Maximum likelihood reconstruction for the Daya Bay antineutrino detector(AD)

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outline

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  - The antineutrino detector
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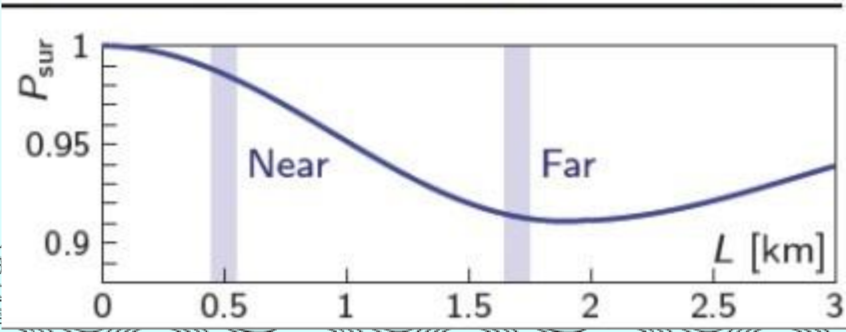
Physics goal

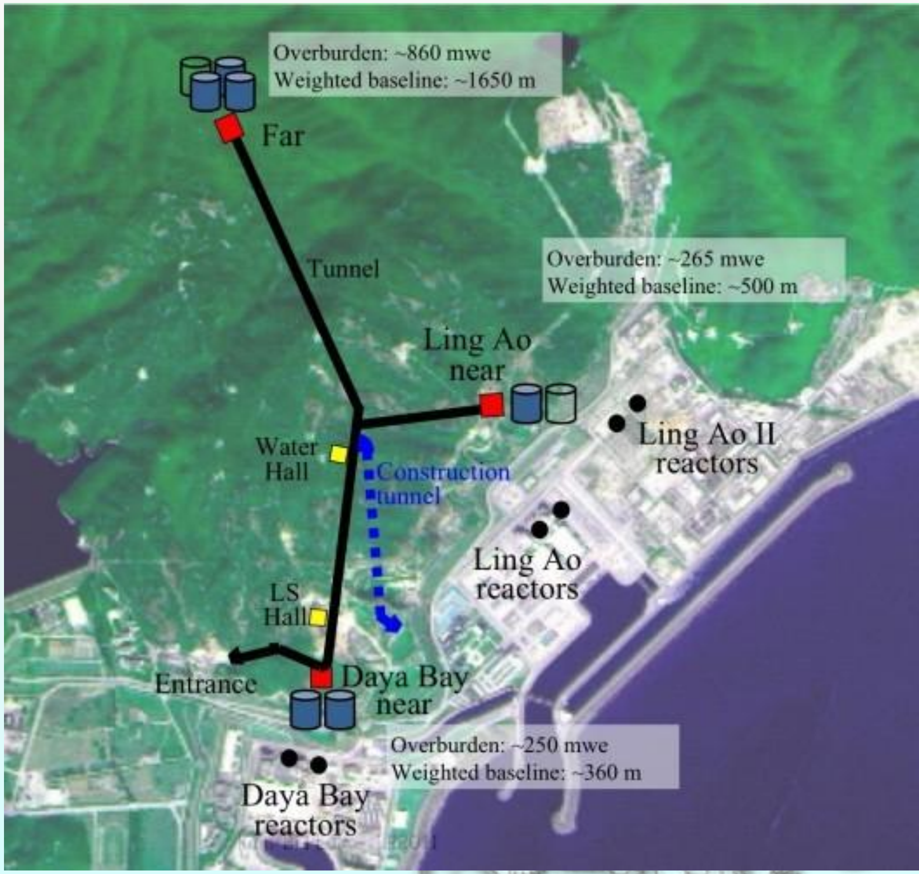
Daya Bay is a reactor neutrino experiment designed to measure $\sin^2 2\theta_{13}$ to 0.01 at 90% CL

- 6 reactor cores, 17.4 GW_{th}
- Relative measurement
  - 2 near sites, 1 far site
- Multiple detector modules
- Good cosmic shielding

