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Reactor neutrino monitoring with a mobile plastic scintillator array (PANDA)

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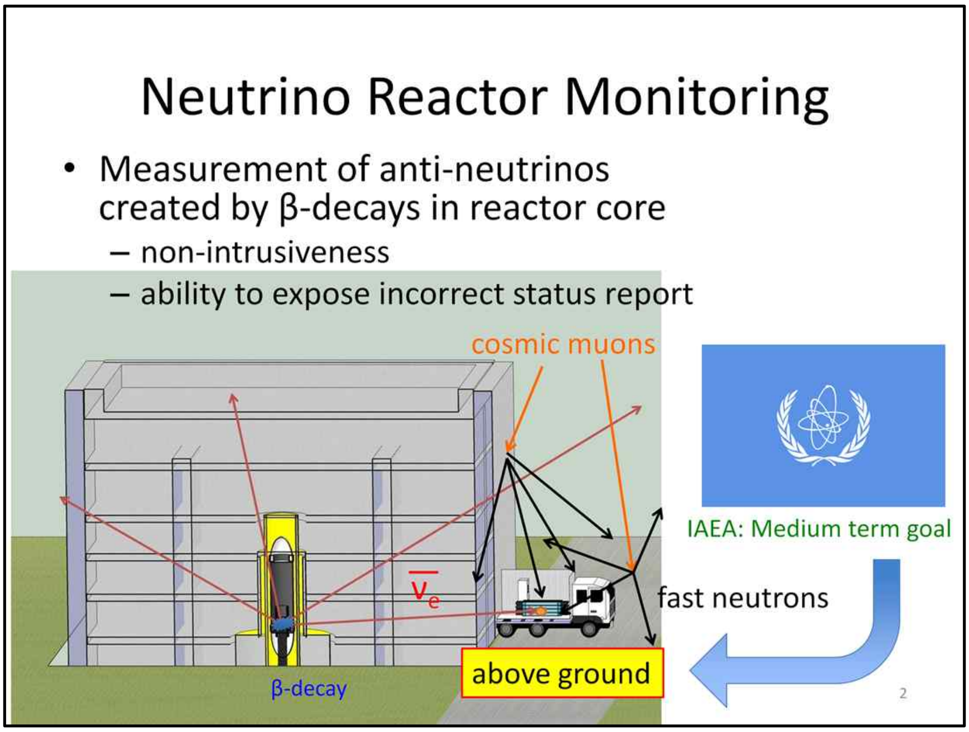
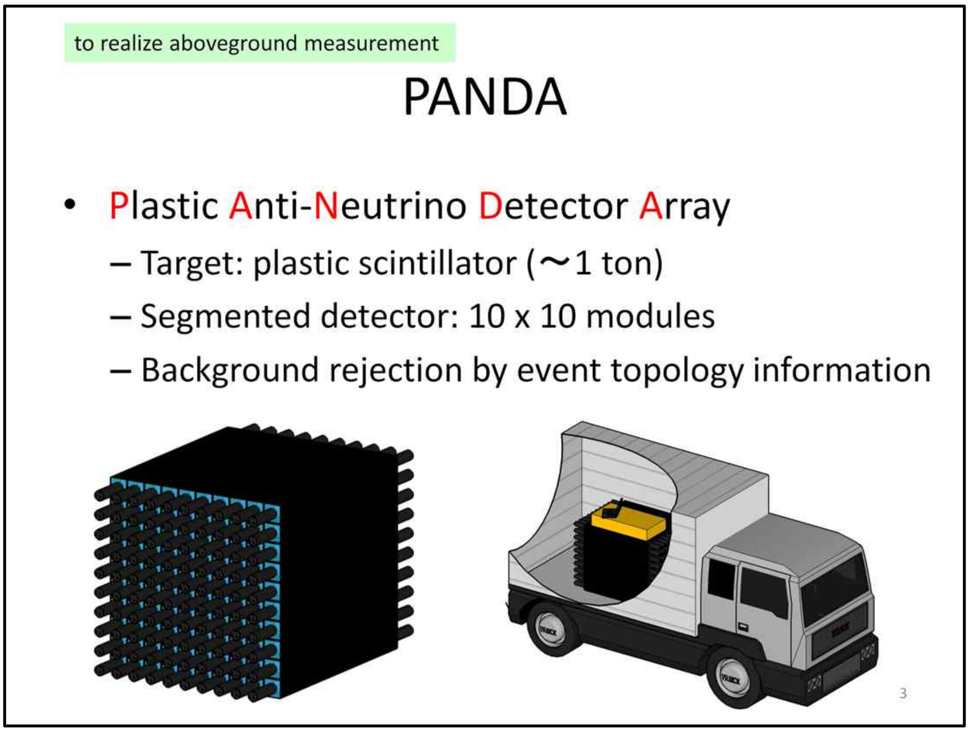
Let me talk about (CLICK) PANDA experiment.
I'm shugo oguri from KEK.



