Prototype of the Daya Bay Neutrino Detector

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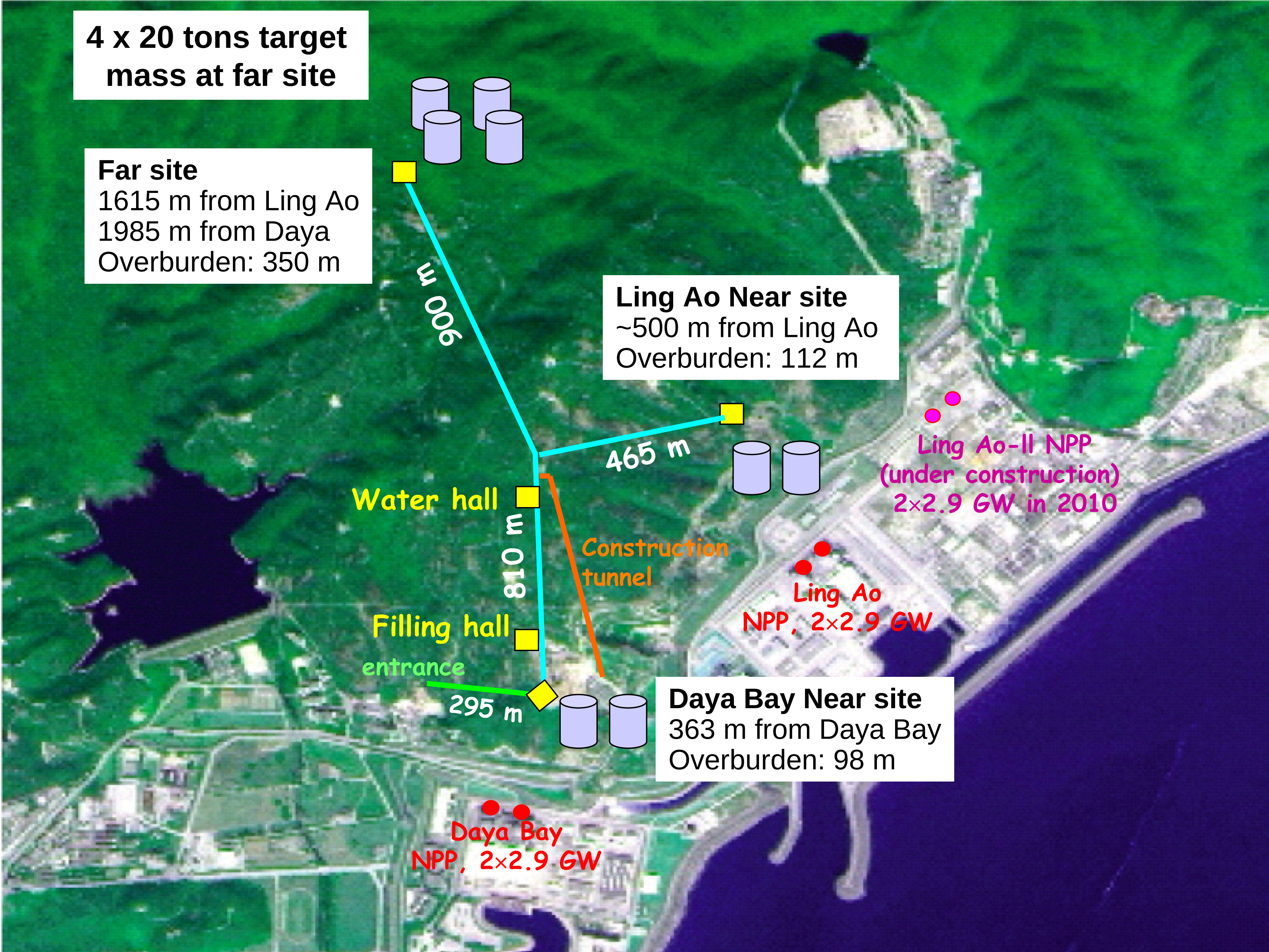
IHEP, Daya Bay


4 x 20 tons target
mass at far site
Far site
1615 m from Ling Ao
1985 m from Daya
Overburden: 350 m
900 m
Ling Ao Near site
~500 m from Ling Ao
Overburden: 112 m
465 m
Ling Ao-II NPP
(under construction)
2×2.9 GW in 2010
Water hall
810 m
Construction
tunnel
Ling Ao
NPP, 2×2.9 GW
Filling hall
entrance
295 m
Daya Bay Near site
363 m from Daya Bay
Overburden: 98 m
Daya Bay
NPP, 2×2.9 GW

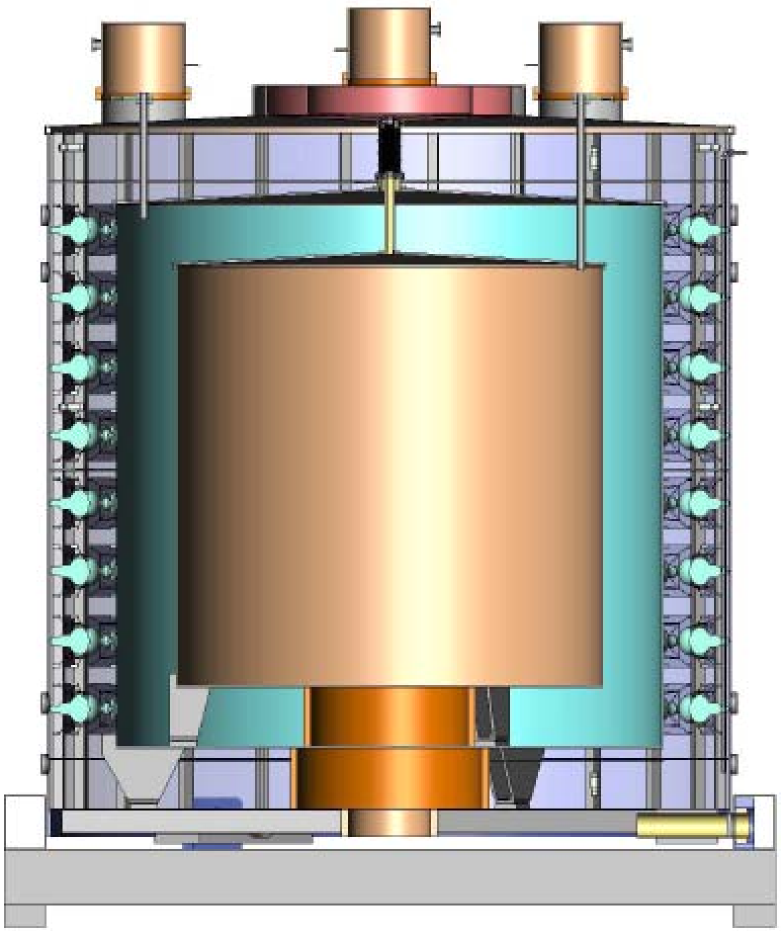
Daya Bay neutrino detector

Low-background 8" PMTs: 192

Top and bottom reflectors

Three concentric zones:

- **Target: 20 t (0.1% Gd LAB-based LS)**
- **Gamma catcher: 20 t (LAB-based LS)**
- **Buffer : 40 t (mineral oil)**



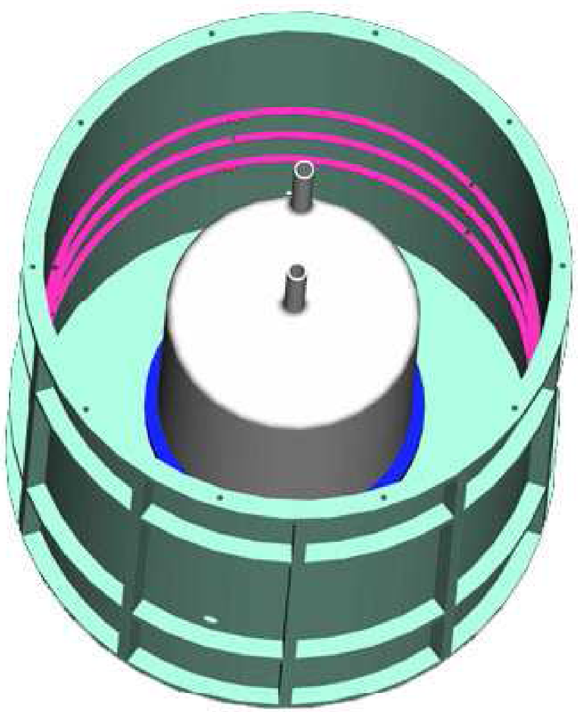
2-zone IHEP Prototype of the Daya Bay Neutrino Detector

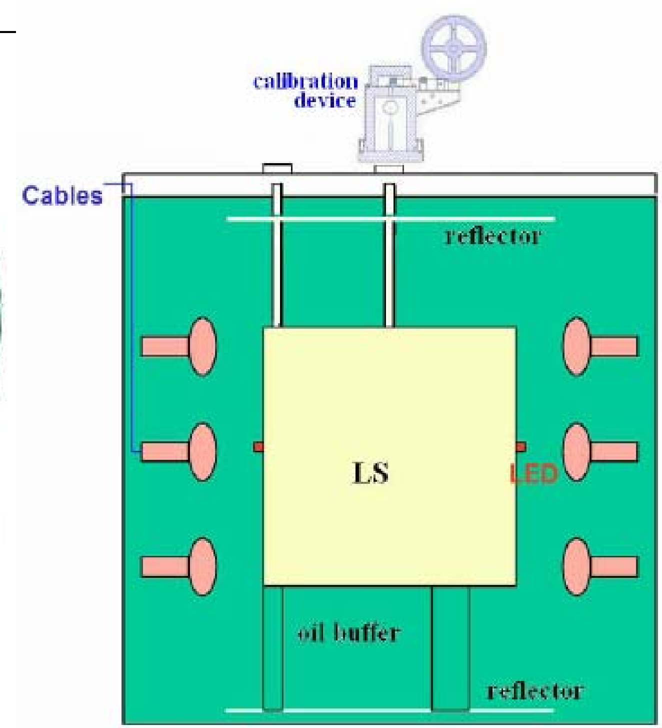
- ➢Validate the Daya Bay detector design;
- ➢Debug the Geant4 simulation program;
- ➢Practice the construction of detector and calibration methods;
- ➢Study LS and GdLS

Acrylic vessel with 0.9m diameter and 1m height dipped in a stainless steel tank with 2m diameter and height filled with mineral oil; 45 8” PMTs with reflecting at top and bottom;

Two stages:

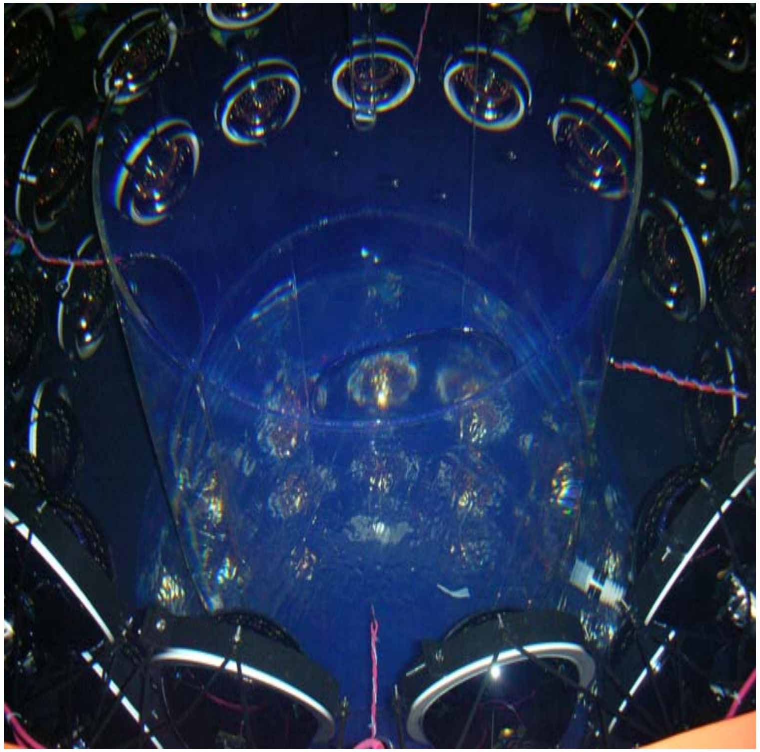
- ➢Phase I (normal LS) (2005.01 ~2006.11)
- ➢Phase II (Gd-loaded LS) (2007.02 ~Now)





09/19/2008

This is the inside view of prototype after installation of PMT and acrylic vessel, and LS filling.



Muon veto system

This prototype is surrounded by a cubic muon veto detector with five sides (except the bottom). The photographs show the prototype, the rack to support the muon veto (left) and the mounted scintillator counters (right).