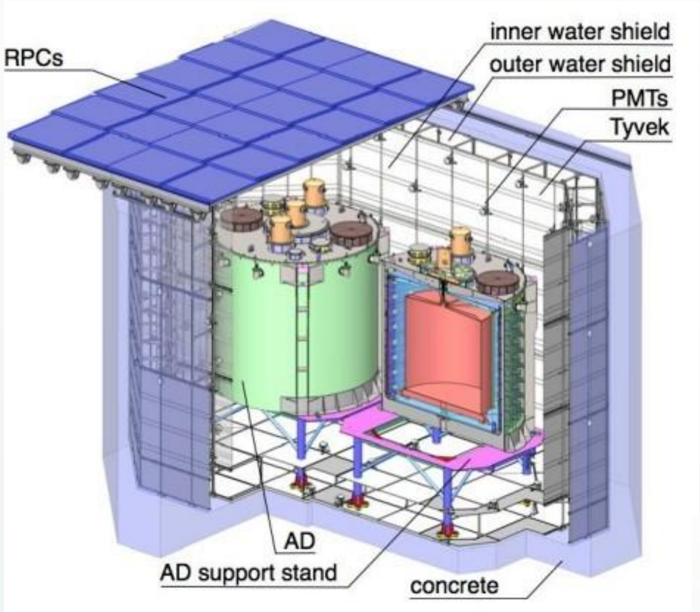
Table 1. Vertical overburden, muon rate R_μ, and average muon energy $<E_\mu>$ of the three EHs.

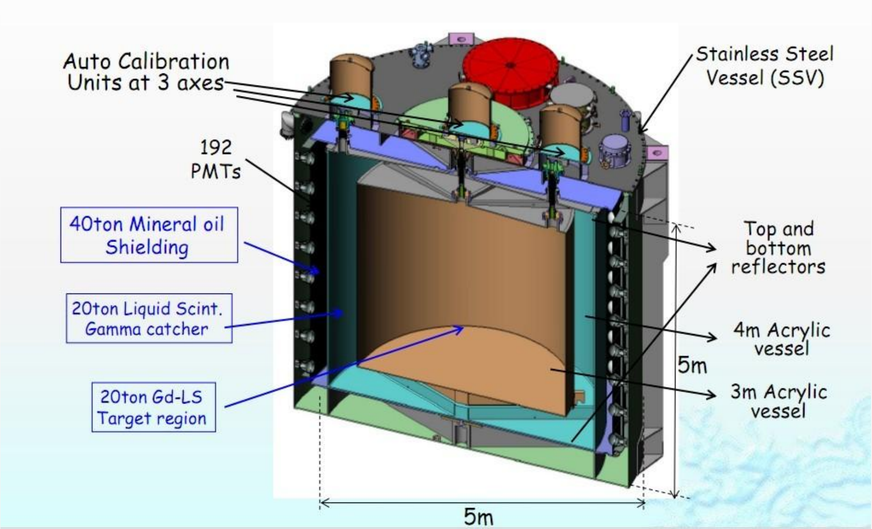
	overburden (m.w.e)	R_μ (Hz/m^2)	$<E_\mu>$/GeV
EH1	250	1.27	57
EH2	265	0.95	58
EH3	860	0.056	137





Antineutrino detector(AD)





- IBD(inverse beta decay)

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

Prompt: e^+ annihilation Delay: neutron capture

Neutrino events: coincidence in time and energy

0.3b $\rightarrow + p \rightarrow D + \gamma\,(2.2\ MeV)$ (delayed) 180μs

50kb $\rightarrow + Gd \rightarrow Gd^* \rightarrow Gd + \gamma\text{'s}\,(8\ MeV)$ (delayed) 28μs 0.1%Gd

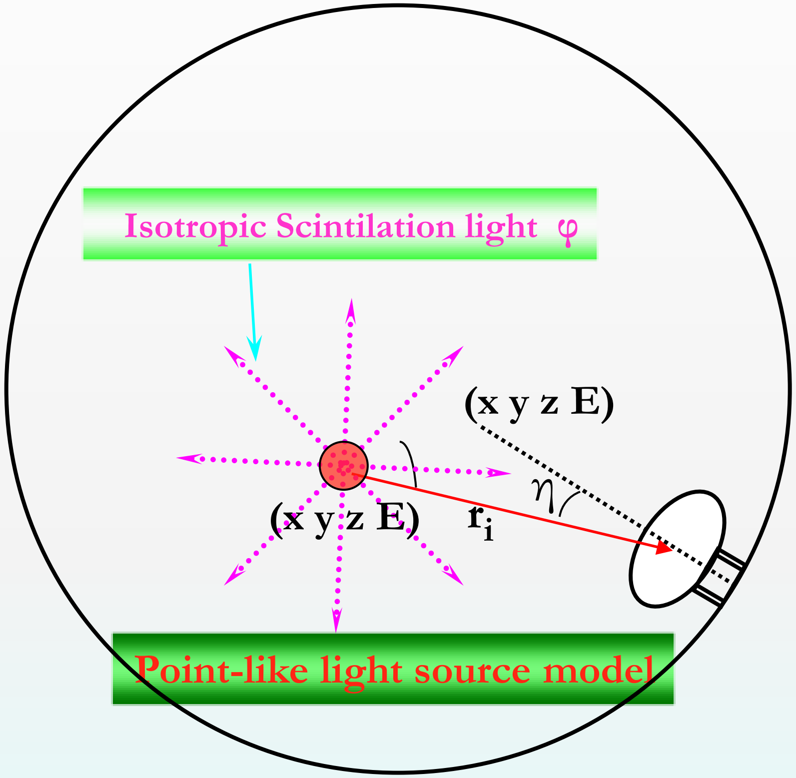
- Multiple Anti-neutrino Detector (AD) modules to reduce syst. err.
  - Far: 4 modules， near: 2 modules
- Multiple muon detectors to reduce veto eff. uncertainties
  - Water Cherenkov： 2 layers
  - RPC： 4 layers at the top + telescopes