You know, Neutrino reactor monitoring is a monitoring method of reactor status using anti-neutrinos created by beta-decays in a reactor core.
There are at least two advantages in this method.
The first is non-intrusiveness because of permeability of anti-neutrinos.
The second is ability to expose incorrect status report.
That's because there is no alternative anti-neutrino source except for the reactor core.
(CLICK)
In order to take advantege of them, aboveground deployment is very important.
It is pointed out in medium term goal of IAEA.
(CLICK)
Because of more background than under the ground,
measurement at the surface is a big challenge.

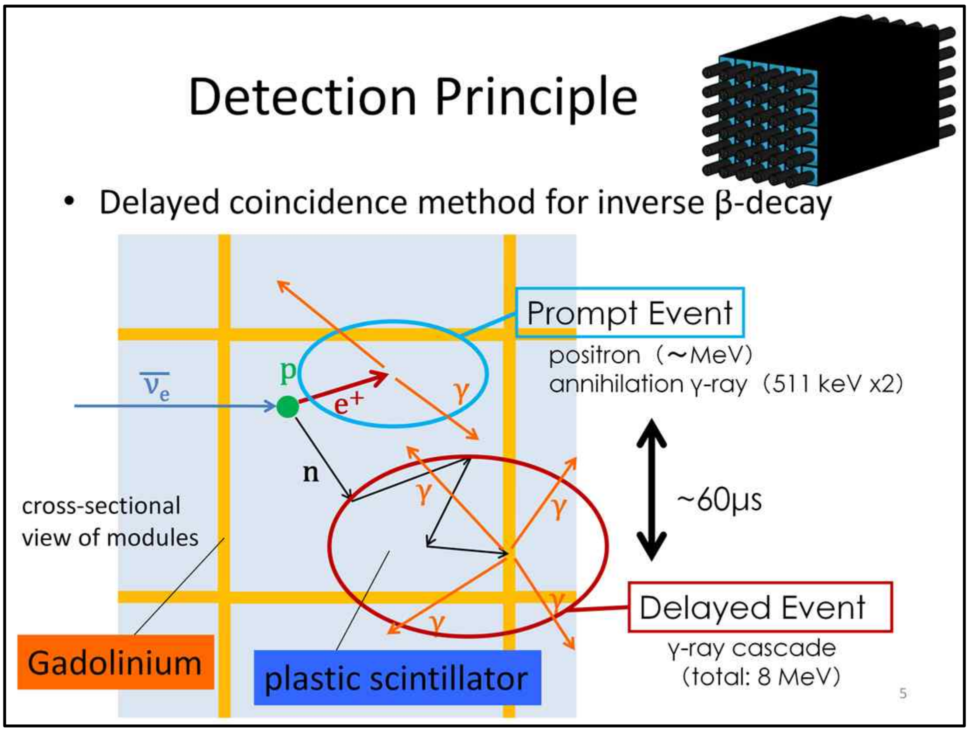


To realize aboveground measurement, we plan PANDA experiment.
PANDA stands for Plastic Anti-Neutrino Detector Array.
The target is plastic scintillator.
That’s why PANDA is easy to be transported using a van.
It consists of 100 modules.
Using the event topology information from the segmented detector,
PANDA has a strong background rejection ability.