Phase I

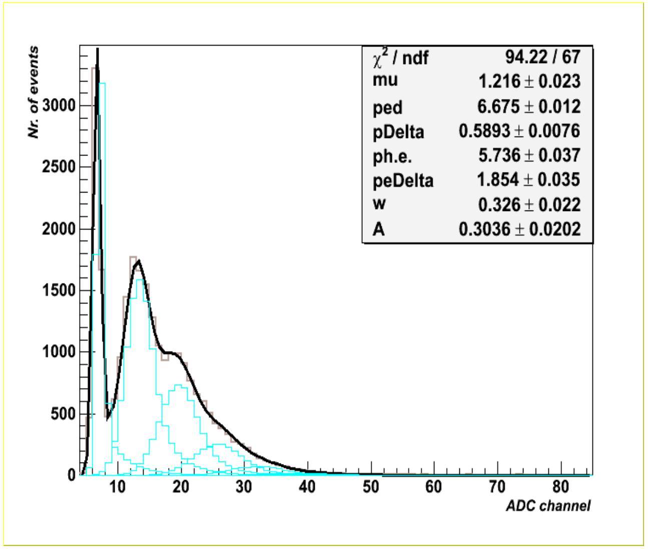
With normal LS: 30% mesitylene, 70% mineral oil, 5 g/L BBO and 10 mg/L bis-MSB

Calibration of PMT gain

The dark noise rates of most of used PMTs with a peak-to-valley ratio larger than 1.5 are less than 5 kHz at 1/3 P.E. threshold. We calibrate the PMT gain with LED and a convoluted function based on NIM A339 (1994) 468-476. The average PMT gain is ~5.5 ADC bin of SPE (~3.5×10^7) .

$$SER(x) = \sum_{n=0}^{N\max} P(n;\mu) \otimes G_n(x) \otimes B(x)$$

$$= \sum_{n=0}^{N\max} \frac{\mu^n e^{-\mu}}{n!} \times \left[(1-w)G_n(x-Q_0) + wI_{G_n \otimes E}(x-Q_0)\right]$$



where:

$$G_n(x) = \frac{1}{\sigma_1\sqrt{2\pi n}} \exp\left(-\frac{(x-nQ_1)^2}{2n\sigma_1^2}\right)$$

$$B(x) = \frac{(1-w)}{\sigma_0\sqrt{2\pi}} \exp\left(-\frac{(x-Q_0)^2}{2\sigma_0^2}\right) + w\alpha\exp(-\alpha(x-Q_0))$$

Monte Carlo simulation with Geant4

We simulate the energy response of the prototype with a Monte Carlo simulation program based on Geant4.

The simulation shows that the response of detector is sensitive to the light yield of LS, and the reflectivity of the reflectors and the inner surface of the stainless steel tank, and is not sensitive to the attenuation length of LS, oil and acrylic vessel if they are longer than 7m, 13m and 1m at the wavelength longer than 420nm.

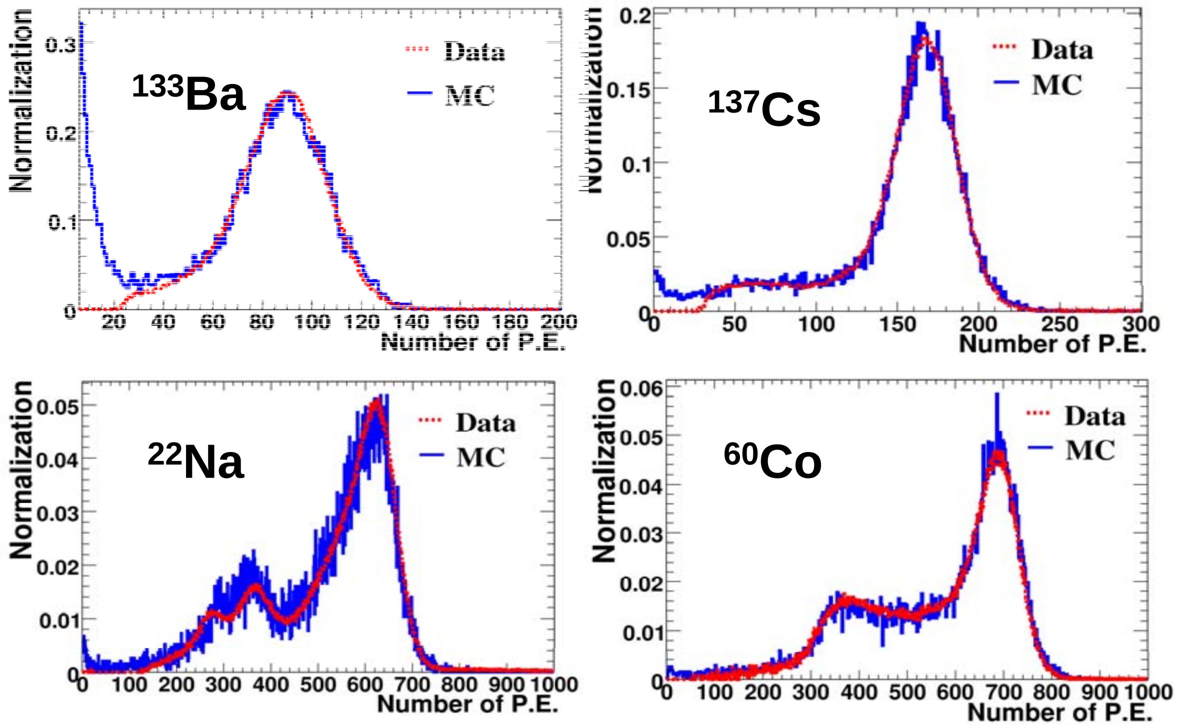
Nominal values of the optical parameters are set at their measured ones.

After the digitization of PMT output, we get the final simulation data.

Phase I

Comparison of data and simulation

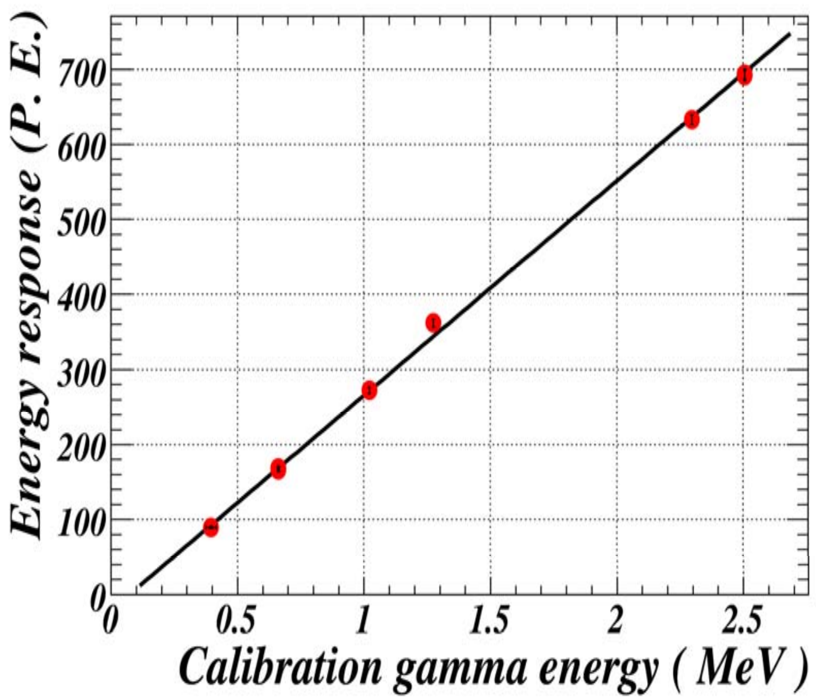
After the digitization of PMT output in simulation, we see that the simulation and experiment data have good agreement.