Joint likelihood

- Point source approximation.
- Mirror reflection, first five orders of reflection is considered.
- Using an 'effective' attenuation length.
- The expected charge pattern $u = u(E, \vec{X})$

is calculated with trial energy E and vertex $\vec{X}$. The minimization by Minuit of $-\log L_{charge}(N, u(E, \vec{X}))$

Will give a maximum likelihood (ML)estimation to the event energy and vertex.



Joint likelihood

$$L_{charge}(Q,\mu) = \prod_{i=1}^{Npmt} f(q_i,\mu_i) = \prod_{i=1}^{Npmt}\left(\sum_{N_i=0}^{\infty}\frac{e^{-\mu_i}\mu_i^{N_i}}{N_i!}r(N_i,q_i)\right)$$

Maximize the likelihood → $E, \vec{X}$

Optical model-expected charge

Direct $\mu_d = \phi(E) \cdot \frac{f(\cos\theta_d)}{R_d^2} \cdot \exp(-R_d/\lambda_a) \cdot \varepsilon_{QE}$

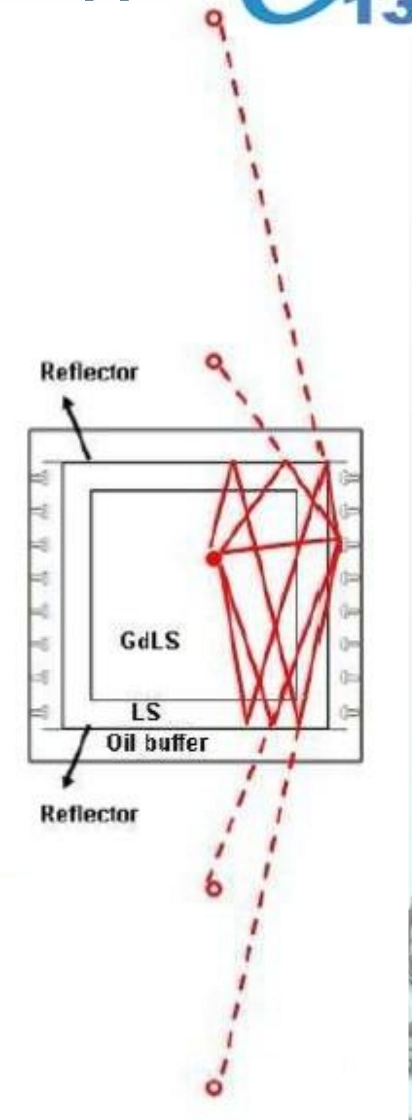
Reflected

$$\mu_{j,k} = \phi \cdot (\varepsilon_b)^j \cdot (\varepsilon_t)^k \frac{f(\cos\theta_{j,k})}{(R_{j,k})^2} \cdot e^{-R_{j,k}/\lambda_a} \cdot \varepsilon^{QE}$$