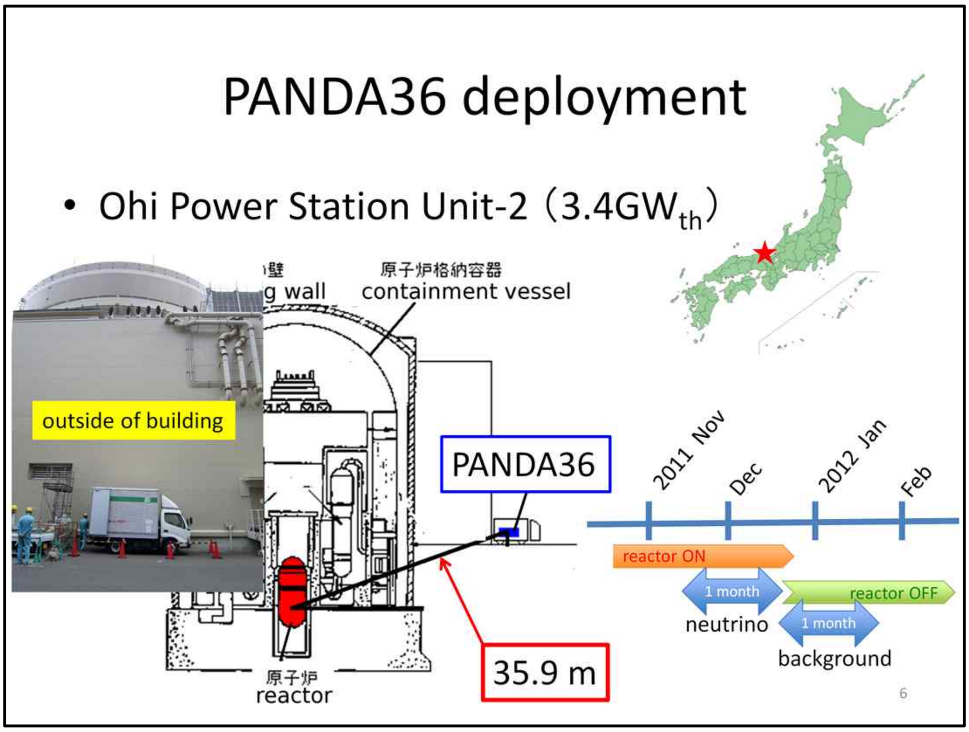
PANDA36

- Prototype of PANDA
  - Target: plastic scintillator (360 kg)
  - Segmented detector: 6 x 6 modules
  - Background rejection by event topology information

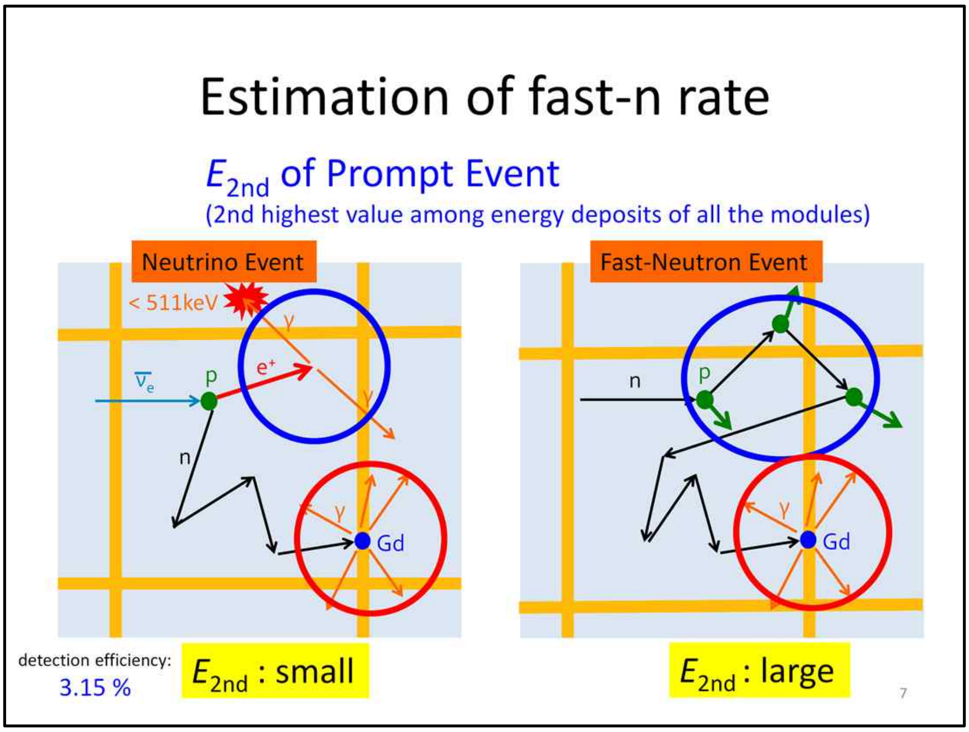
We have developed a prototype of PANDA which consists of 36 modules.
We operated the prototype for two months near a reactor core.
In this talk, we report the result and discuss the background candidates.



