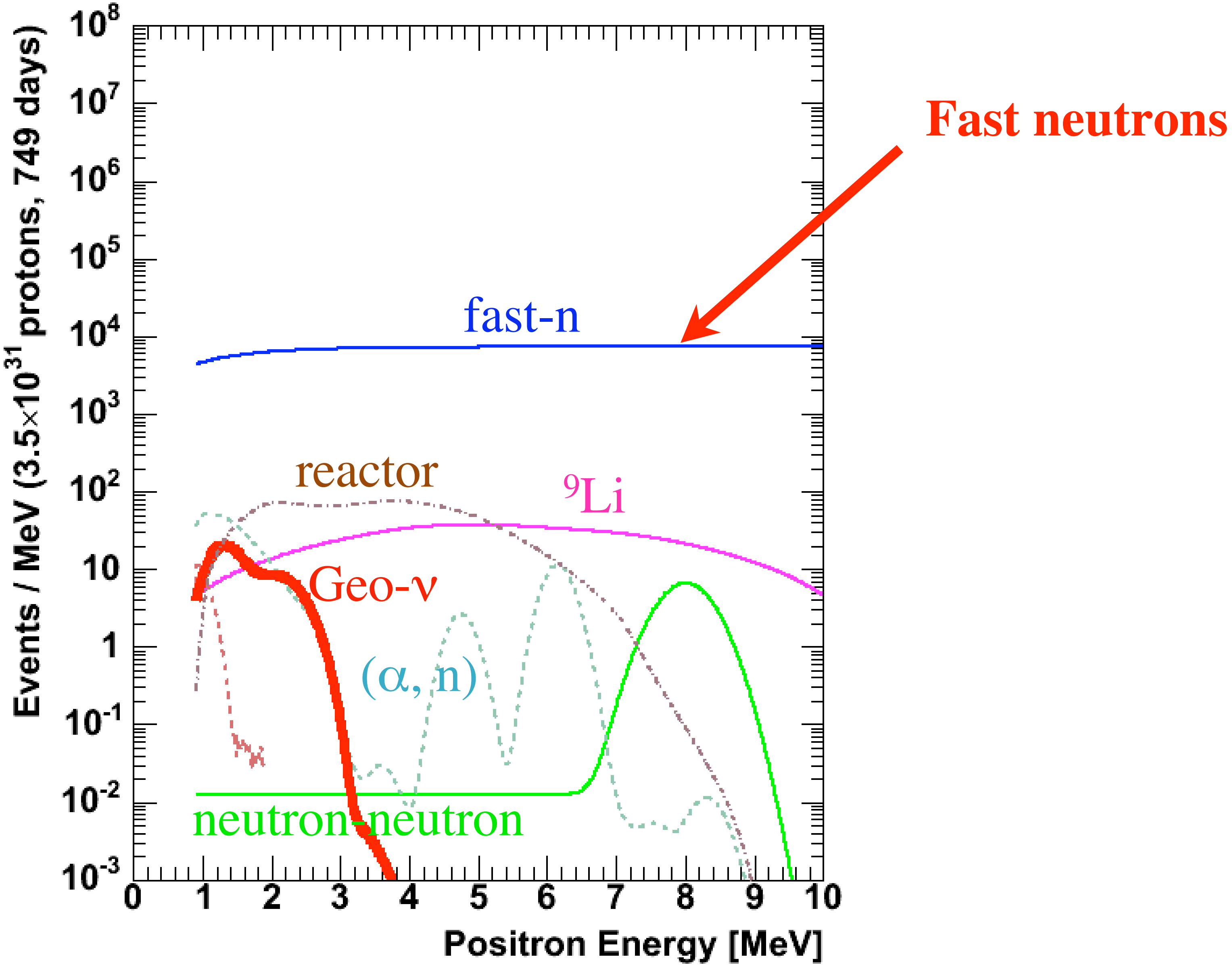


- Real KamLAND:
  - ~400~500 p.e. / MeV (scintillation)
  - ~30 p.e. / MeV (Cherenkov)
- “Che/Sci detector”:
  - ~30 p.e. / MeV (scintillation)
  - ~30 p.e. / MeV (Cherenkov)

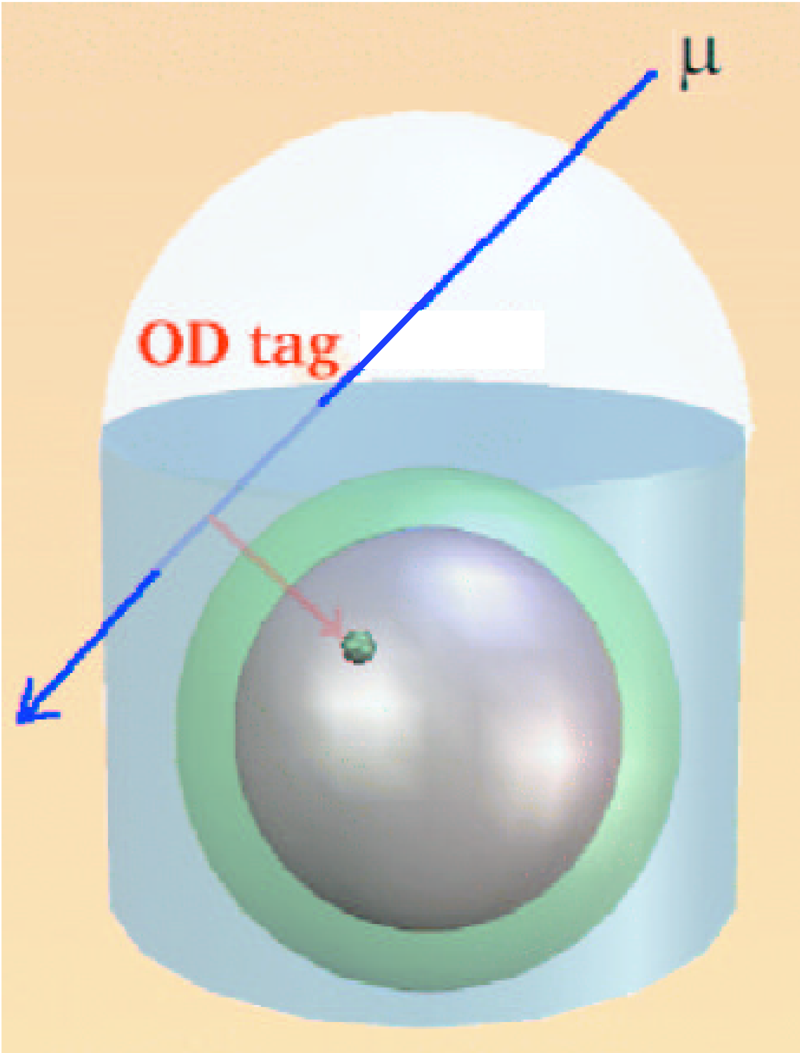
Lower energy resolution, but no problem



- Real KamLAND:
  $\sigma_E = 6.2\% / \sqrt{E/\mathrm{MeV}}$
  (~400~500 p.e. / MeV)
- "Che/Sci detector":
  $\sigma_E = 16\% / \sqrt{E/\mathrm{MeV}}$
  (~60 p.e. / MeV)