Total expected

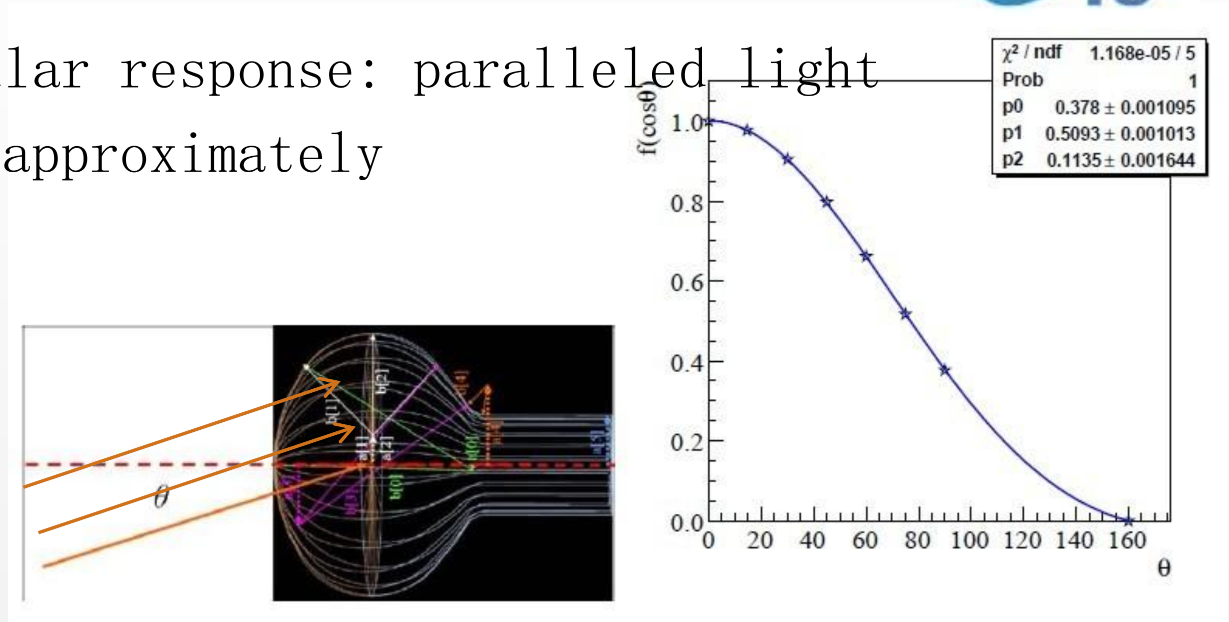
$$\mu = \mu_d + \mu_{ref} = \mu_d + \sum_{j,k} \mu_{j,k}$$

- $\phi = E \cdot \eta_{LightYield} \cdot \frac{S_{pmt}}{4\pi} \cdot \varepsilon^{QE}$ is normalization parameter proportional to E
  - $\eta_{LightYield}(\text{photons/MeV})$ now is set to be a constant
  - S_{pmt} is the PMT photocathode area
- $\mu^{reflection}$ Superscript j, k in represent that the mirror source is j-th order reflected by bottom reflector, and the k-th order reflected by top reflector.



Optical model-parameters

$f(\cos\theta_d)$ Angular response: paralleled light angular response approximately