PANDA detects "Delayed Coincidence" of inverse beta decay, as usual.
This figure shows the cross-sectional view of PANDA modules.
Light blue area shows the plastic scintillator.
Yellow area shows (CLICK) the gadolinium doped sheet,
which is wrapped around the plastic scintillator.
It is one of unique features of PANDA.
We detect neutrinos using the pair of events.



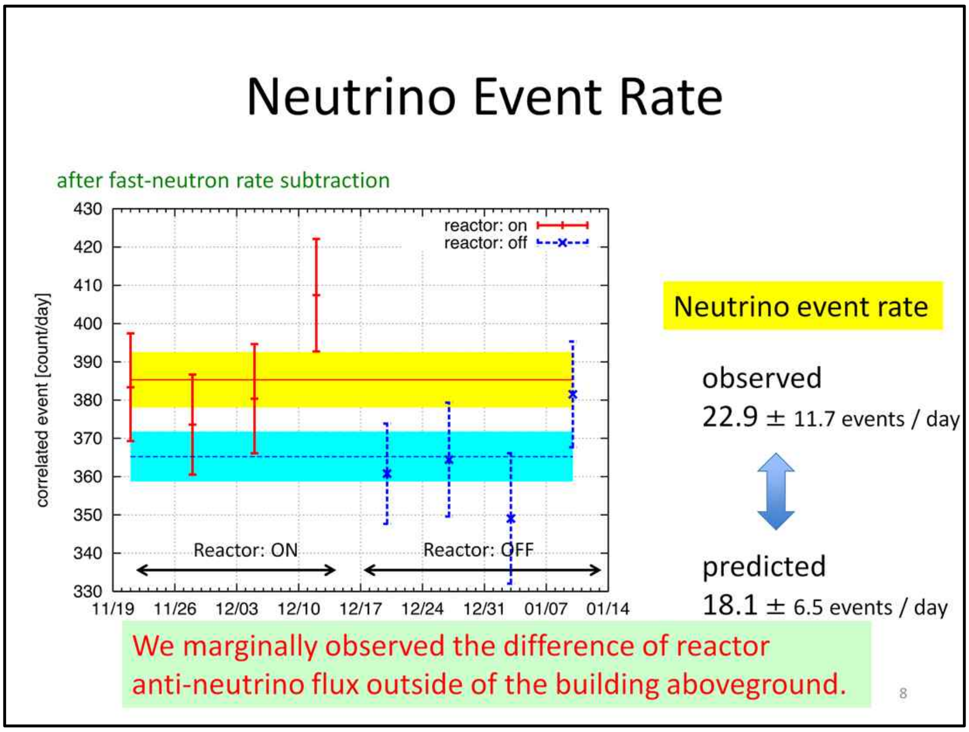
PANDA36 was operated in Ohi Power Station Unit-2 in Fukui, Japan.
The length between the detector and the reactor core was about 35.9 m.
Of cause, (CLICK) the detector was deployed outside of building.
The reactor was shutdown on Dec. 16th.
We measured the reactor neutrino for one month and background for one month.