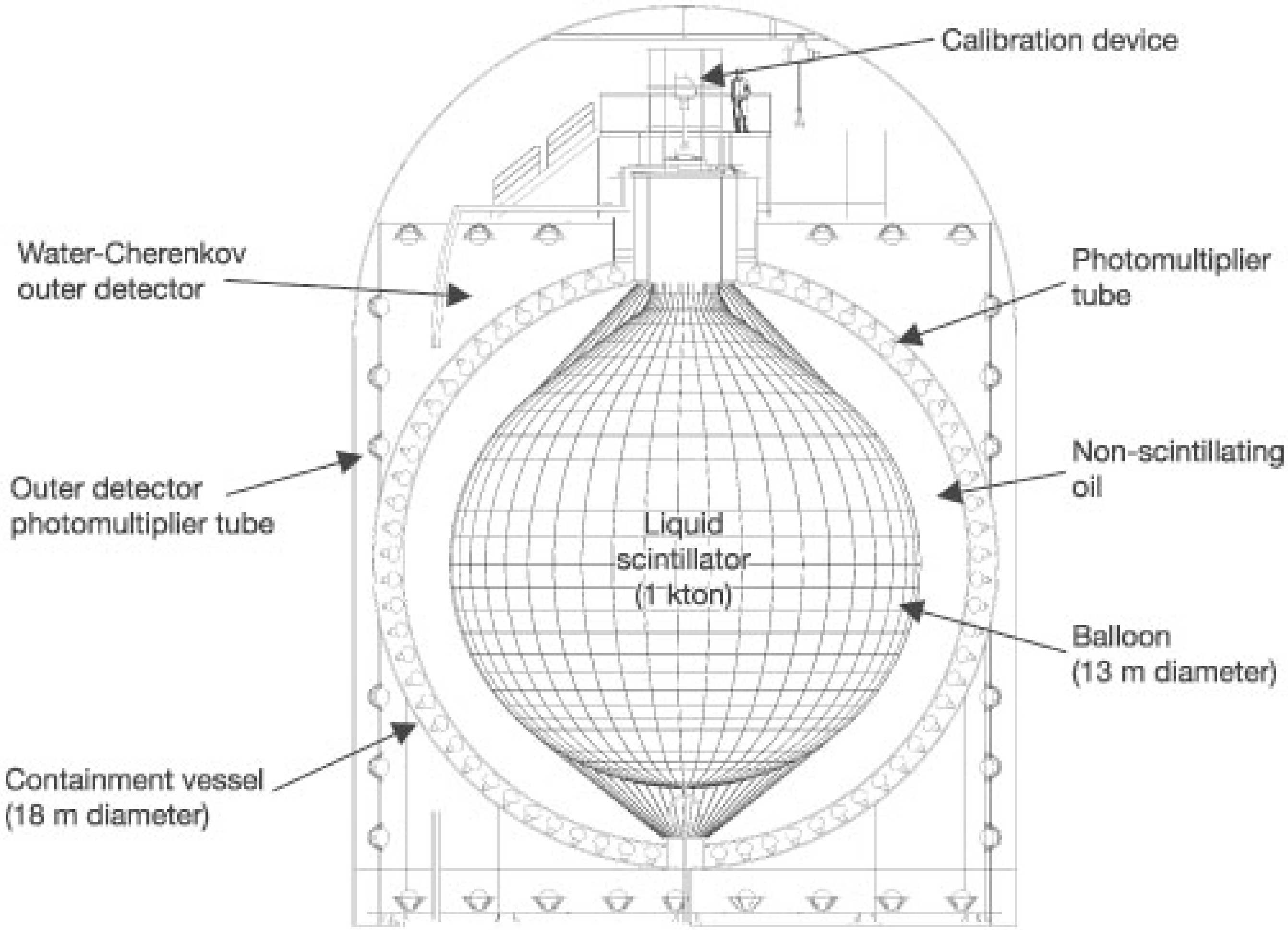

Fast neutrons
fast-n
reactor
^{9}Li
Geo-ν
(α, n)
neutron-neutron
Events / MeV (3.5×10^{31} protons, 749 days)
Positron Energy [MeV]
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
0 1 2 3 4 5 6 7 8 9 10

Fast neutron event rejection by outer detector (OD)