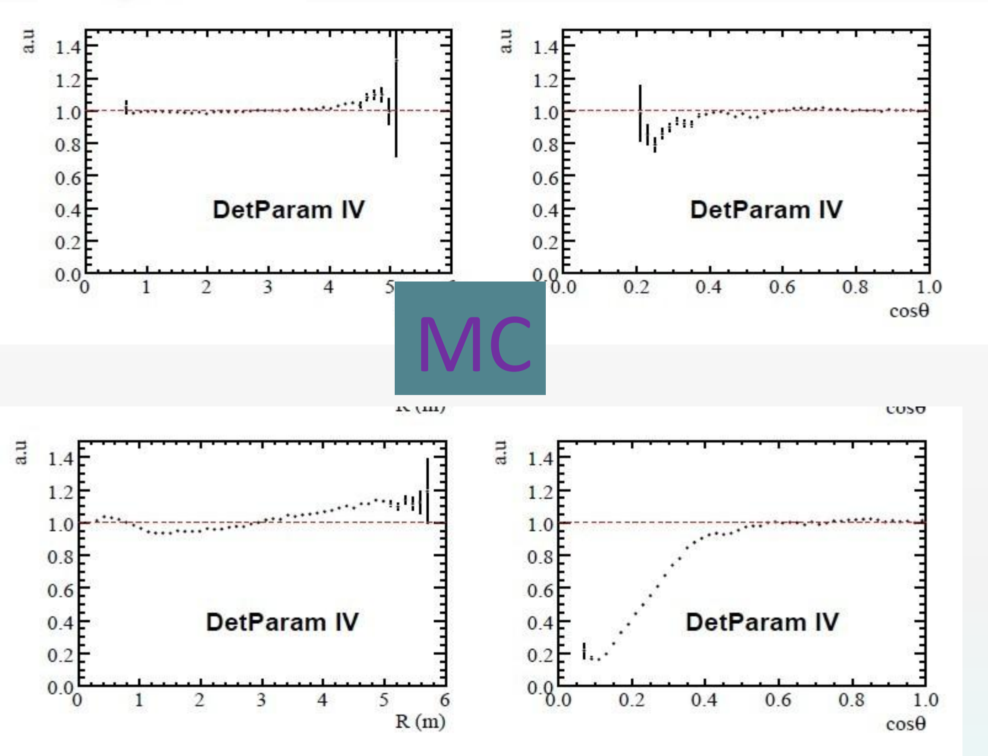


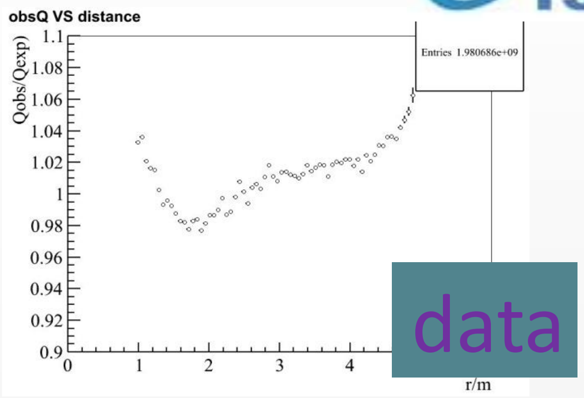
ε^{QE} Quantum efficiency, calibrated by calibration source Co60 at the center of AD.

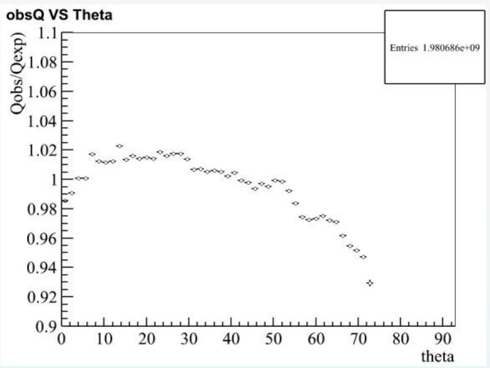
λ_{attl} Average attenuation length for GdLS and LS.

ε_{topRef}, ε_{botRef} Top reflectivity and Bottom reflectivity. Use the measured reflectivity of the ESR