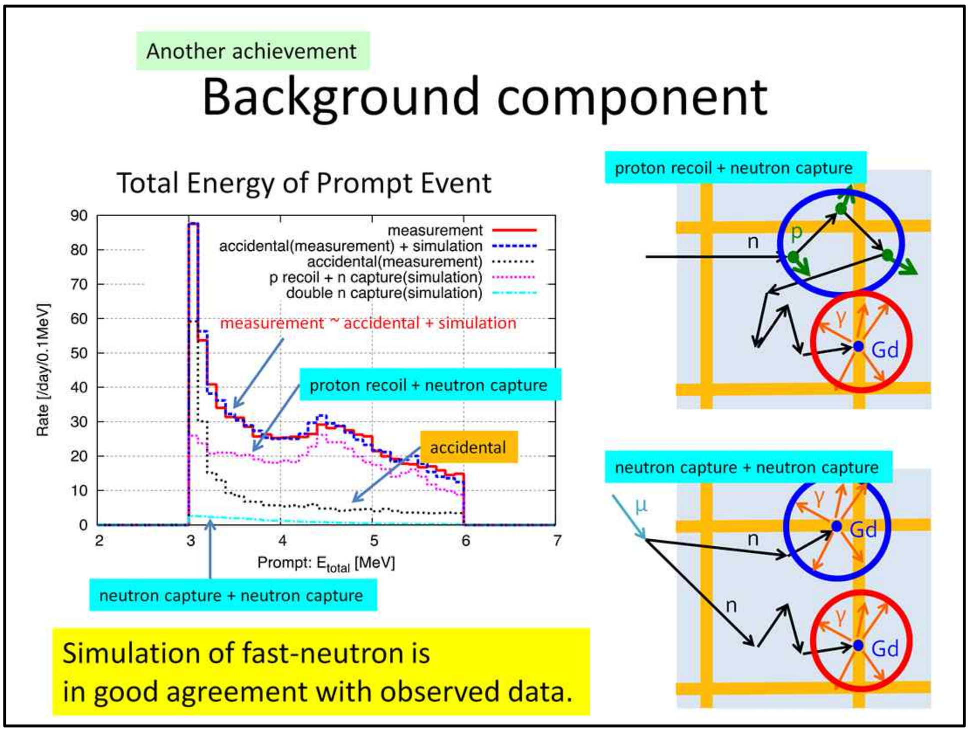
We also estimated the difference of fast neutron flux.
We paid attention (CLICK) to the annihilation gamma-rays, they are usually hit in other module than neutrino-hit module.
The energy deposit of Compton scattering of the annihilation gamma-ray is less than 511 keV.
On the other hand, the energy deposit of ionization of the positron is some MeV. (CLICK)
So, we used the 2nd highest value among energy deposits of all the modules, it is called E2nd.
In the case of neutrino event, E2nd must be less than 511 keV.
That's why we selected the events whose E2nd are small as neutrino events.
We also made another selection criteria.
In the criteria, the events whose E2nd are large were selected.
Therefore, the neutrino events were not selected.
Using this criteria, we estimated the fast neutron flux.

そこで、BGの変化量を見積もる必要があります。
私たちは、プロンプトイベントの対消滅γ線に注目しました。
このγ線は多くの場合違うモジュールで検出されますが、こちらの発光量は511keV以下となります。
一方で、ポジトロンの方は数MeVで明るく光りますので、この2番目に明るく光ったモジュールのエネルギーに着目しました。

通常のニュートリノセレクションでは、E2ndの小さいものを選んでいますが、
逆にE2ndの大きいものだけをとることで、ニュートリノイベントに感度のないセレクション条件ができます。
これにより、BGの変化量を見積もりました。



The time series data of neutrino like event rate is shown in this figure.
Estimated fast neutron event rate is subtracted from the selected event.
The reactor was in shutdown state from December 16th.
The differential rate between the reactor on period and off period, it means the observed neutrino event rate, is 22.9 events/day.
The result is consistent with the predicted neutrino event rate.
Therefore, we marginally observed the difference of reactor anti-neutrino flux outside of the building aboveground.



Another achievement of PANDA36 measurement is to clarify the background candidates.
This figure shows the spectrum of the total energy of the prompt event.
The blue dashed line shows the sum of the fast-neutron simulation and accidental background.
It is in good agreement with observed data which is shown by red solid line.
These two component is correlated background created by fast-neutron.
"Proton recoil and neutron capture" is a single fast-neutron event.
"Double neutron capture event" consists of two neutron events which is created by the same cosmic muon.