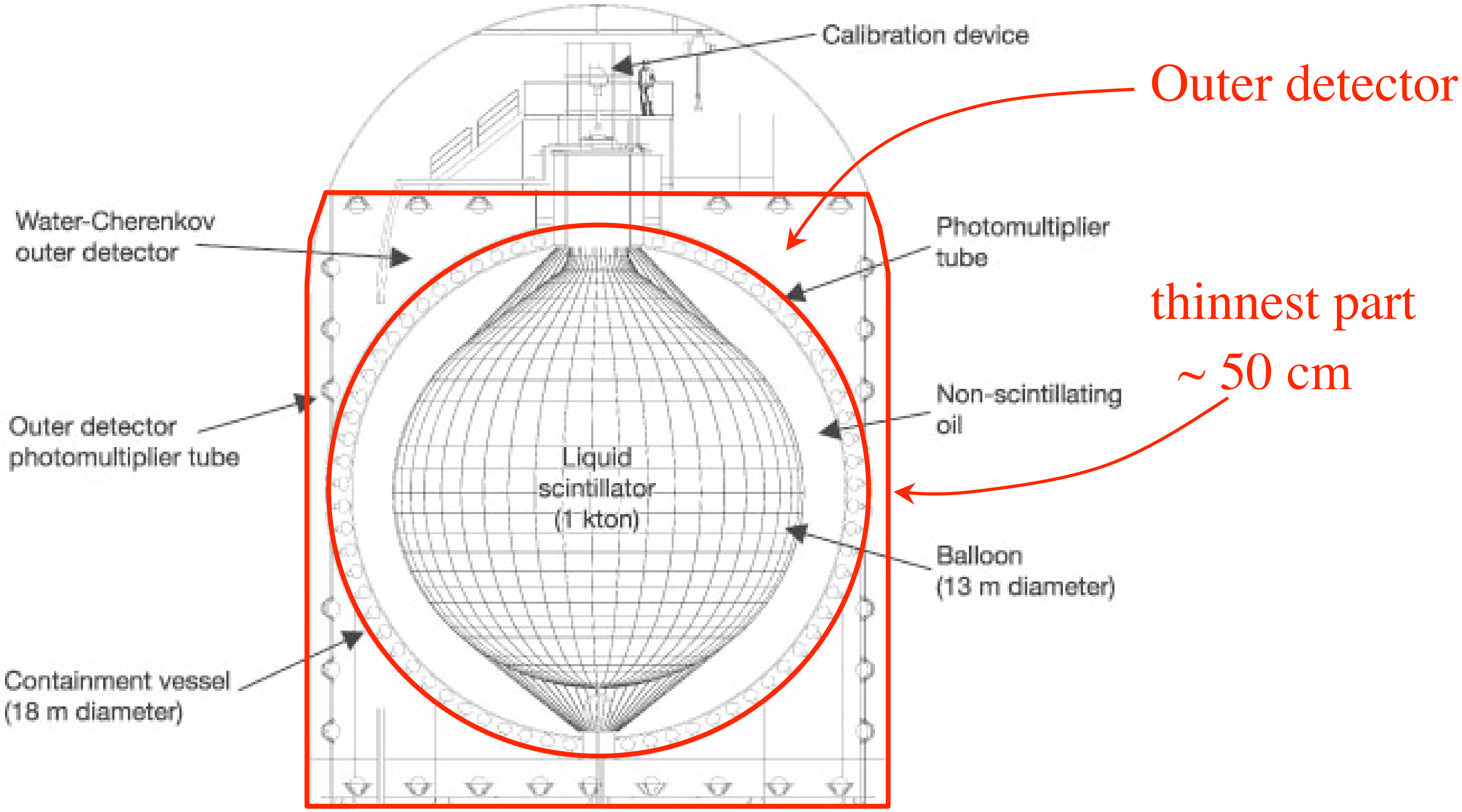


- By tagging the parent muon of the fast neutron, that event can be rejected (muon is in the same event as the prompt)
- Simple shielding of the neutron is not enough because shielding material also creates fast neutrons.