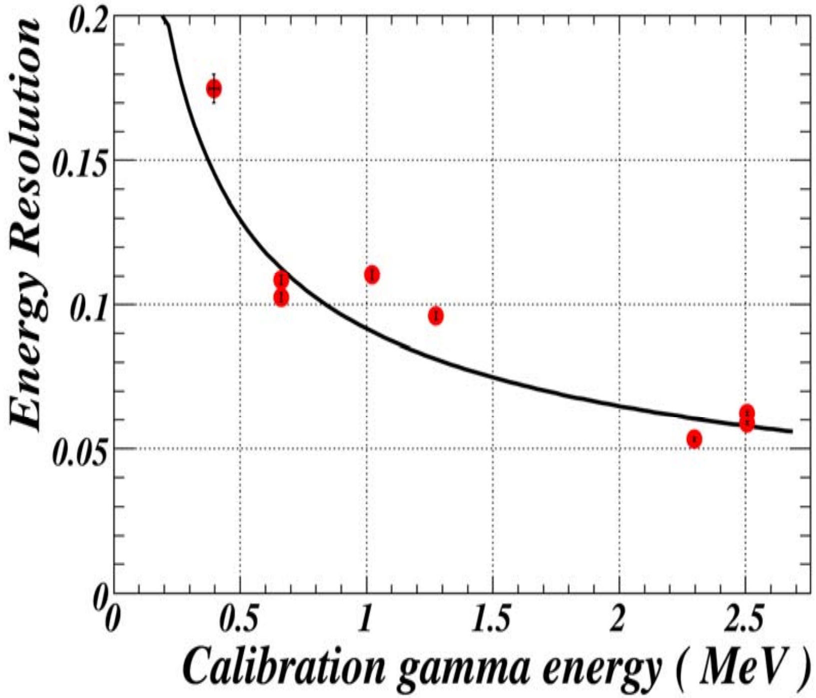


The comparison of simulation and data with ^{133}Ba, ^{137}Cs, ^{22}Na and ^{60}Co at centre of the detector show that they agree well, and we have preliminarily understood the detector.

Energy response linearity and resolution

The energy to photoelectron conversion factor of the prototype at the detector centre is 286.4 P.E./MeV (left), and its resolution is 9.2%/ $\sqrt{E}$ (MeV) (right) with 40 PMTs.



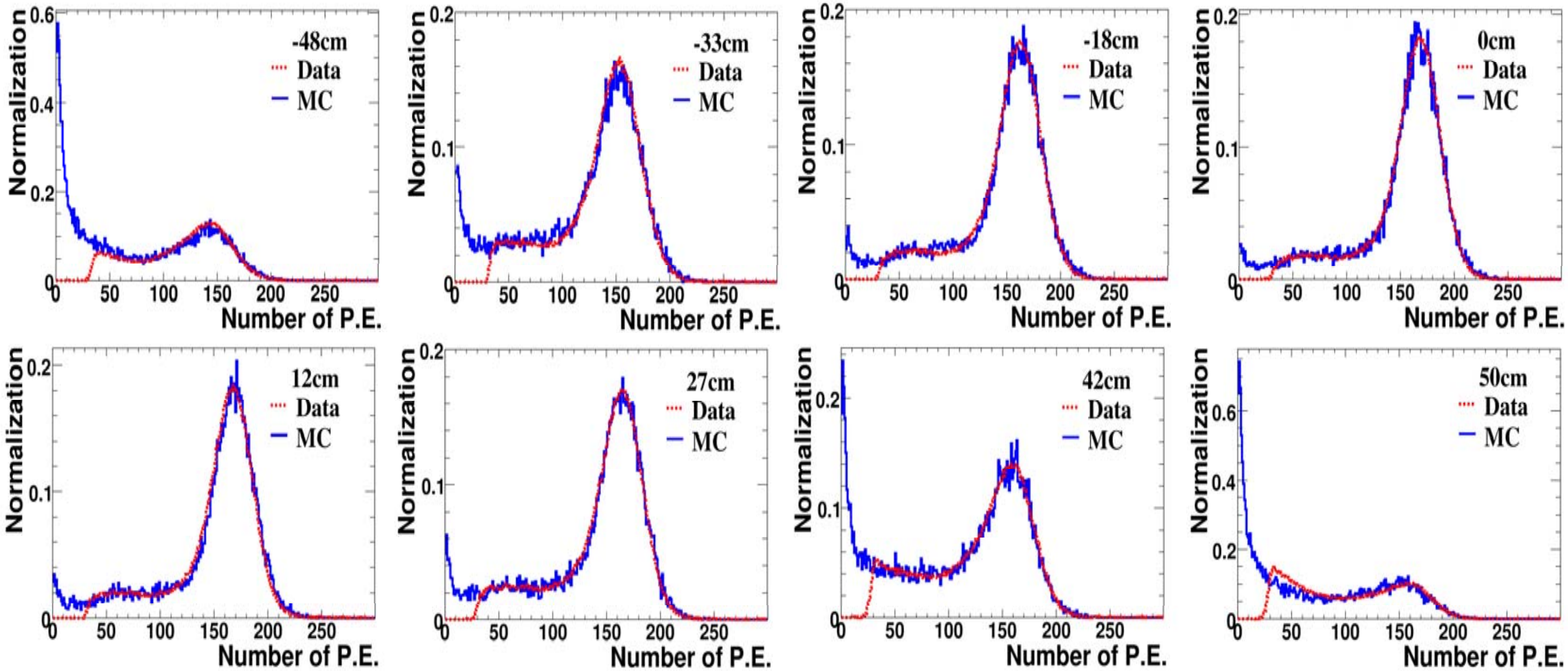


The detector has a good energy response and resolution.