Performance



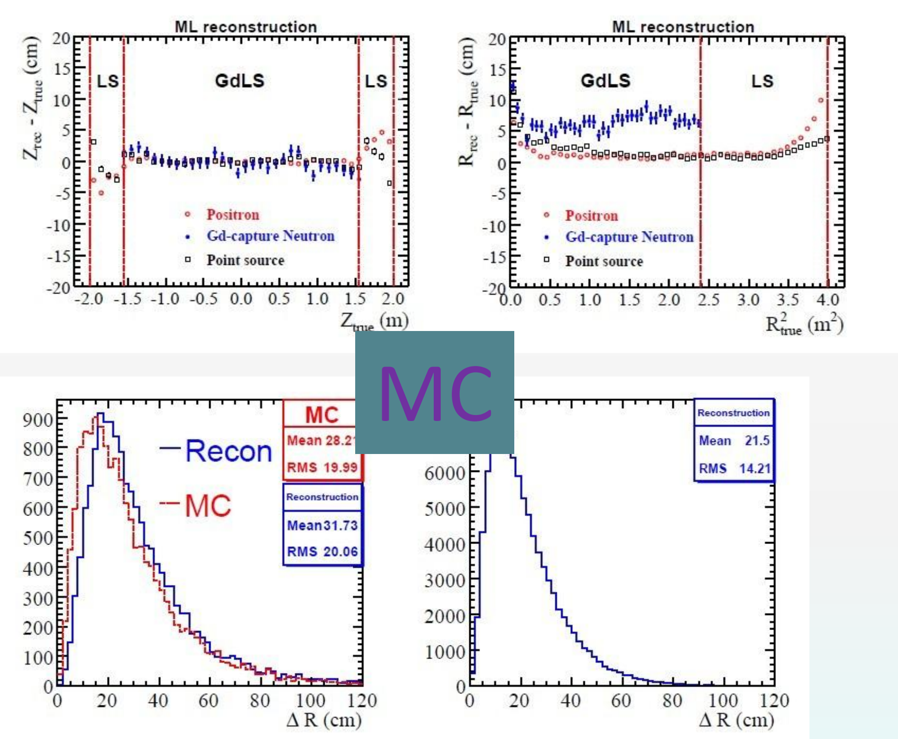


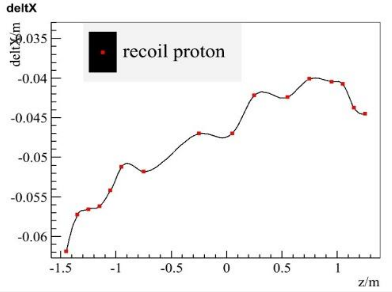


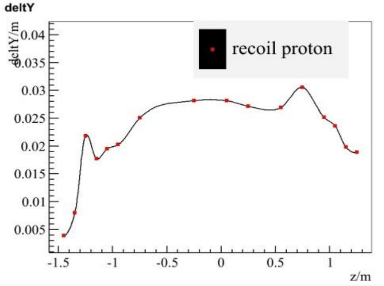
Qobs/Qexp vs the distance(R) from the source to PMT.
Qobs/Qexp vs the angular(cosθ) from the source to PMTs.

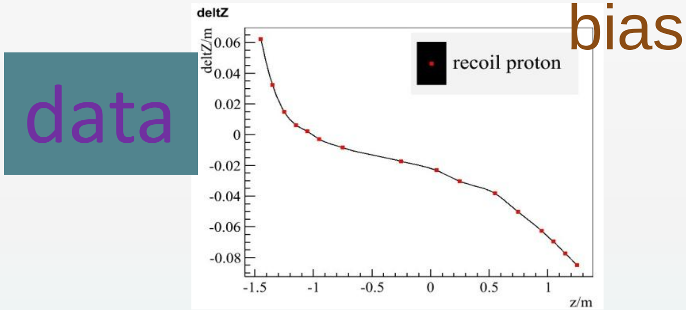
- The optical model well describe events in GdLS from the MC study.
- The performance of real data is not as good as MC, some parameters need fixing.

Performance –vertex reconstruction





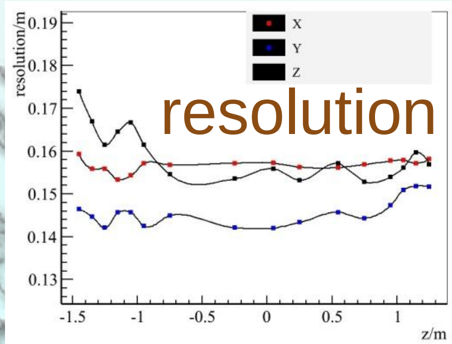




- The bias is small for the three sources in MC study.
- The bias is less than 10cm for protons source.
- The resolution is less than 18cm.

◆The biases are define as the mean value of the differences between the ML reconstructed vertex and the real vertex.

◆The resolution is the sigma of the Gaussian fit for the vertex distribution.



