Towards a Precise Determination of the Reactor Antineutrino Flux at Daya Bay

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on behalf of Daya Bay Collaboration

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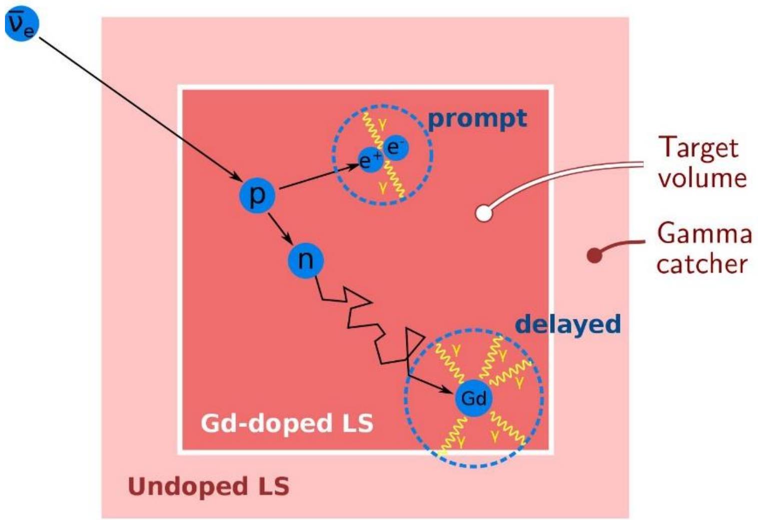
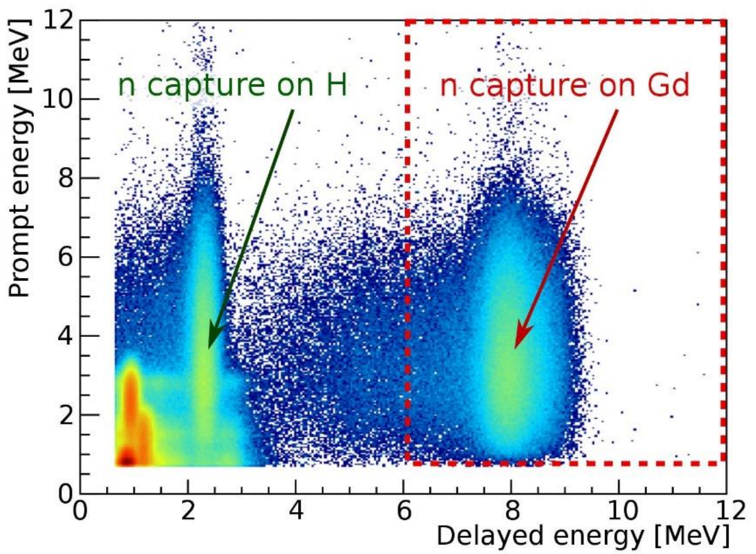
Outline

- Detection of Reactor Antineutrinos
- “Reactor Antineutrino Anomaly” (RAA)
- Reactor Antineutrino Flux Measurement at Daya Bay
- New Neutron Calibration Campaign in 2016
- Summary

Detection of Antineutrinos via Inverse Beta Decay (IBD)





Coincidence in time, space and energy

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

(delayed) $n + p \longrightarrow D + \gamma$ (2.2MeV)

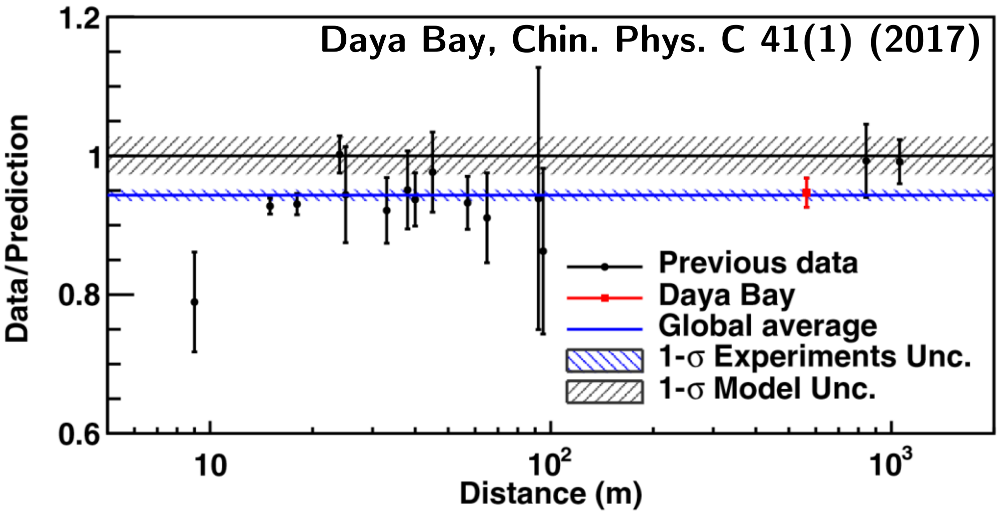
$n + Gd \longrightarrow Gd^* \rightarrow Gd + n\gamma$ (8MeV)