Phase I

Uniformity and leakage of energy

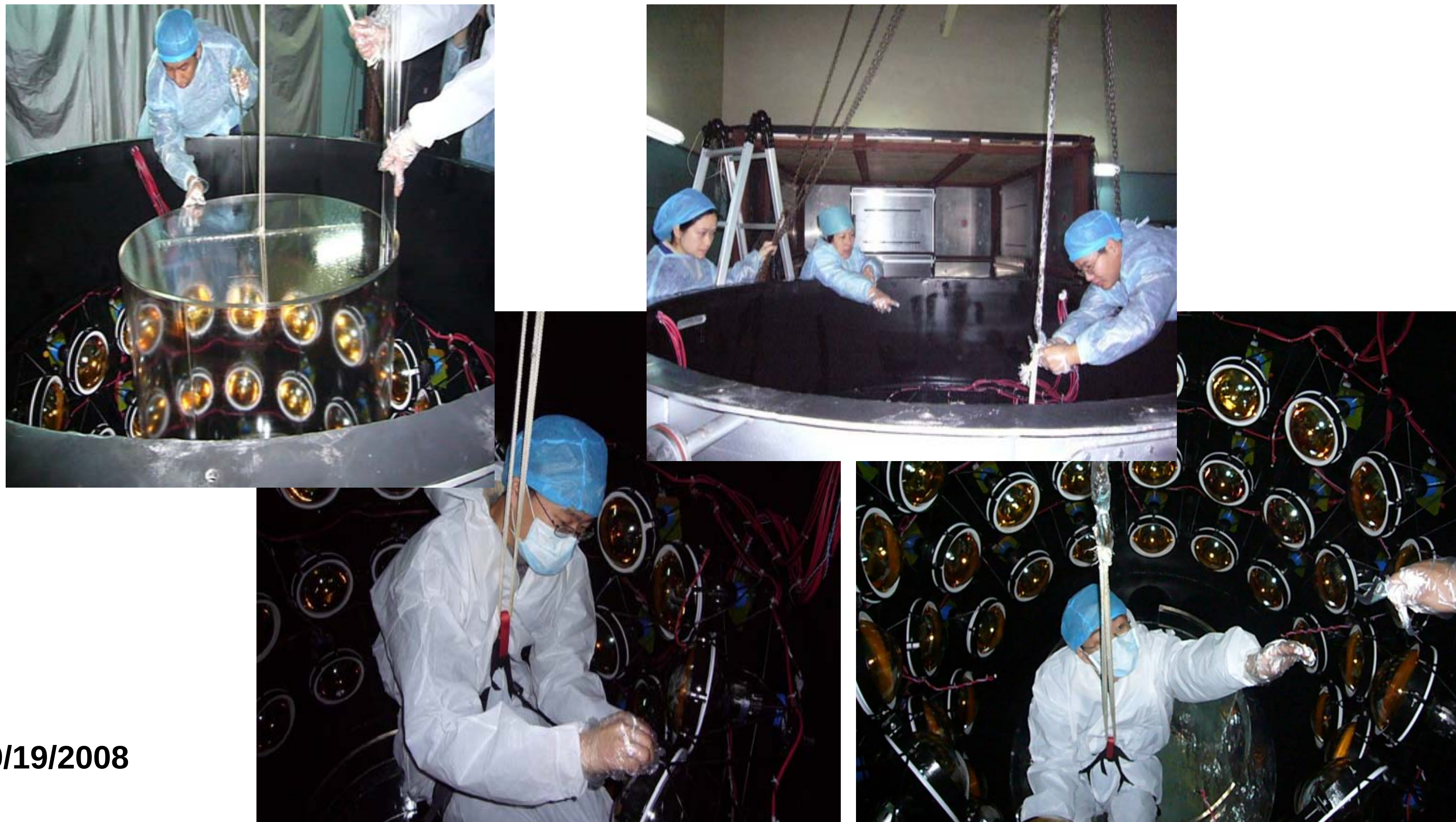
To study the uniformity and position effect of the prototype, the 137Cs source is moved along the detector's cylindrical central axis and the respective energy response is measured.



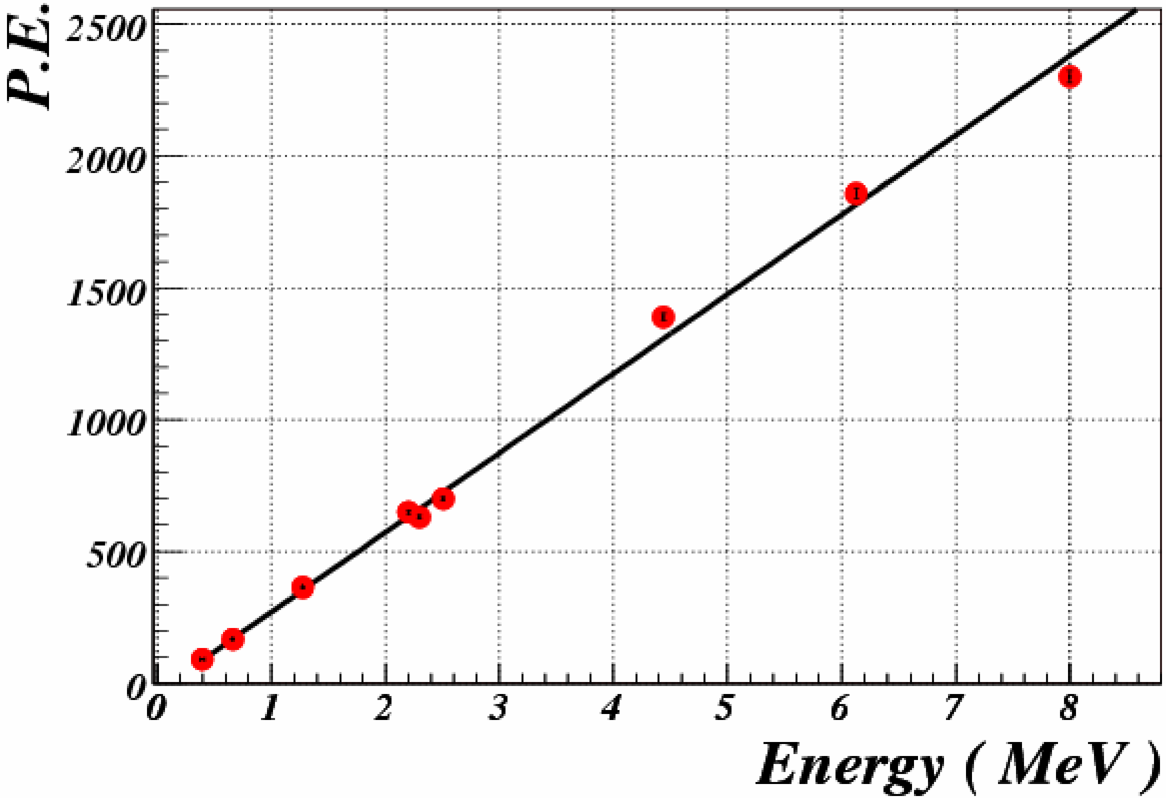
The position effect of our prototype has been also preliminarily understood. The gamma catcher with ~45cm thickness will effectively reduce the energy leakage effect of gamma in the future Daya Bay detector.

Phase II of prototype with GdLS

At 2007.2, the prototype was refilled with GdLS: ~750L GdLS (~0.6ton, 3g/L PPO, 15mg/L bis-MSB, 0.1% Gd, 100% LAB); Change the top reflector to ESR from Al film;



Energy response linearity of Phase II



P.E. output of phase II at the centre of detector is ~301 P.E. / MeV with 38 PMTs, which is *~11%* larger than Phase I.