Energy reconstruction

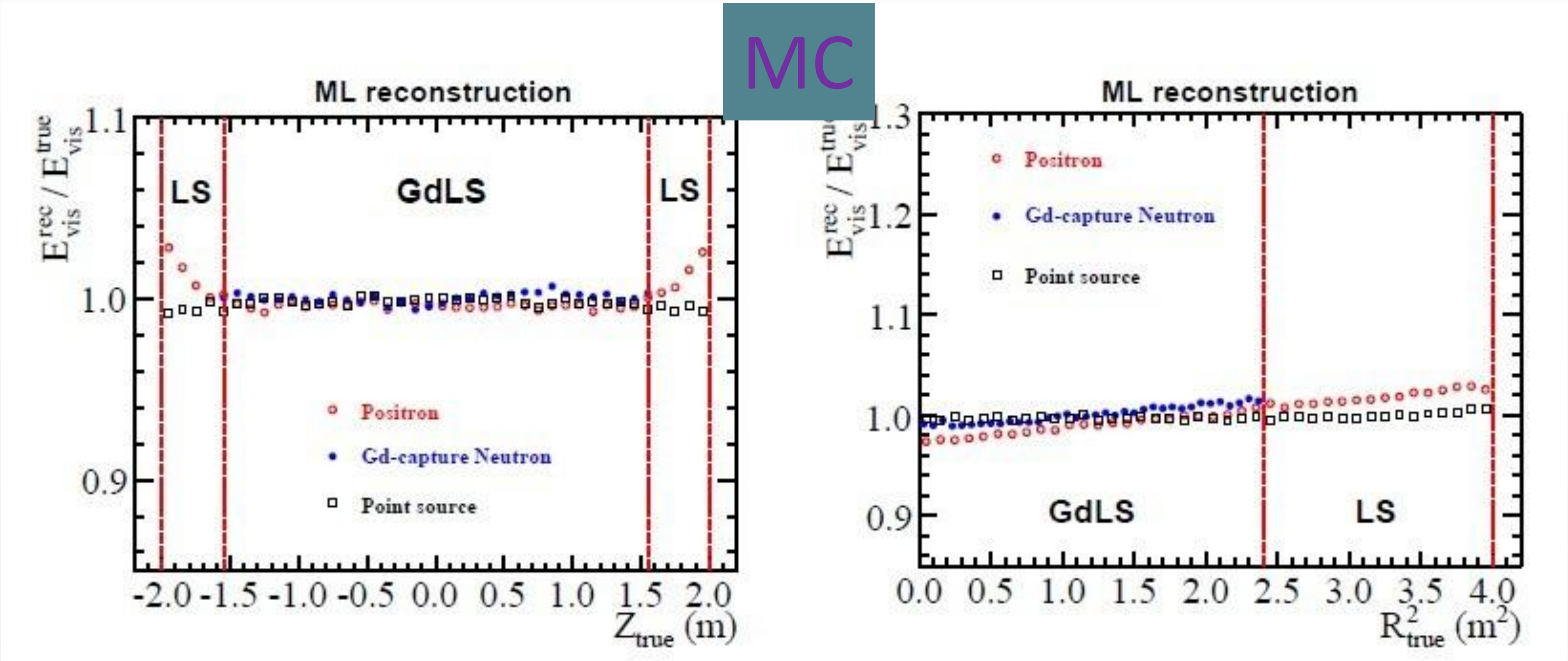


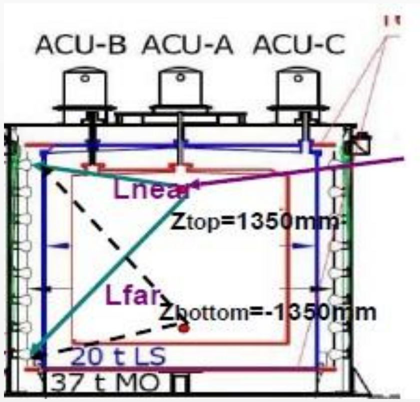
Figure 6: Ratio of reconstructed visible energy to true visible energy by ML reconstruction along vertical (Left:a) and radial (Right:b) direction.

◆This result comes from MC study.
◆Good energy reconstruction for different calibration sources.

Attenuation length monitoring for GdLS and LS

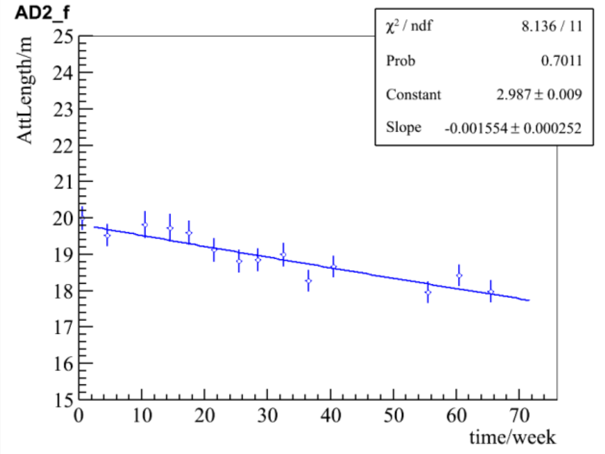
$$q_{ipmt} = const * \exp(-\frac{L}{\lambda})$$

Q 1/ Q 8



Q 8/Q 1

$$\lambda_t = \frac{2(L_8 - L_1)}{\ln\left((\frac{Q_8}{Q_1})_{top} * (\frac{Q_1}{Q_8})_{bottom}\right)_t - \ln\left((\frac{Q_8}{Q_1})_{top} * (\frac{Q_1}{Q_8})_{bottom}\right)_0 + \frac{2(L_8 - L_1)}{\lambda_0}}$$



$$\lambda = \lambda_0 * \exp(-\frac{t}{\tau})$$

$$\tau = -\frac{1}{Slope}$$

$$\Delta\lambda = \frac{\lambda_0 - \lambda}{\lambda_0} = 1 - \exp(t * Slope)$$

Attnuation length changed since the start time of each AD till now for GdLS and LS