$\tau \approx 30\mu s$

$$E_{\bar{\nu}_e} \approx T_{e^+} + T_n + (m_n - m_p) + m_{e^+} \approx T_{e^+} + 1.8\text{MeV}$$

"Reactor Antineutrino Anomaly" (RAA)

- In 2011, the theoretical treatment of reactor antineutrino flux was improved by Huber & Mueller (HM) *et al.*
- Daya Bay observed a flux deficit in comparison to the HM flux: 5.4% $\pm$ 2% (exp.)
- Past global average: 5.8% $\pm$ 0.9% (exp.)

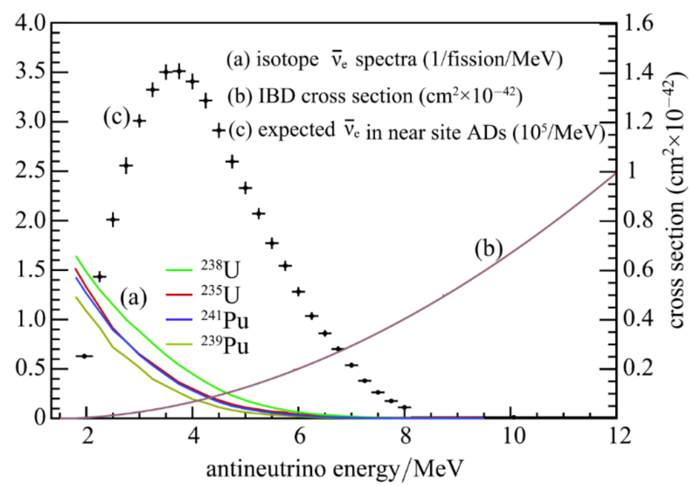


Possible Explanation

The Reactor Antineutrino Anomaly
G. Mention, M. Fechner (DAPNIA, Saclay), Th. Lasserre (DAPNIA, Saclay & APC, Pa
(DSM, DAPNIA, Saclay). Jan 2011. 19 pp.
Published in **Phys.Rev. D83 (2011) 073006**
DOI: 10.1103/PhysRevD.83.073006
e-Print: **arXiv:1101.2755 [hep-ex]** | **PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
详细记录 - Cited by 782 records 500+

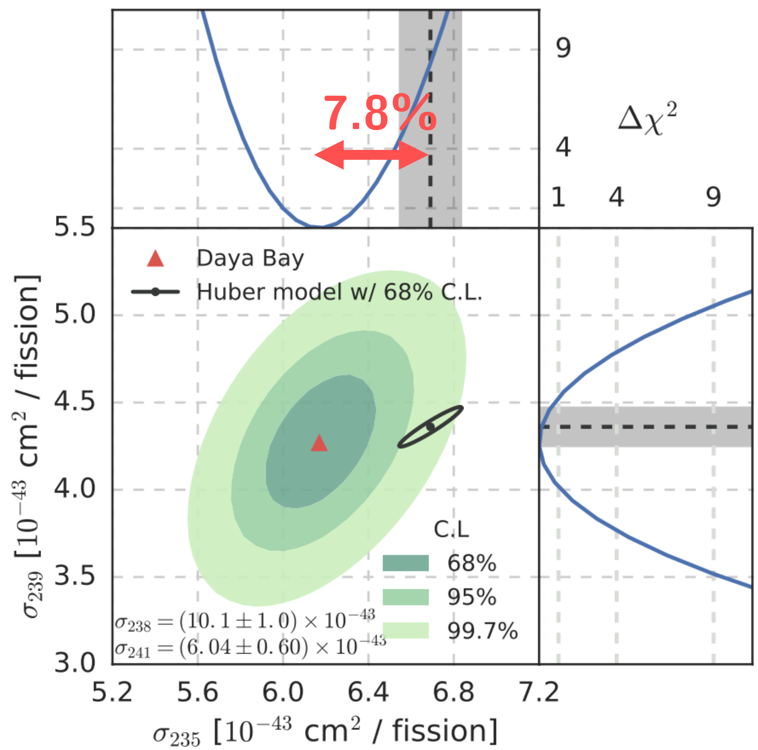
- The existence of eV scale sterile neutrinos!
- Systematic uncertainties in reactor flux calculations (^{235}U, ^{239}Pu, ^{238}U, ^{241}Pu)

Daya Bay can probe this!