Neutron capture

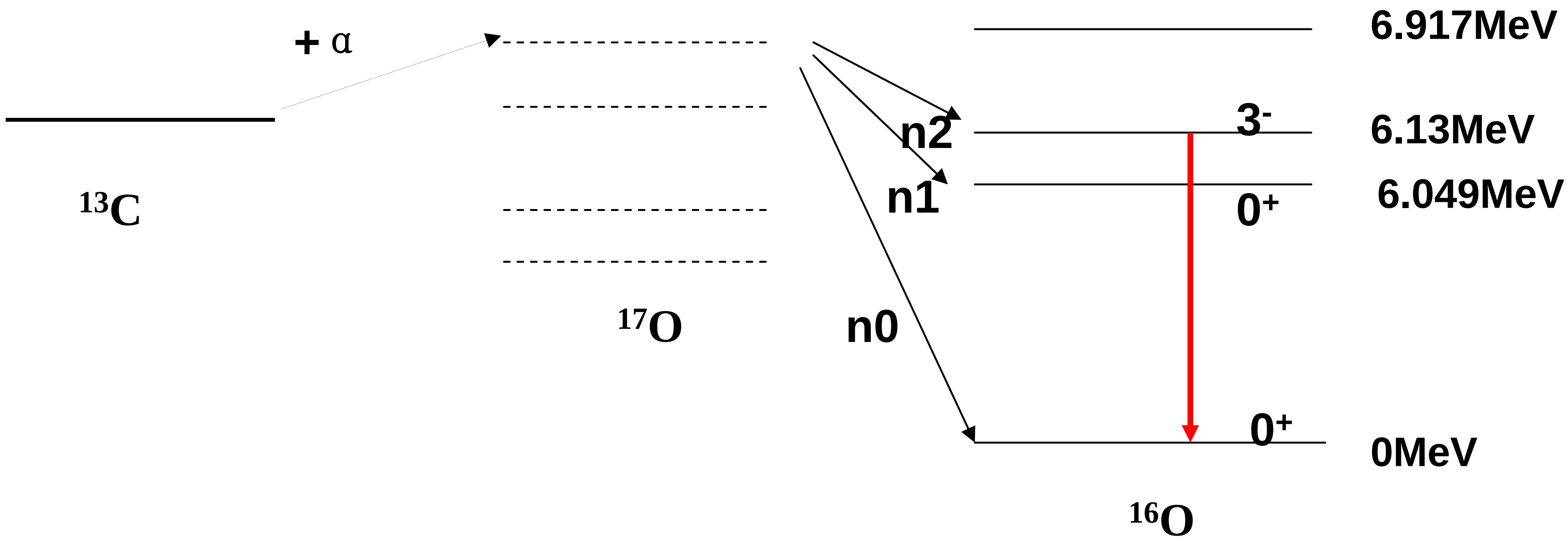
We use PuC as the neutron sources to calibrate the captured neutron of the detector.

^{238}Pu - ^{13}C source

α from ^{238}Pu E_α ~ 5.48 MeV

α + ^{13}C ---- ^{16}O + n + 2.216MeV

n	E*(^{16}O) (MeV)	Reaction threshold (MeV)	En_{max} (MeV)
n_0	0	0	6.81
n_1	6.049	5.01	0.38
n_2	6.130	5.12	0.29
n_3	6.917	6.14	x