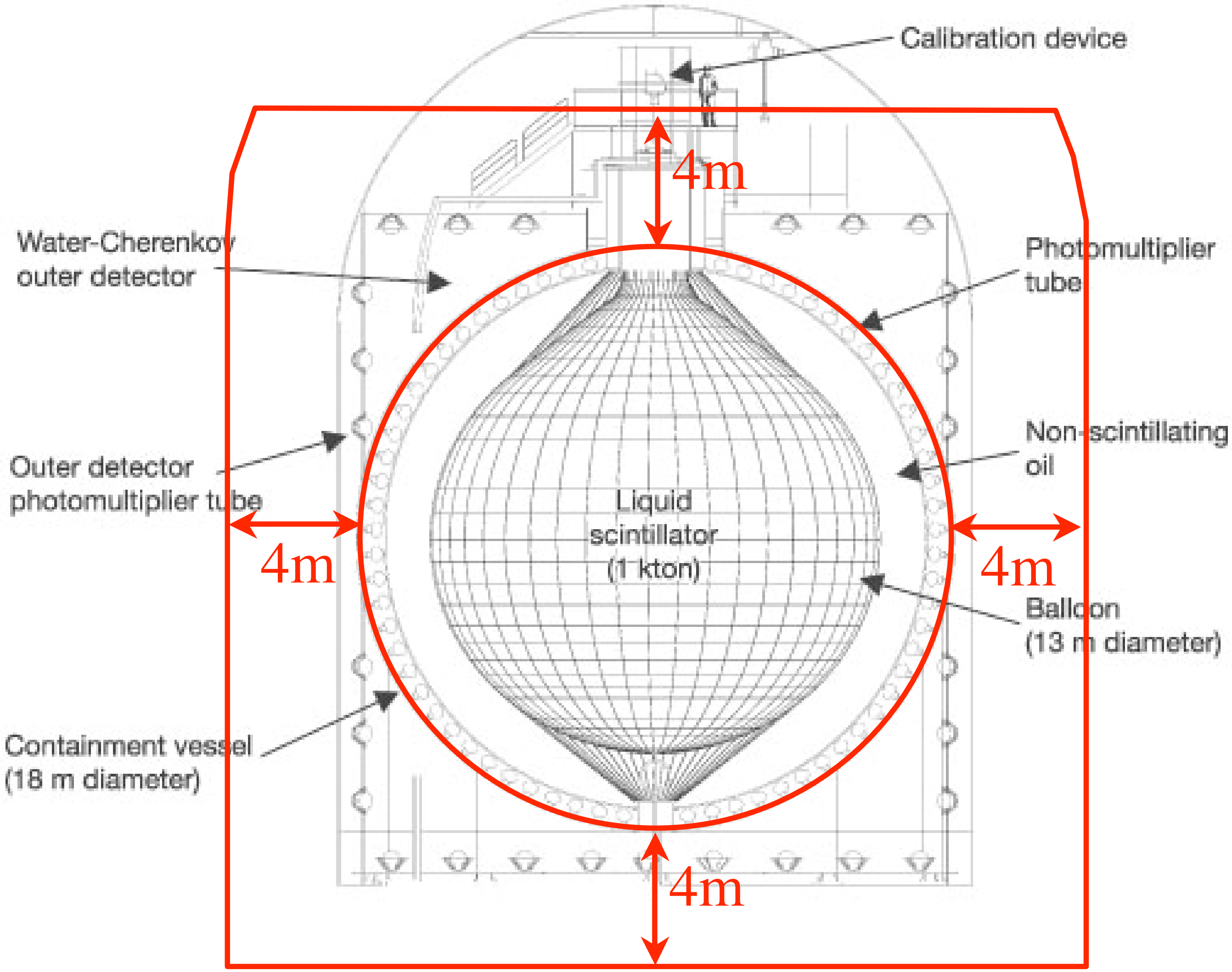
KamLAND detector



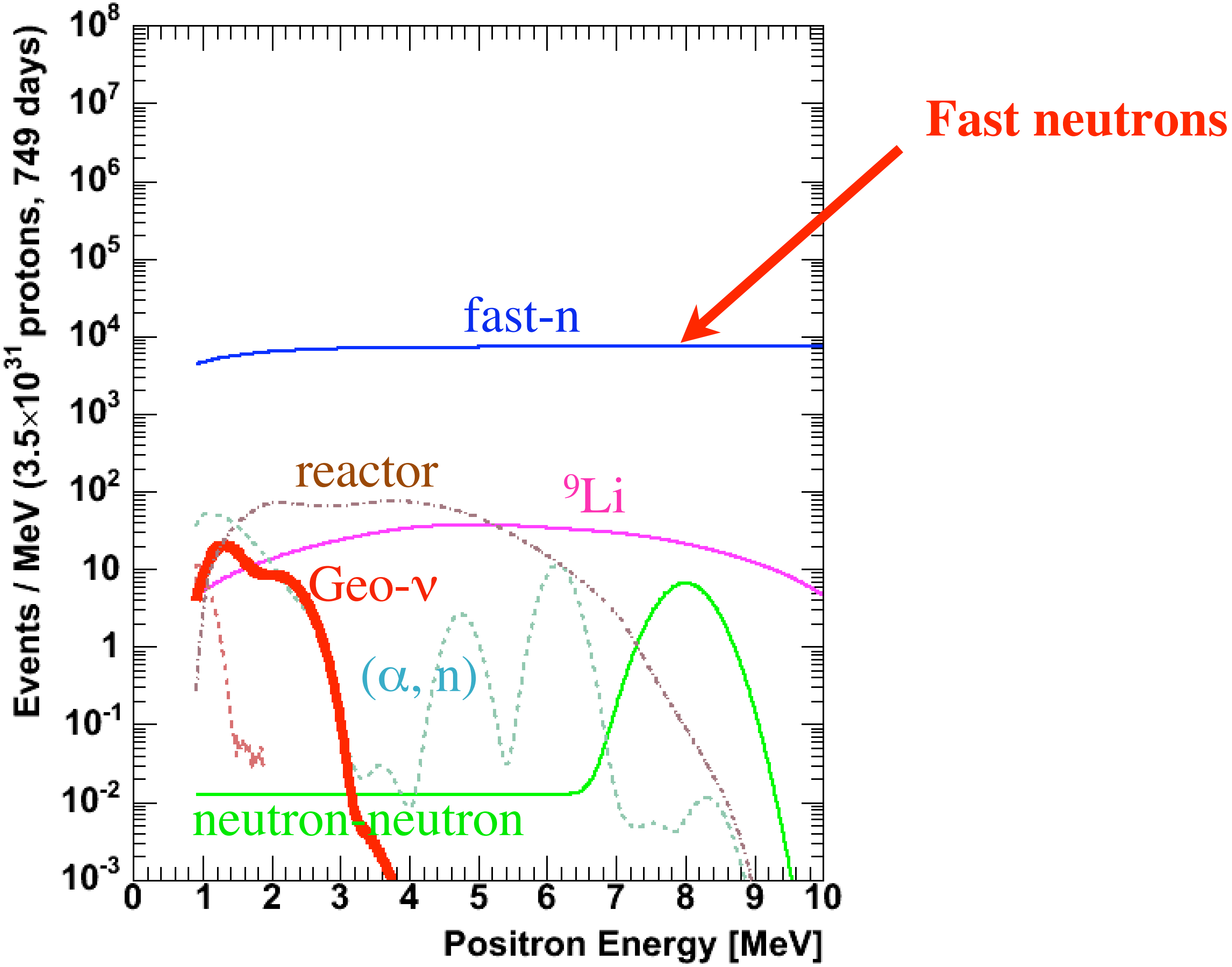
KamLAND outer detector



KamLAND with large OD



- 10 kton pure water
- 400 PMTs
  (c.f. present KamLAND = 225 PMTs)
- 600 Hz
  (300 m.w.e)
  (mean interval: 1.5 ms)
- ~5-MeV neutron
  → β~0.1
  → 30m~1μs
- Dead time:
  ~ 0.1 %