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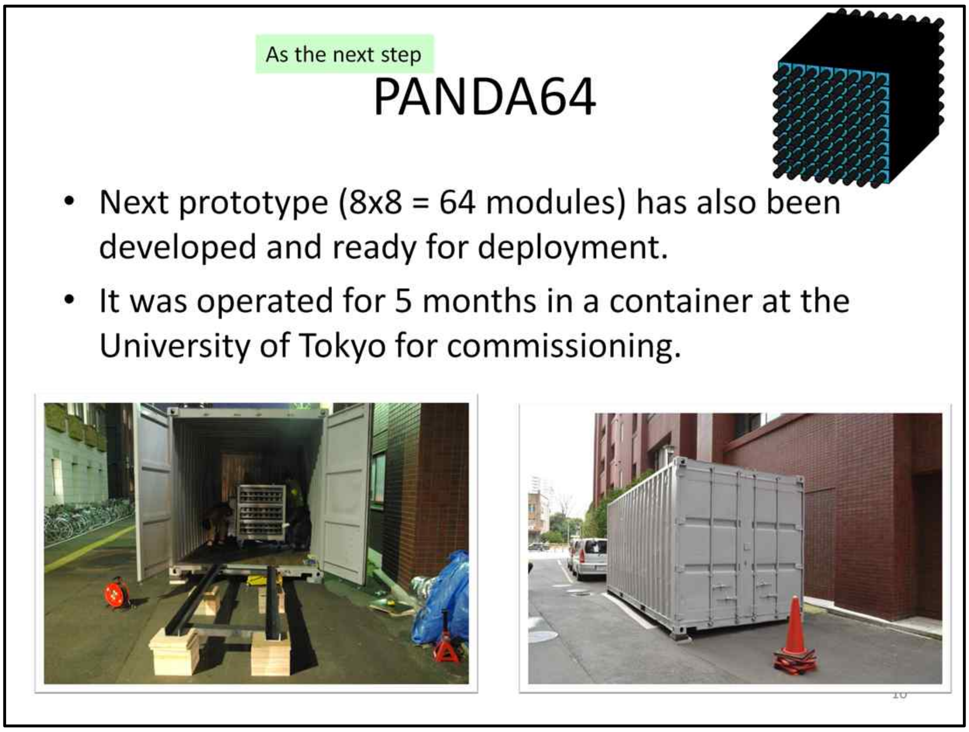
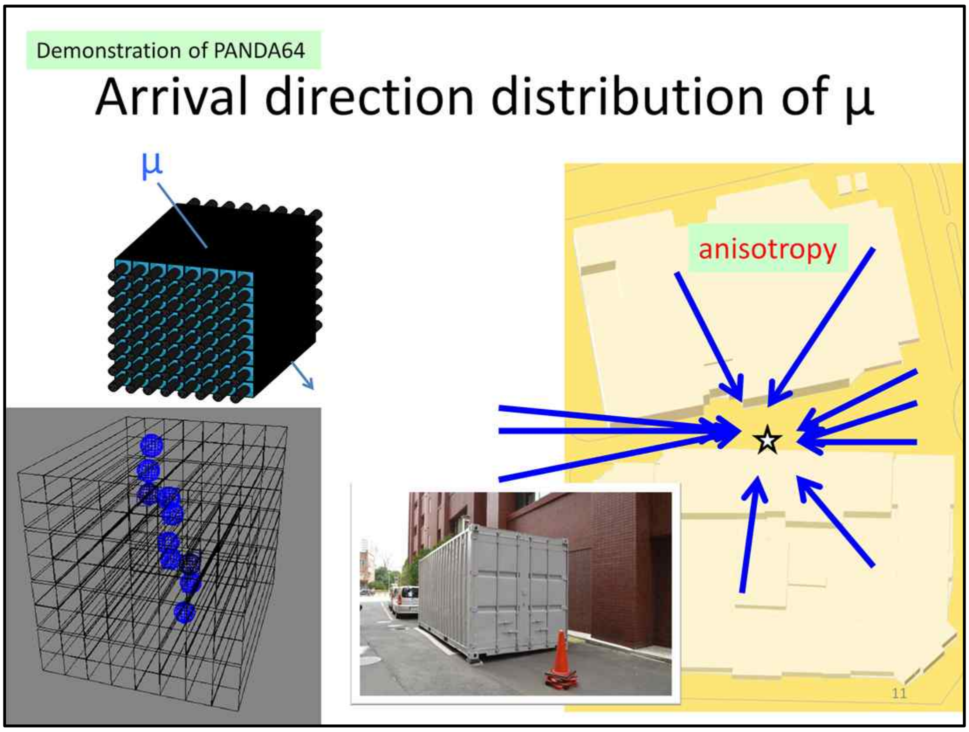
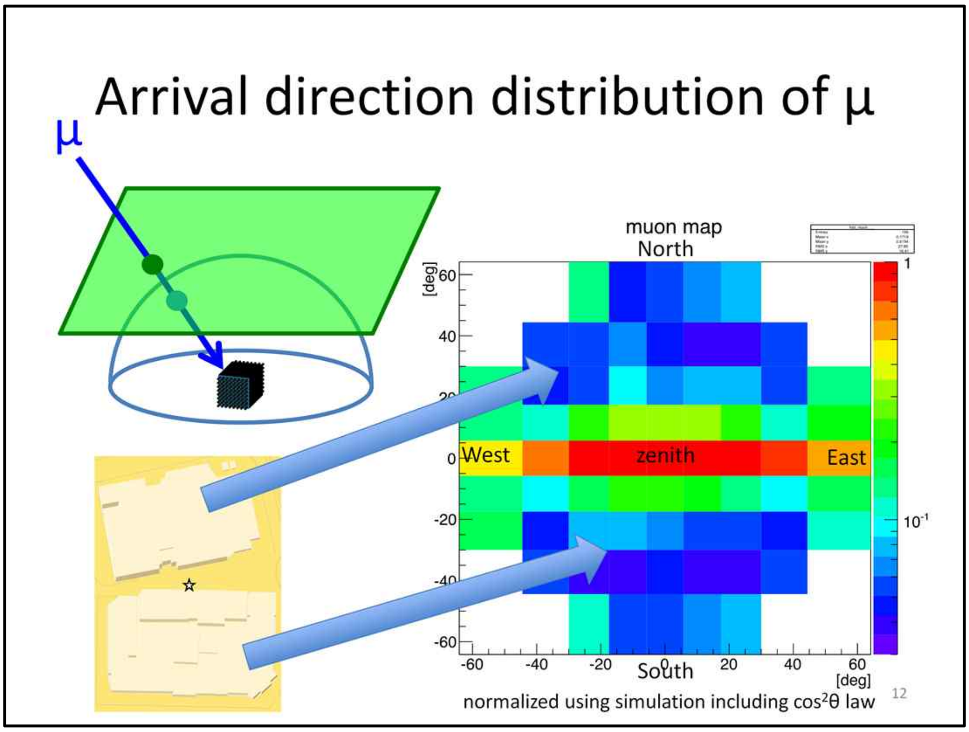
Quenching Factor
G.V. O'Rielly, N.R. Kolb, and R.E. Pywell. Nucl. Instrum. Meth. A, 368:745–749, 1996.