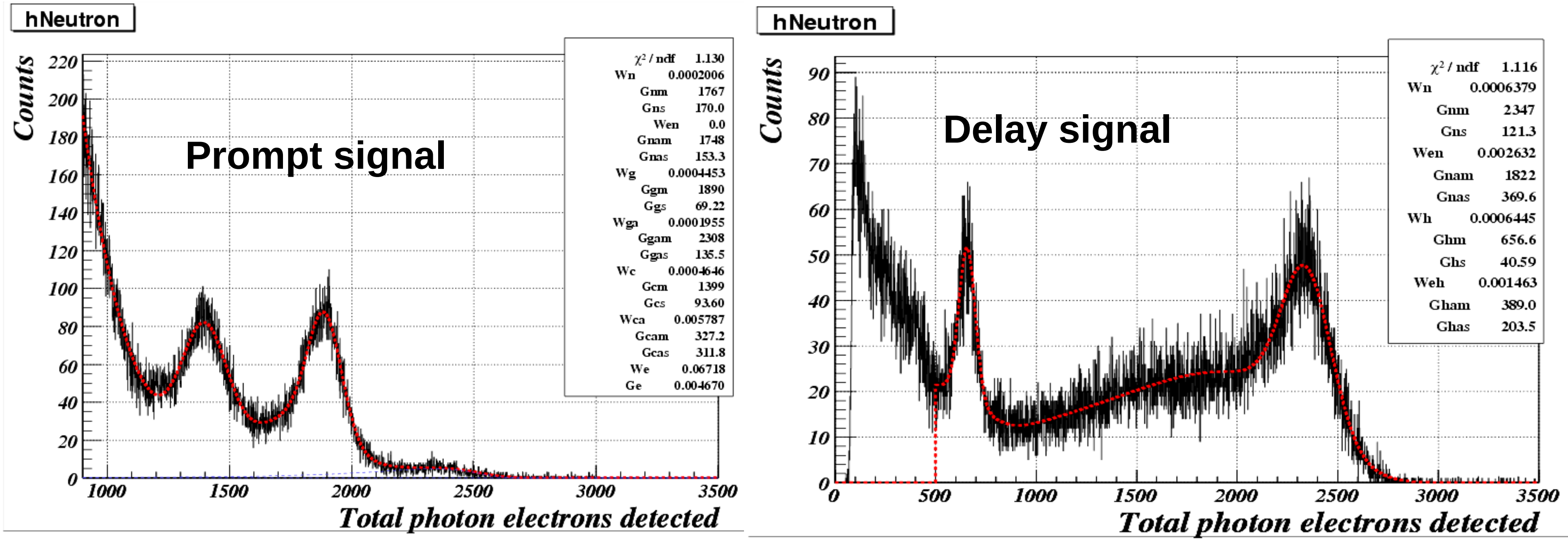


Goal: to get the events of 6.13MeV Gamma associated with neutron

Phase II

PuC neutron source

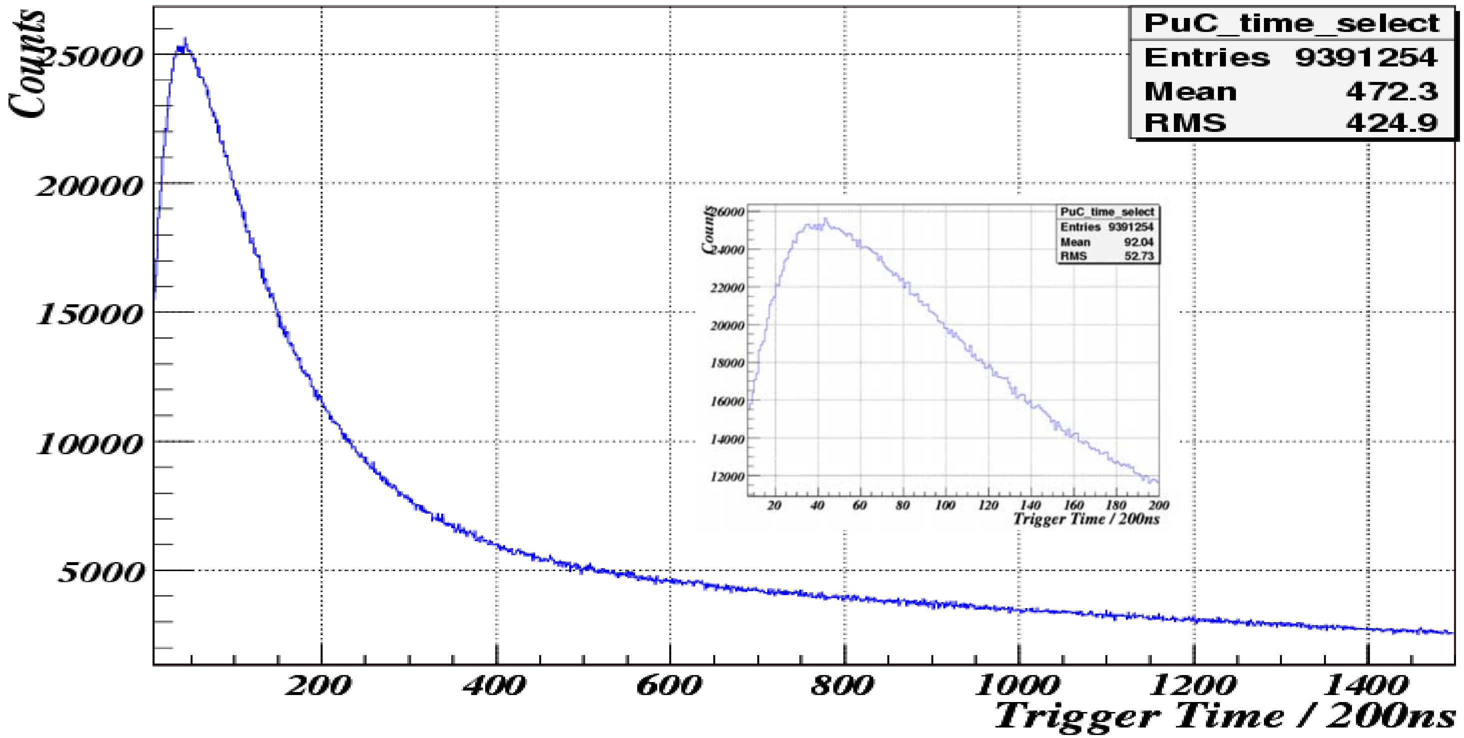
With associated event cuts: prompt signal, delay signal and its interval, we get:



In the prompt signal spectrum, there are two peaks at ~4.5 MeV and ~6.13 MeV. In the delay signal spectrum, there are also two peaks at ~2.2 MeV and ~8 MeV, which clearly shows the neutron capture by proton and Gd.

Interval between prompt and delay signals of PuC

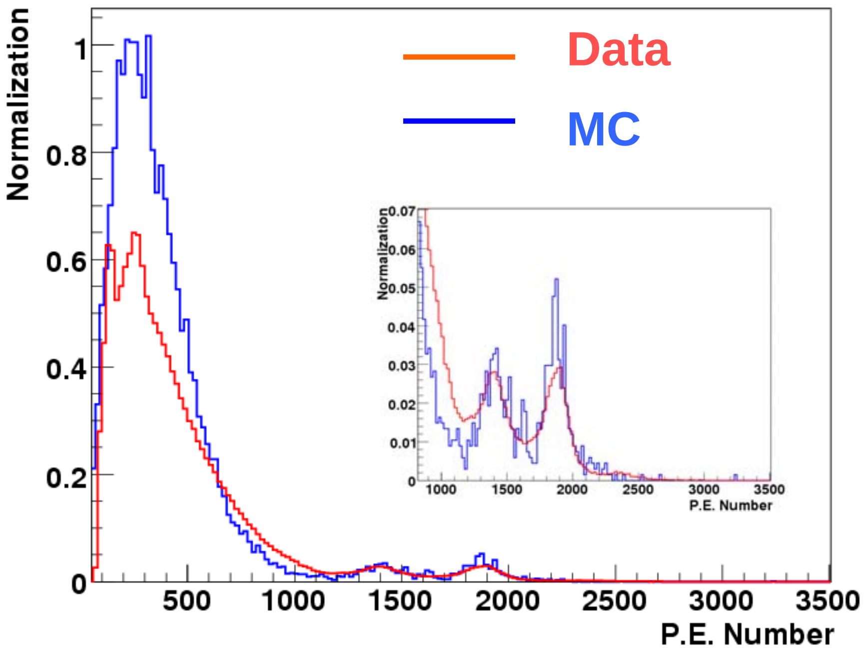
(neutron capture time)



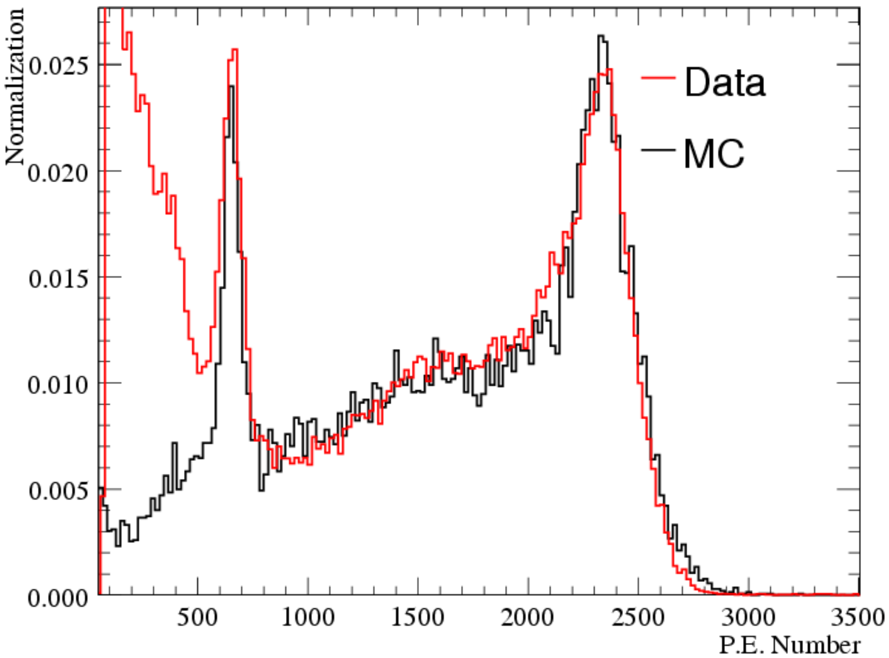
The peak of interval spectrum of neutron capture is at ~8us. The neutron capture time is ~26.3us fitted with exponential functions.