Fast neutrons
fast-n
reactor
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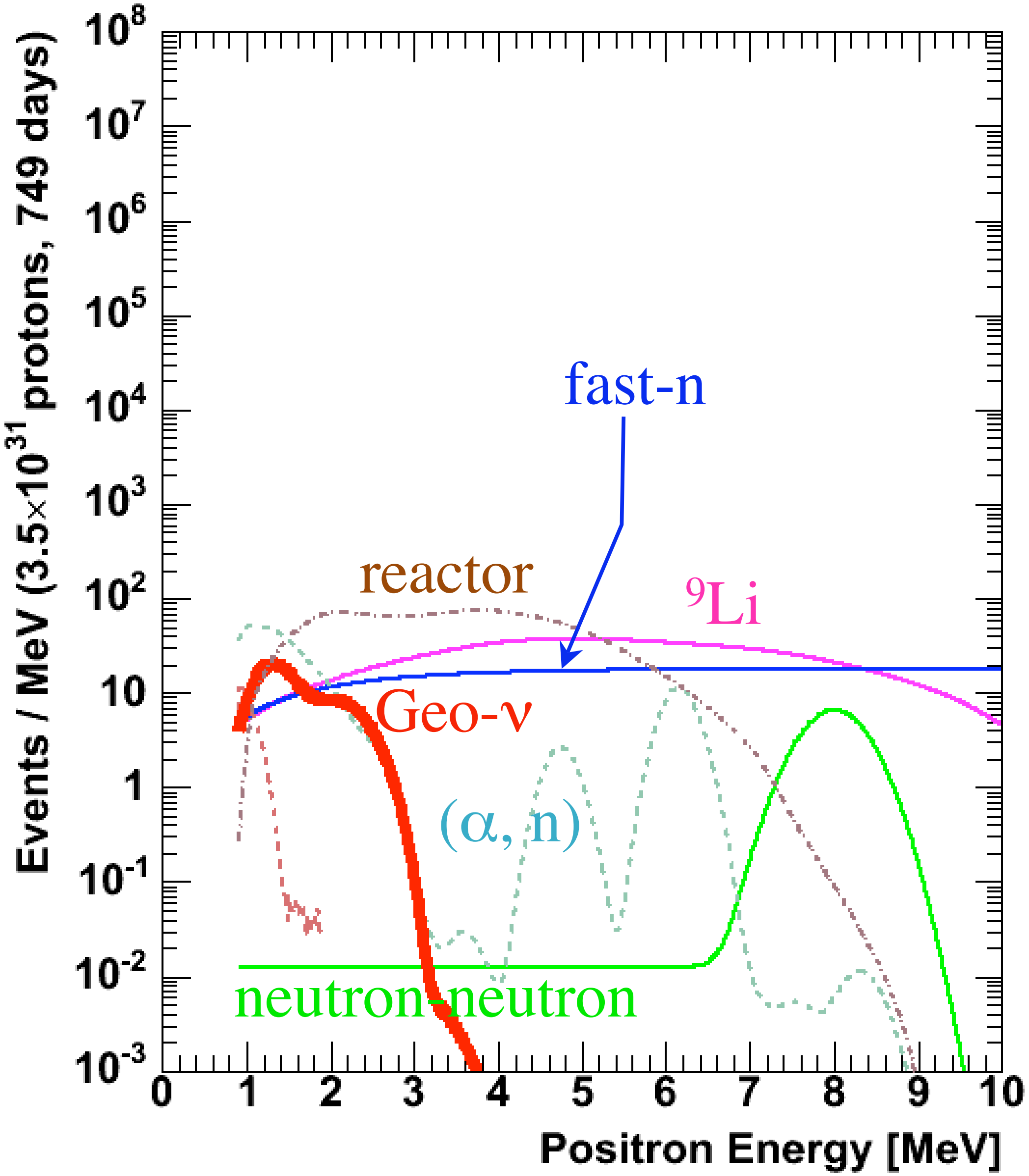
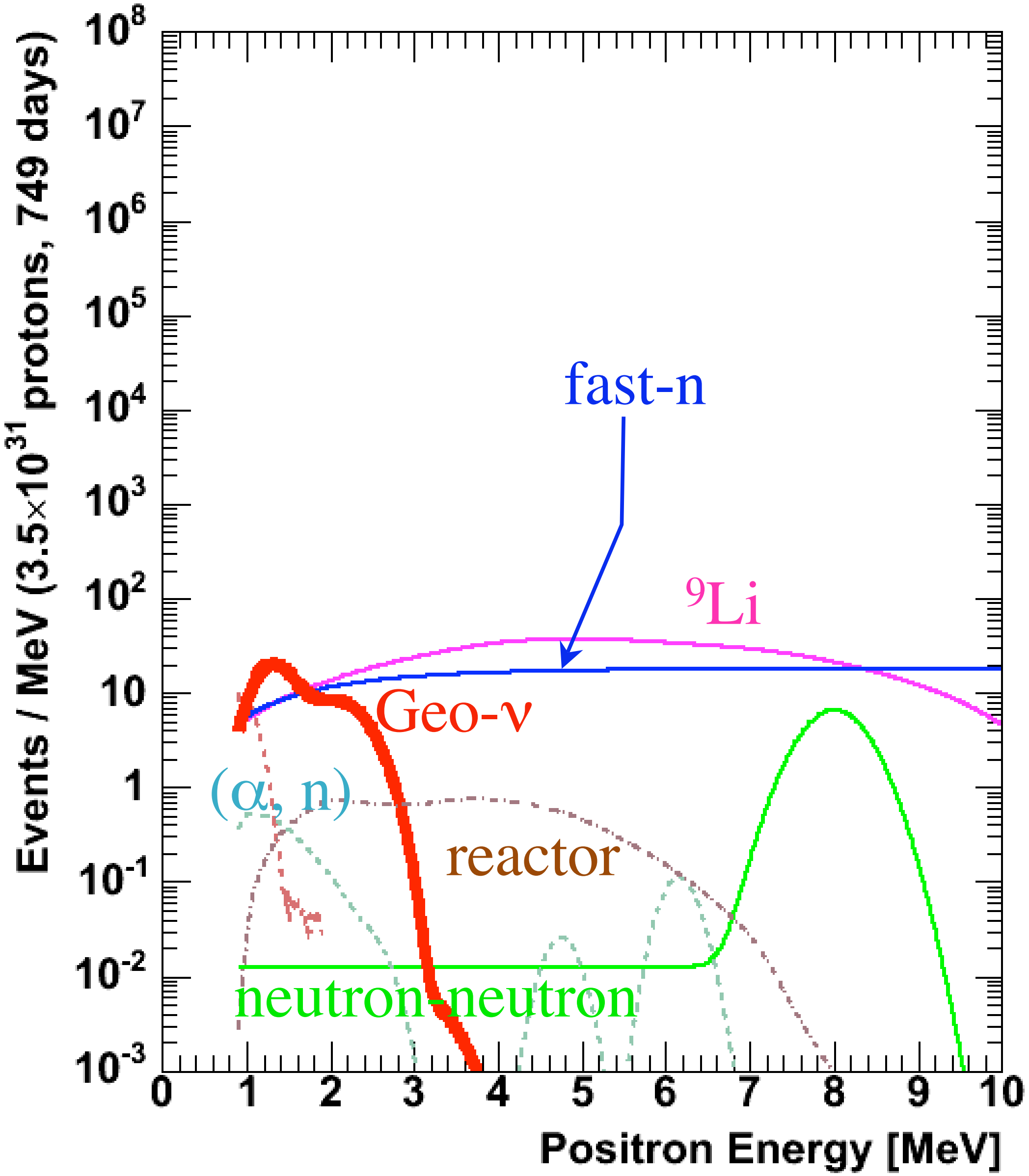
(α, n)
neutron-neutron
Events / MeV (3.5×10^{31} protons, 749 days)
Positron Energy [MeV]
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
10^{-1}
10^{-2}
10^{-3}
0
1
2
3
4
5
6
7
8
9
10

Fast neutron rejection by "large (4-m thick) OD"



- Large (4-m thick) OD detects the parent muon of fast neutrons
- Not only for a shield, but an active OD is needed to reject fast neutron background.
- OD inefficiency should be $< 10^{-3}$
  $\rightarrow$ monolithic OD