	EH1-AD1	EH1-AD2	EH2-AD1	EH3-AD1	EH3-AD2	EH3-AD3
Start time	Sep23 2011		Oct.31 2011	Dec.24 2011		
AttLength shorter(%)/GdLS	8+-1.6	10+-1.6	6.7+-1.5	0.4+-1.3	5.0+-1.3	6.7+-1.3
AttLength shorter(%)/LS	5.9+-2.6	-3.5+-2.8		0.89+-1.9	-2.5+-1.8	-5.8 +-2

- This method is based on maximum likelihood optical model.
- The attenuation length λ_t can be monitored through the DoubleRatio $\left((\frac{Q_{near}}{Q_{far}})_{top} * (\frac{Q_{far}}{Q_{near}})_{bottom}\right)_t$, while the optical path difference L8-L1 is known for calibration data.

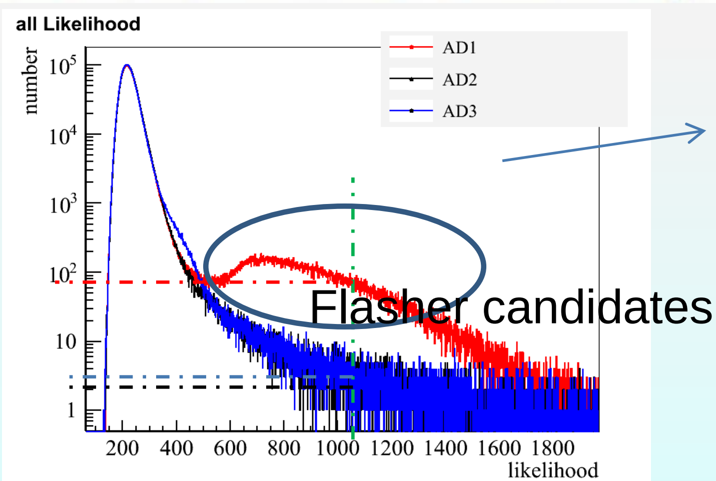
PMT Flashers identification

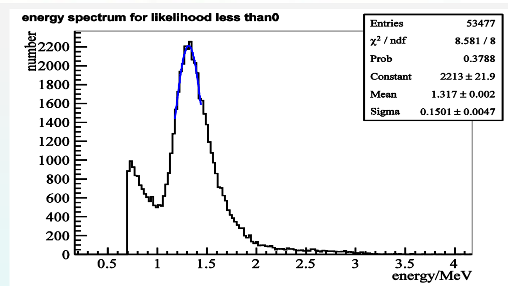
◆Maximum likelihood reconstruction is based on the observed charges on 192 PMTs, we get the energy and vertex when the combined probability is minimum, and likelihood we define here to identify flasher is derived from combined probability.

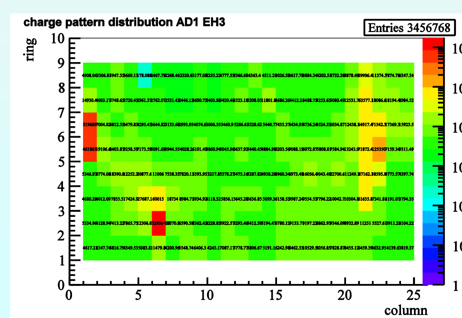
$$L_{charge}(Q,\mu) = \prod_{i=0}^{Npmt} f(q_i,\mu_i) = \prod_{i=0}^{Npmt}\left(\sum_{N_i=0}^{\infty}\frac{e^{-\mu_i}\cdot\mu_i^{N_i}}{N_i!}\cdot r(N_i,q_i)\right)$$

Identify residual Flasher events, Which is one of the accicidential background in the Daya Bay Experiment.

◆Likelihood should be smaller for physical events compare to flashers, because the optical model matches the maximum likelihood reconstruction for physical event while flasher doesn't. Hence, we can identify flashers with likelihood.







Charege pattern for Flashers

summary

- A maximum likelihood reconstruction algorithm is developed to determine the vertex and the energy from PMT’s charge pattern for a liquid scintillator detector with a reflective panel.
- This reconstruction is aimed to improve the simpler charge center or charge pattern based reconstructions used in the current official analysis in the Daya Bay experiment.
- The bias and the resolution of the maximum likelihood reconstruction are small.
- The fiducial volume in the Daya Bay experiment is well defined by the acrylic vessel, without the need of an accurate vertex reconstruction or a position cut, however we can indentify flashers and monitor the attenuation length for GdLS and LS using ML reconstruction optical model.
- Further more, the vertex information is important to understand the energy response and to distinguish the external radiation background.

thanks