As the next step, we have developed another prototype, which is called PANDA64.
It is ready for deployment.
But, unfortunately, most of the nuclear reactor is in shutdown state in Japan, and we have not measure the reactor neutrino yet.
We have operated it for 5 months at the university of Tokyo for commissioning.

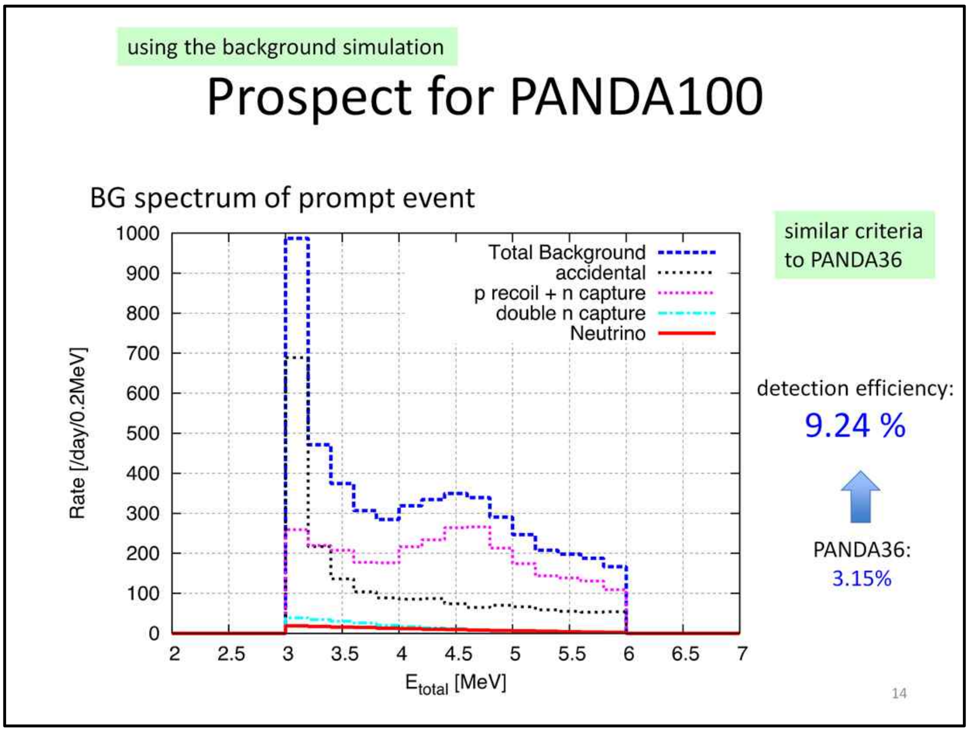


As the demonstration of PANDA64, we measure the arrival direction distribution of muon.
The animation shows the reconstruction of the path of a muon.
Some of muons are shielded by nearby buildings.
So we expects to measure the anisotropy of muon arrival direction like muon tomography.