If reactor and (α, n) are also reduced …

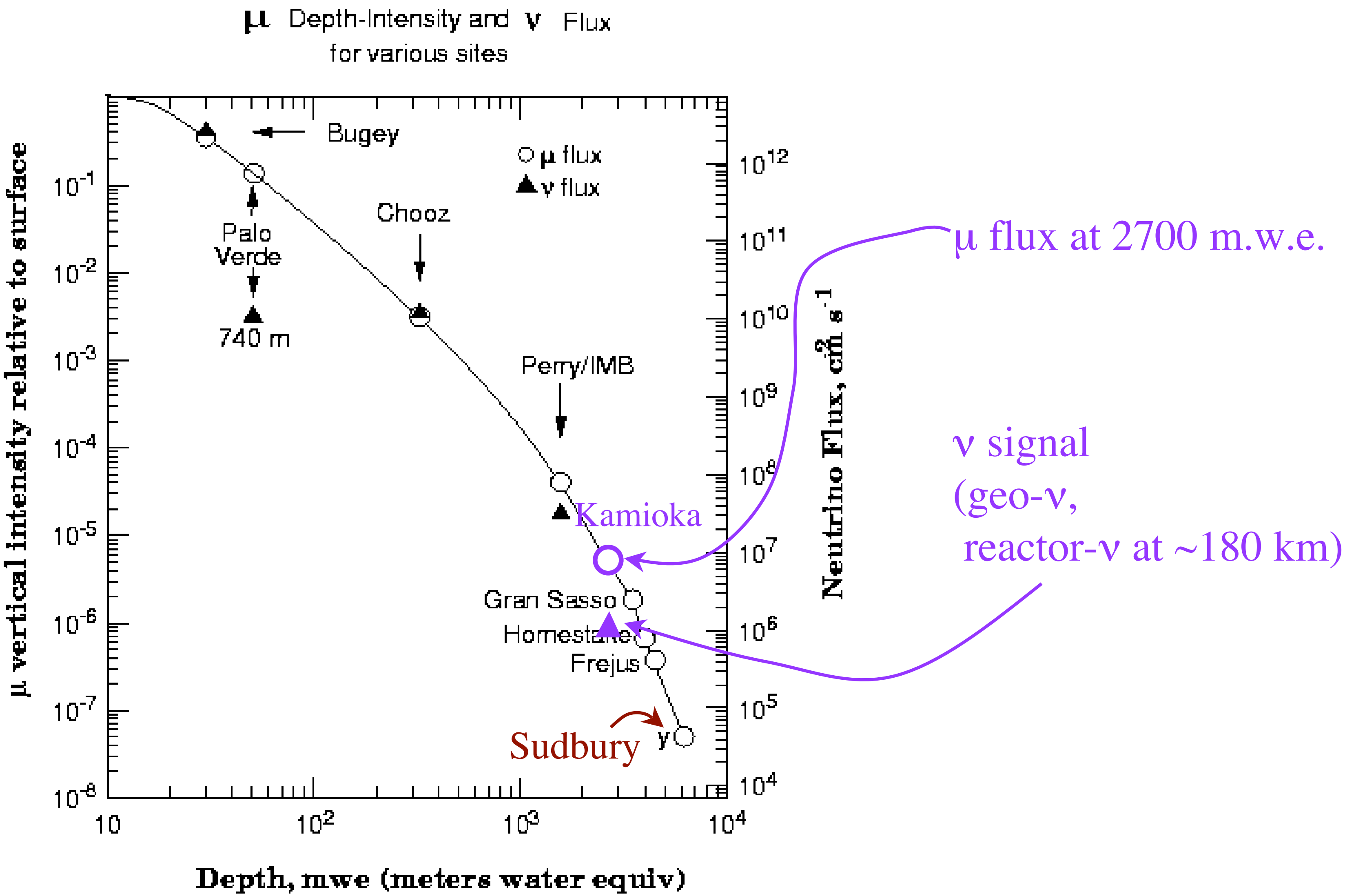


- Site with no neaby powerful reactor (like Hanohano)
- $^{13}C(\alpha, n)$ …

  … (from ^{222}Rn)

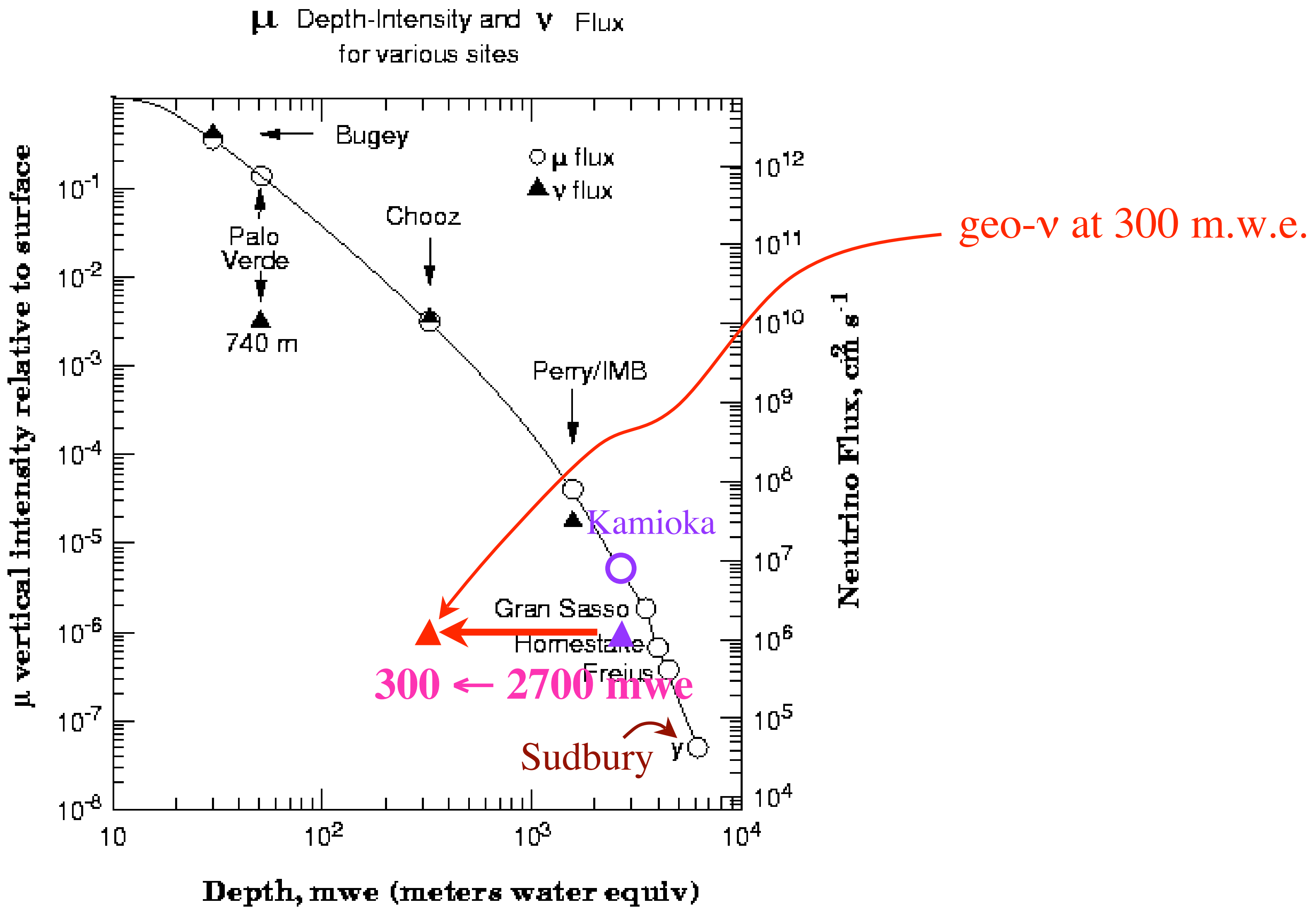
  Lesson of KamLAND …

ν signal intensity v.s. depth



CHOOZ full paper (arXiv:hep-ex/0301017)