Reactor Antineutrino Flux from Individual Isotopes at Daya Bay

- Daya Bay data implies that HM flux overestimates the antineutrino flux from ^{235}U



Can We Improve Further?

- Uncertainty budget in the Daya Bay flux measurement

Daya Bay, Chin. Phys. C 41(1) (2017)

contribution	uncertainty
statistics	0.1%
oscillation	0.1%
reactor	0.9%
detection efficiency	1.93%
total	2.1%

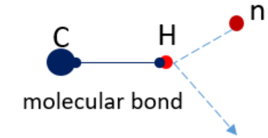
dominant!

Systematics/Difficulties for Detection Efficiency

- Ab initio scattering model not available for thermal neutron in the scintillator
- n-Gd capture γ model lacks constraints under n-H peak

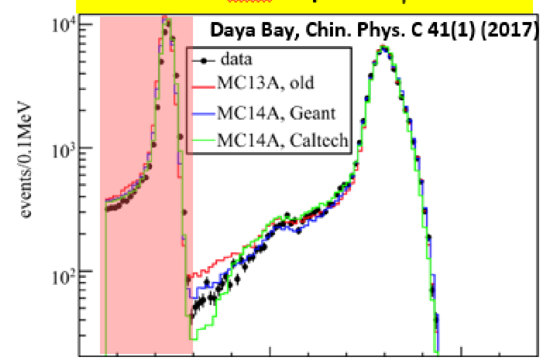
$\Rightarrow$ "full volume" neutron calibration will help

Thermal neutron scattering (<4eV)



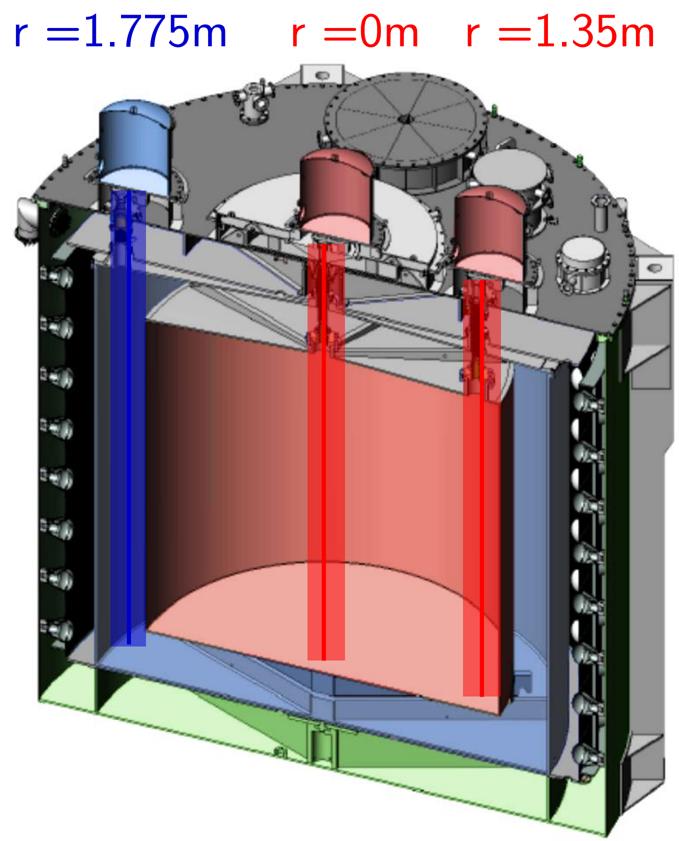
$$\frac{d^2\sigma}{dE d\hat{\Omega}} = \frac{\sigma_b}{4\pi kT}\sqrt{\frac{E'}{E}}S(\alpha,\beta)$$