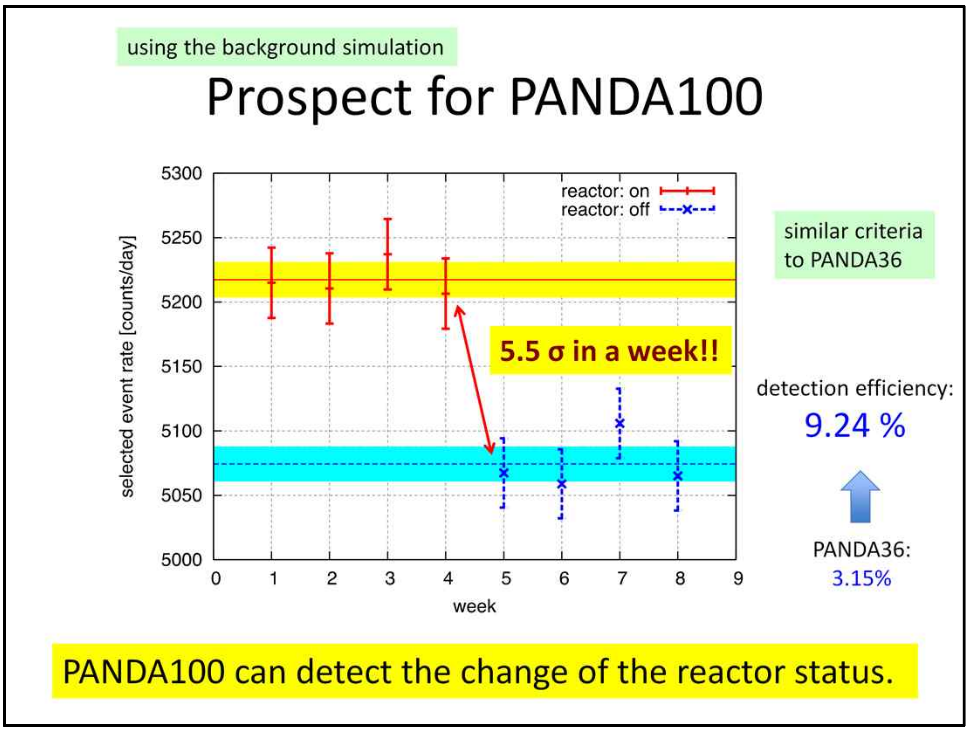


After the reconstruction of muons, we project the arrival direction to this plane.
(CLICK)
The distribution of muon arrival direction is shown in this color map.
It is normalized using simulation including square of cosine law.
It means that if there is no building, all pixel should be the same color.
This color map shows the anisotropy of arrival direction distribution.
(CLICK)
The two blue areas correspond to the shades of the buildings.

Our goal is PANDA100, whose target mass is 1 ton.
We have already prepared all parts, for example, plastic scintillator, acrylic light guide,



Using the background simulation of PANDA36, spectrum of prompt event is expected as shown in this figure.
We use similar selection criteria to PANDA36.
The detection efficiency is 9.24 %.
The efficiency increases threefold because the capture efficiency of cascade gamma-rays in delayed event increases.
The series of selected event rate is…



… this figure.
PANDA100 can detect the change of the reactor status by 5.5 sigma in a week aboveground.
In this case, we use the similar selection criteria to PANDA36.
Because we optimize the criteria for PANDA100, the signal-to-noise ratio is additionally expected to be improved.

Summary

- PANDA36 was operated for two months at Ohi Power Station Unit 2 (3.4 GW_{th}).
  - Detected neutrino event rate was 22.9±11.7 events/day (expected: 18.1±6.5 events/day)
  - Event topology information from segmented detector enables us to estimate the fast-neutron BG rate.
- PANDA64 is ready for deployment.
  - demonstration: muon arrival direction distribution
- PANDA100 is ready for development.
  - We have already prepared plastic scintillators, light guides, PMTs, DAQ, …