Data and simulation with Geant4

Prompt signal



Delay signal

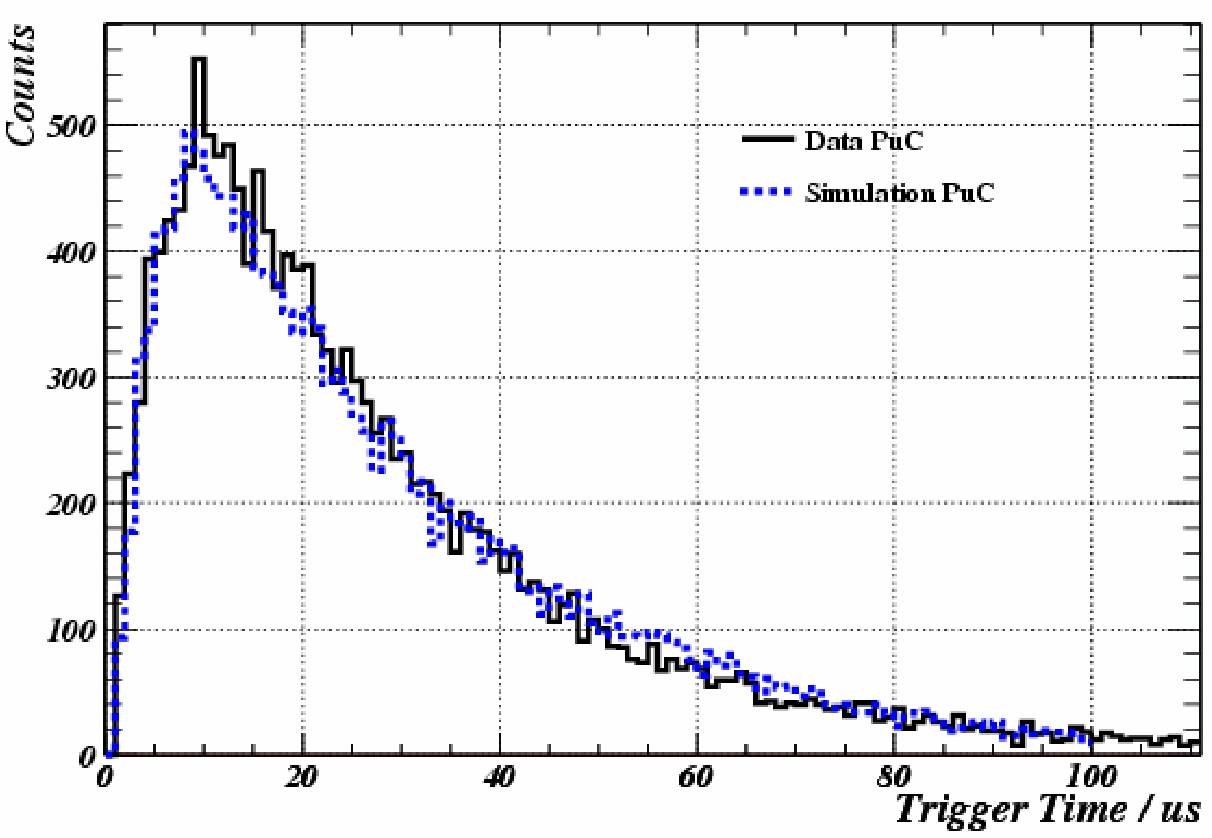


The sources of the peaks in the spectra have clearly understood. The two peaks of prompt signal come from the excited ^{12}C (~4.438MeV) + proton recoil (~0.10MeV) and the ~6.13MeV gamma.

The measured nonlinearity of 8MeV and 2.2MeV peaks is ~3%.

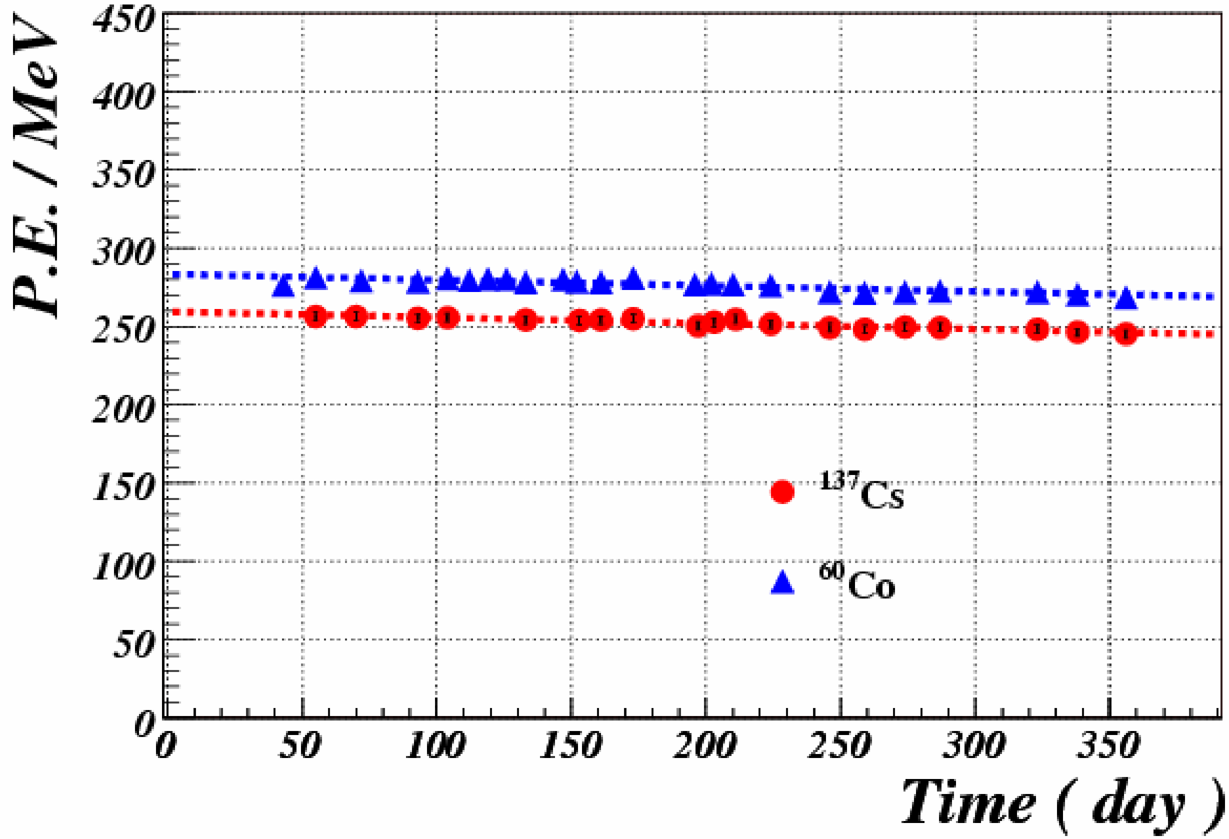
Phase II

data and simulation
(neutron capture time)



The neutron capture time spectra got from data and simulation agree with each other.

Gd-LS stability monitoring by prototype



Place the 137Cs and 60Co at the centre of the detector to monitor the photoelectron output of the detector, totally 356days from 2/8/2007 to 1/29/2008; it shows good stability.

Conclusion

- **Validated the detector design of Daya Bay.**
- **Preliminary understood the detector response with the geant4 MC simulation.**
- **GdLS works properly to capture neutrons with a good stability.**
- **PuC neutron source provides the events of 6.13MeV Gamma associated with neutron.**