Different Gd-capture γ model

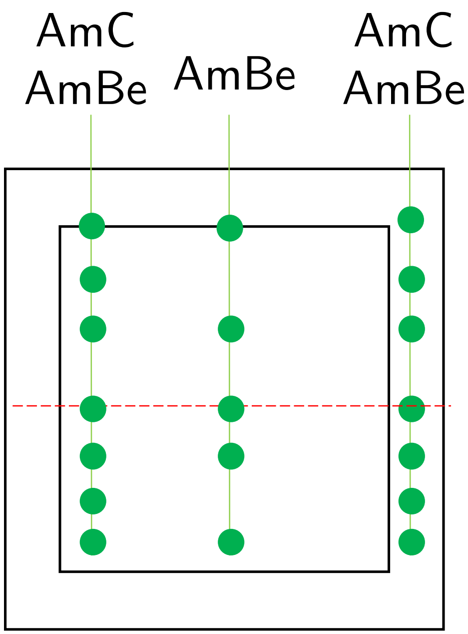


Neutron Calibration Campaign

- Extensive neutron calibration campaign at the end of 2016 at Daya Bay
- AmC and AmBe (few MeV) sources along three z-axes of the automated calibration units (ACU)
- Target: improve the IBD detection efficiency (x2) $\Rightarrow$ more precise reactor flux measurement



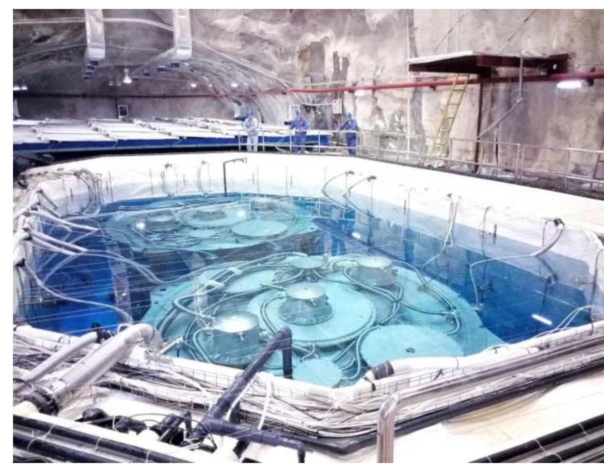
Neutron calibration (AmC, AmBe)



ACU-A	ACU-B	ACU-C
1.5 (m)	1.5	1.6
-	1.35	1.35
0.75	0.75	0.75
0	0	0
-0.75	-0.75	-0.75
-	-1.35	-1.35
-1.45	-1.45	-1.6
AmBe ~ 3.5 hours (per location)	AmC ~ 5 hours AmBe ~ 2.5 hours	AmC ~ 5 hours AmBe ~ 1.5 hours

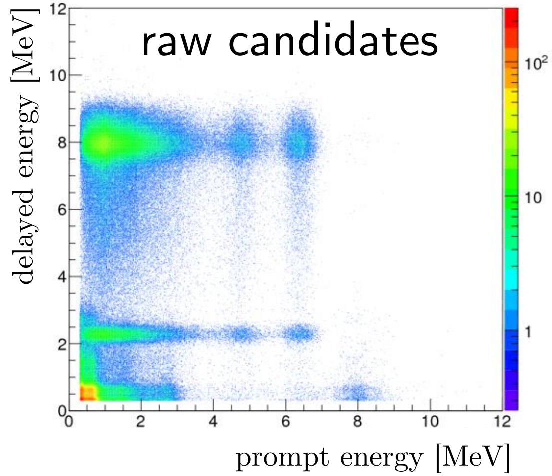
- Total down time for neutrino data: 25 days (including system upgrade and data collection)