ν signal intensity v.s. depth



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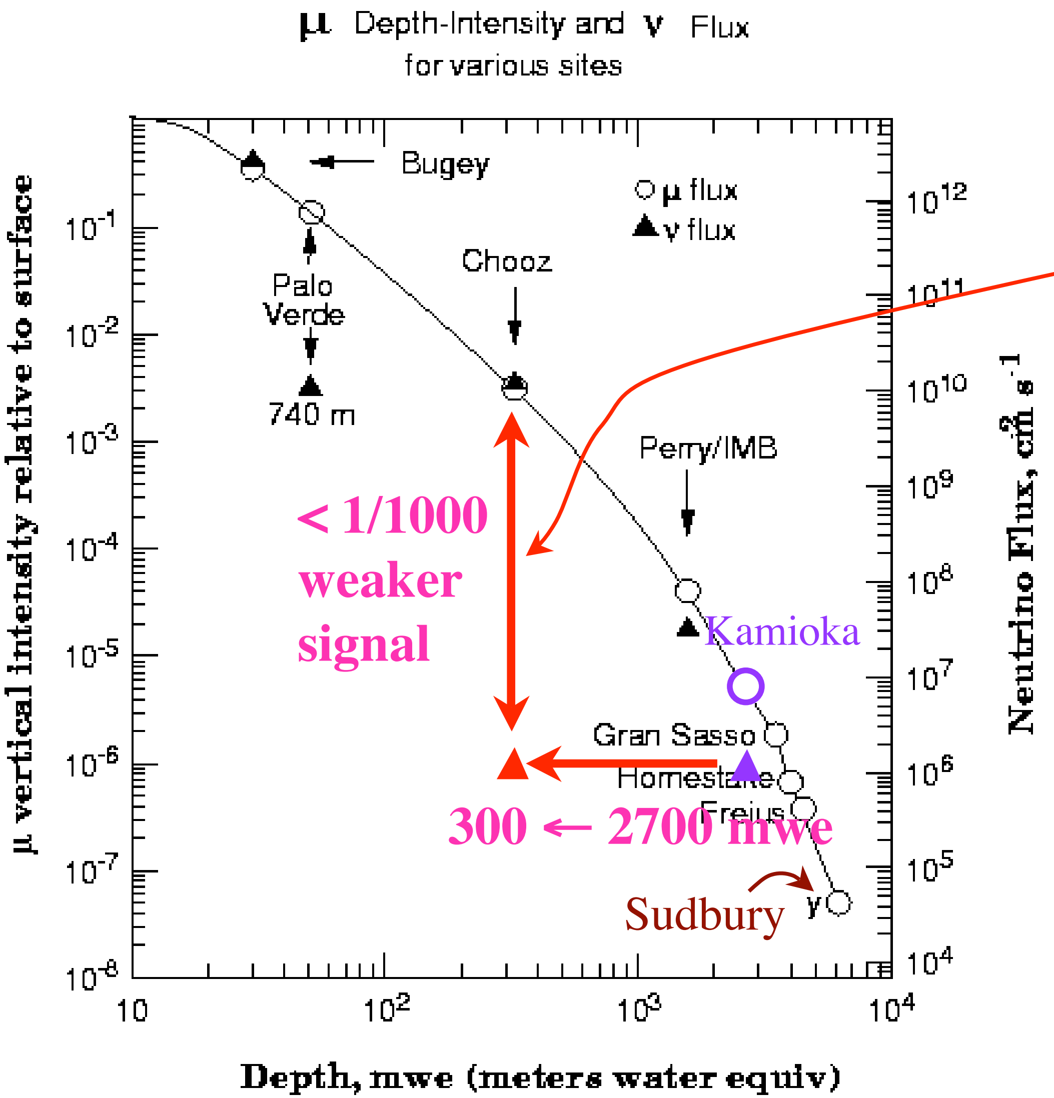
ν signal intensity v.s. depth



CHOOZ full paper (arXiv:hep-ex/0301017)

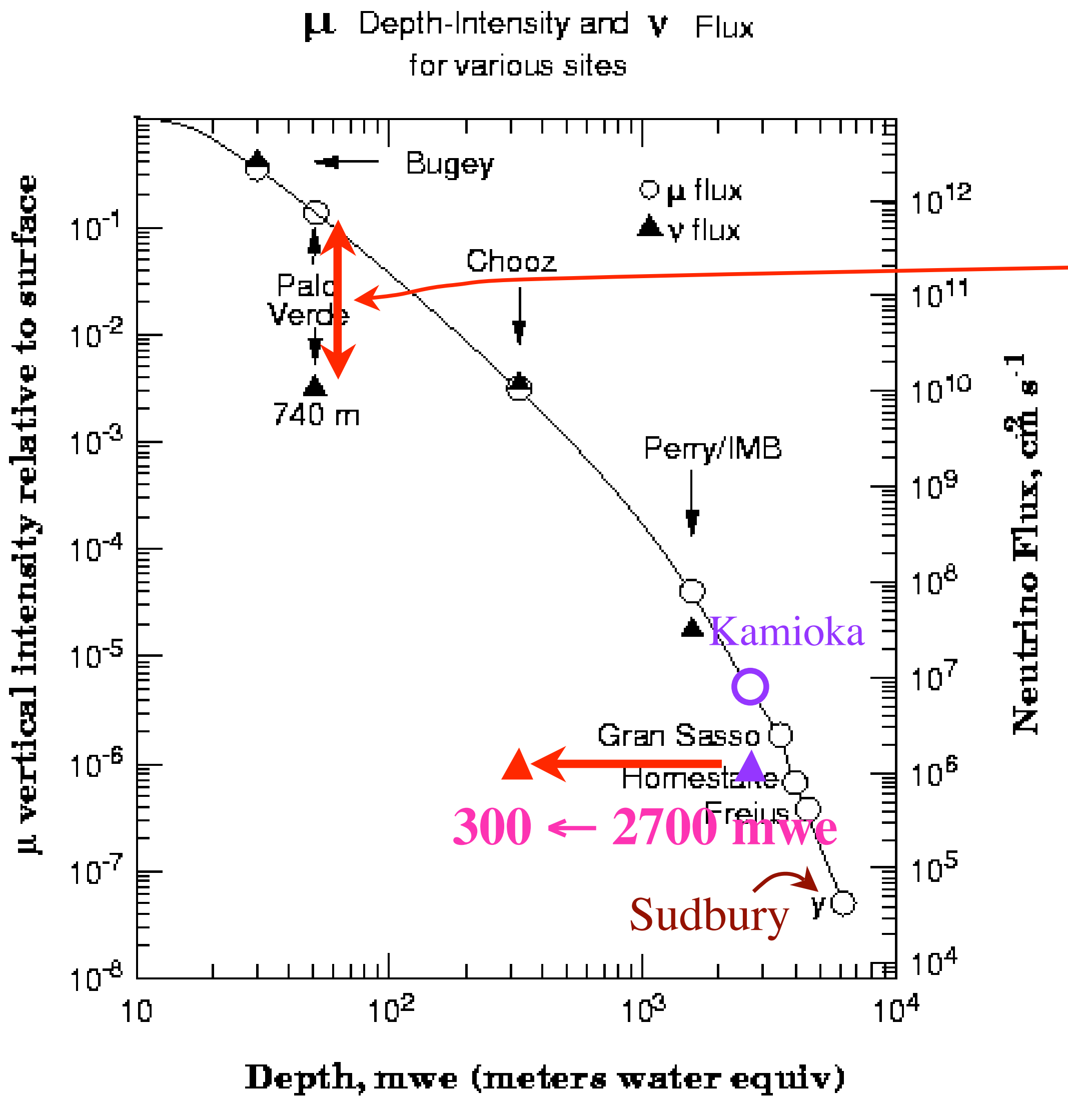
Challenging signal/noise ratio:

Not easy

Simple expectation in previous slides are just simple and naive

→Developing "shallow detector" for the next (or next-to-next) step is needed to start now!

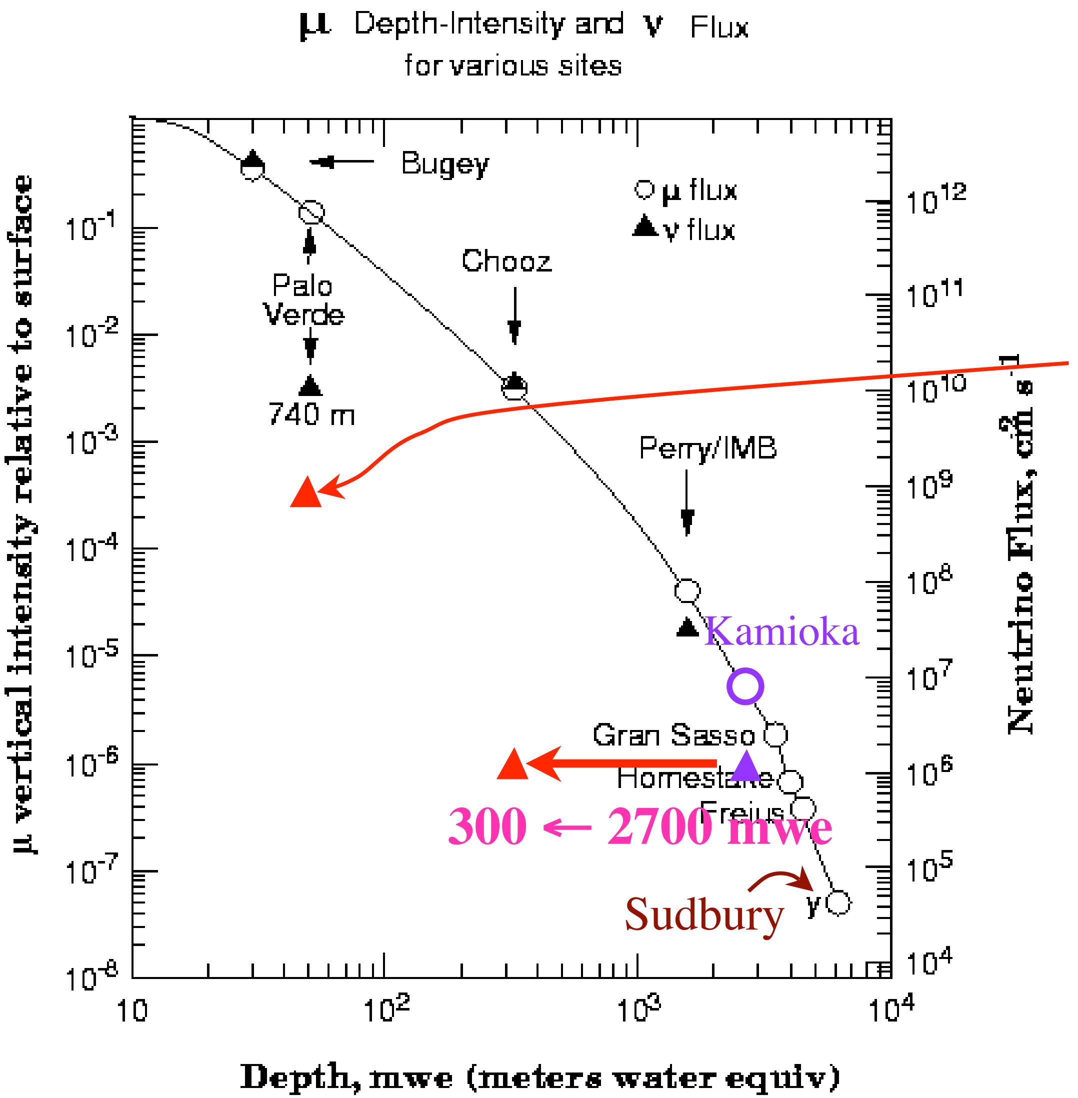
ν signal intensity v.s. depth



CHOOZ full paper (arXiv:hep-ex/0301017)

The most successful shallow experiment so far is Palo Verde.
It rejects cosmogenic b.g. with the segmented detector.
For geo-ν, kton is needed so segmentation is not realistic.
Here another idea:
large OD
and cherenkov PID

ν signal intensity v.s. depth



CHOOZ full paper (arXiv:hep-ex/0301017)

Here another idea:
large OD
and cherenkov PID

R&D of those techniques
with a reactor site …
usuful

KamLAND front detector?
(to confirm reactor
spectrum before
oscillation)

Conclusions

- Cheap, fast, shallow detector is needed for geophysics and applied physics.
- Delayed coincidence may make it possible.
- Is geo-ν at 300 m.w.e possible?