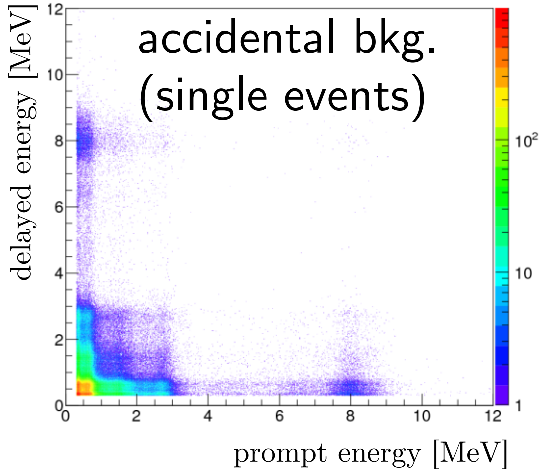
Happy Time

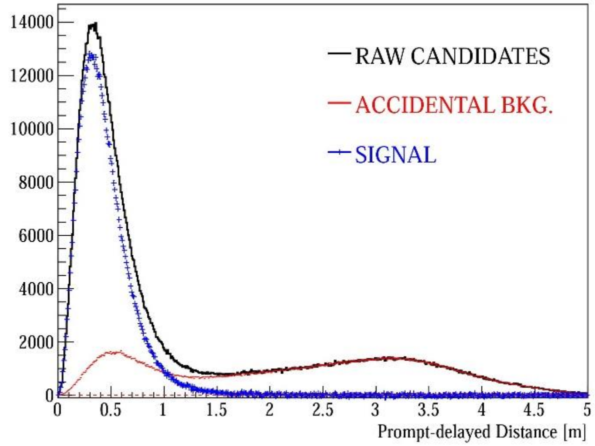


Data Selection

- IBD-like selection with the coincidence time window enlarged to $1200\mu s$
- The ‘accidental background’ (from ambient radioactivity)
    - Estimated from the distribution of single events
    - Normalized with the prompt-delayed spatial coincidence







Monte Carlo (MC) Simulation

- Geant4-based MC simulation

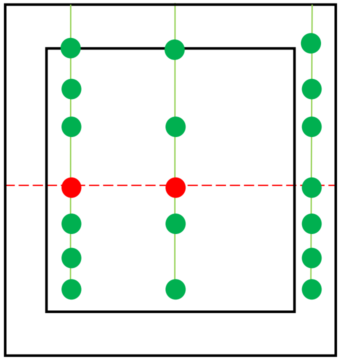
- Scattering: ‘water’ model from nuclear database (ENDF)

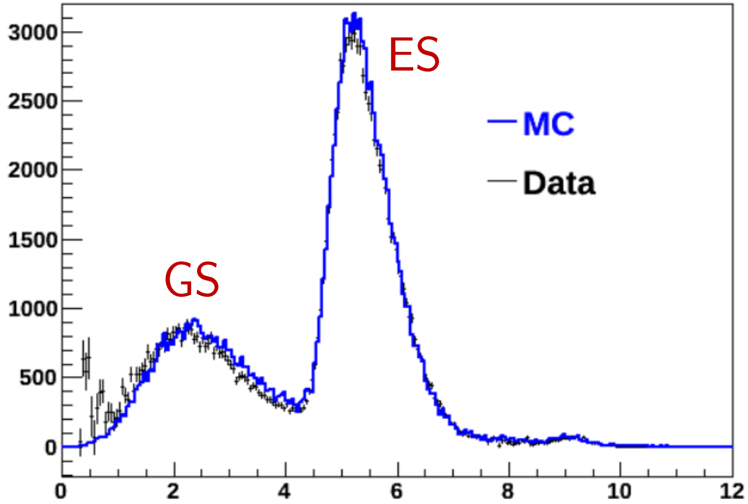
$\Rightarrow$ Approximation for thermal neutron scattering in the scintillator

$\Rightarrow$ Alternative: ’polyethylene’ model

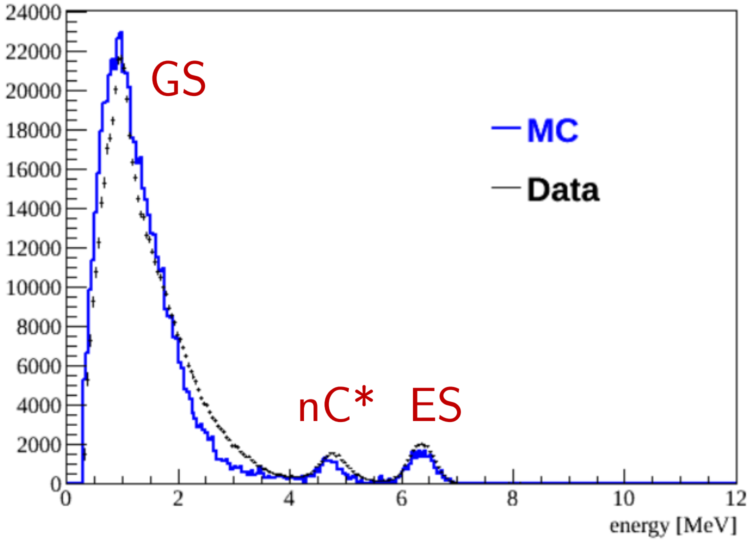
- Capture gammas: Four different Gd γ models inherited from previous analysis

Data v.s. Nominal MC: Prompt Energy





AmBe at ACU-A z=0m

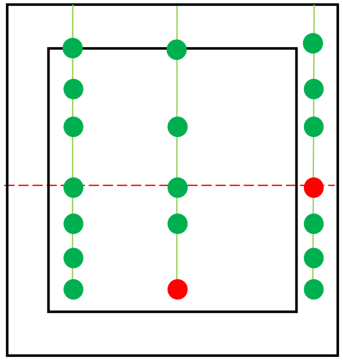


AmC at ACU-B z=0m

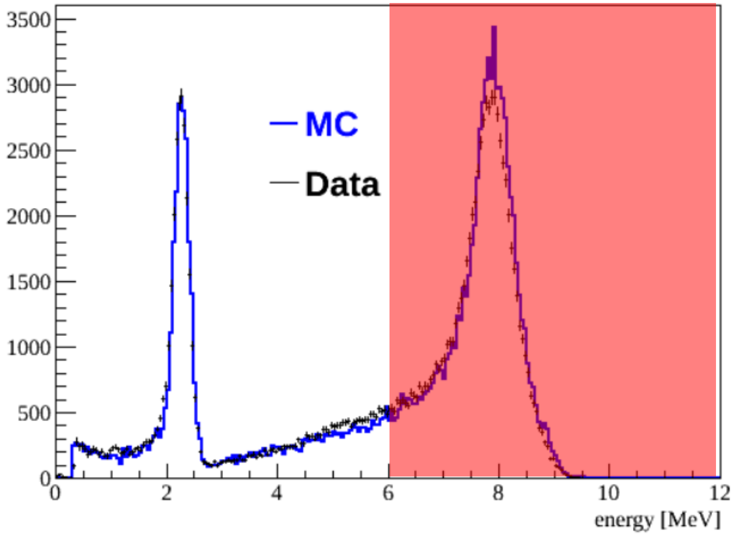
A reasonable agreement between data and MC for

- Ground state (GS): proton recoil
- Excited state (ES): proton recoil + γ

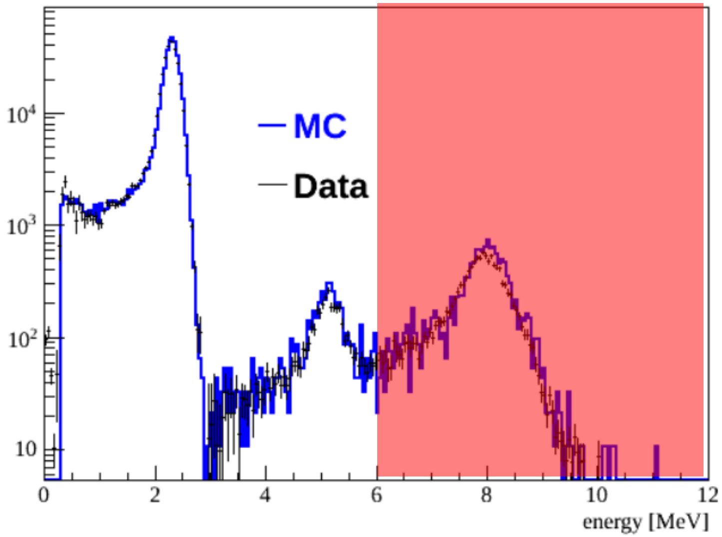
Data v.s. Nominal MC: Delayed Energy



Efficiency:
$F = N([6,12]\mathrm{MeV}) / N([1.5,12]\mathrm{MeV})$



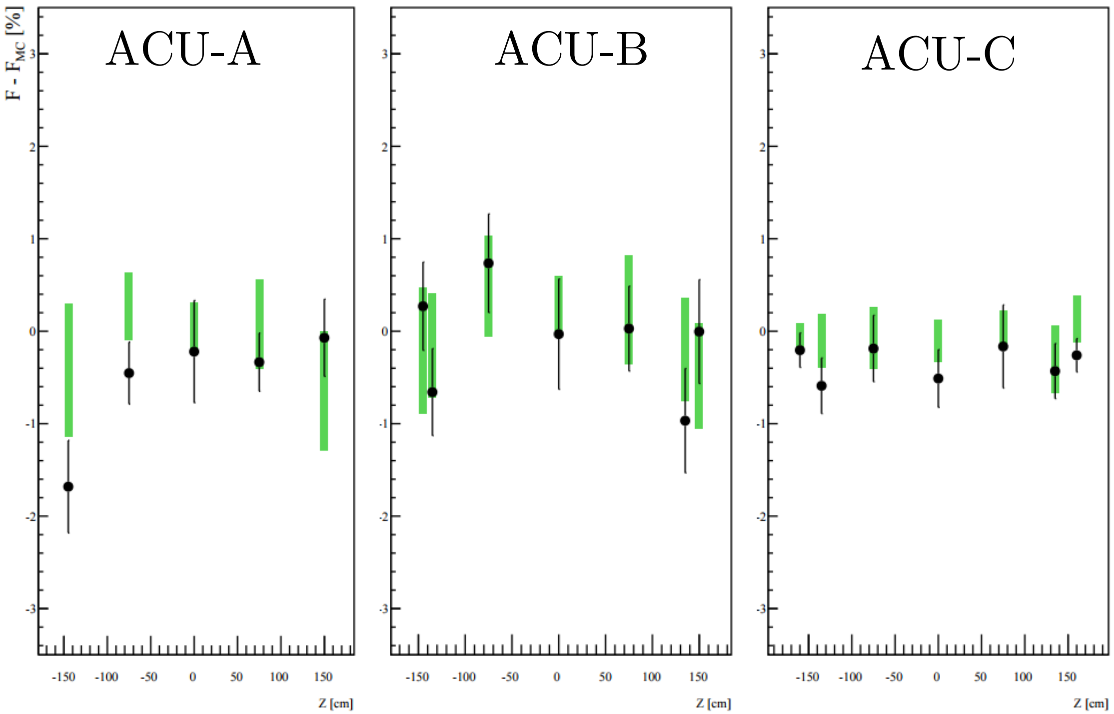
AmBe (ES) at ACU-A z=-1.45m
(bottom of the target volume)



AmC (GS) at ACU-C z=0m
(boundary of the target volume)

A reasonable agreement between data and MC

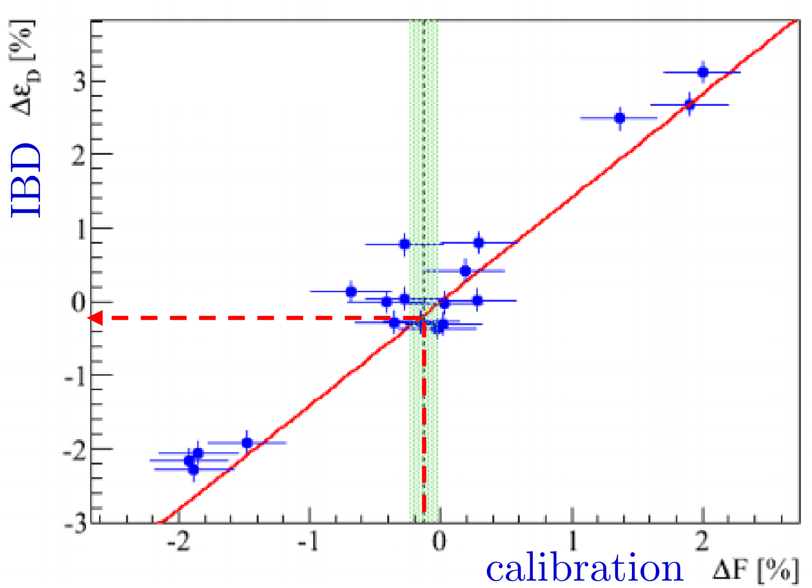
Efficiency: (Data – MC) for AmBe (GS)



Green bar: systematic uncertainty from model variation in MC

- Data in reasonable agreement with MC (within model uncertainty)

Efficiency Correction for IBD



IBD and neutron source efficiency correlated for given model

- Using measured neutron source efficiency ⇒ correction to IBD efficiency
- Different subsets of calibration data ⇒ different correction ⇒ systematic uncertainty

This analysis is VERY near completion!

Summary

- The RAA is being probed experimentally at Daya Bay
  - Bias in theoretical prediction for ^{235}U may be responsible for RAA
- An elaborated neutron calibration campaign was performed at Daya Bay in 2016, aiming to further improve the IBD detection efficiency
- Stay tuned!