

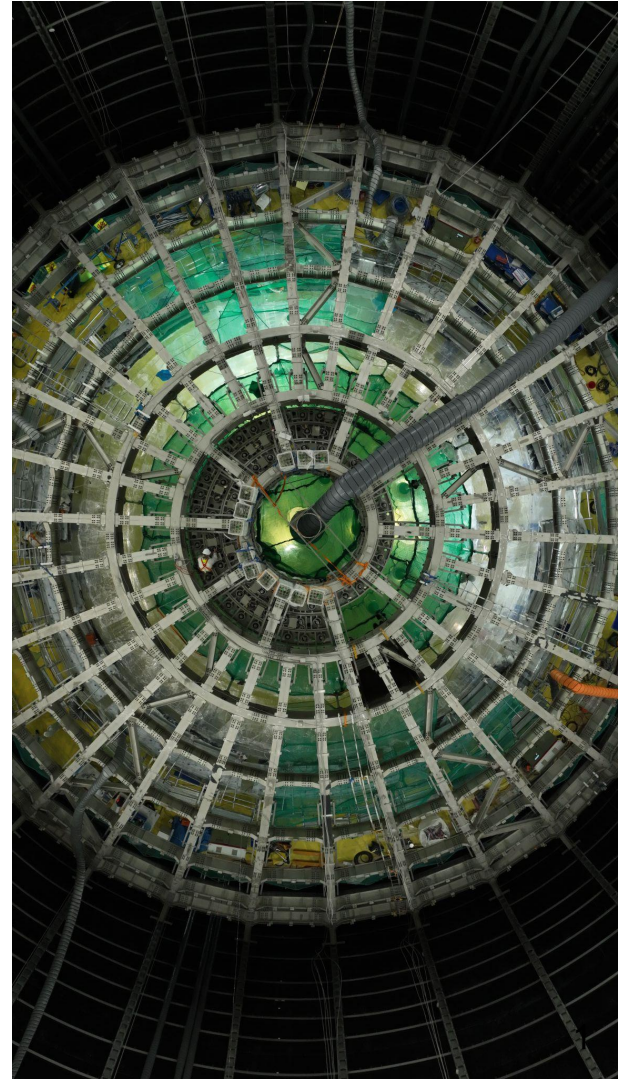
Calibration strategy for JUNO detector

Davide Basilico on behalf of the JUNO collaboration

Physics Opportunities of Large Liquid Scintillator Detectors
2026 Oct 14 - Mainz



UNIVERSITÀ
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Jiangmen Underground Neutrino Observatory

Huge and multipurpose **liquid-scintillator** detector underground in Southern China.

Main goal : determine NMO, enter precision era for ν oscillations



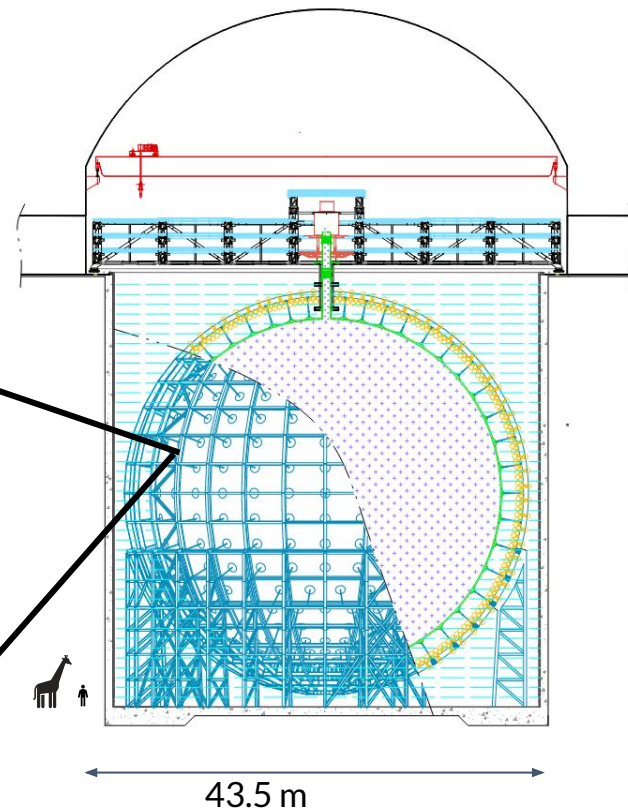
JUNO detector

Technical achievements:

- acrylic sphere with diameter 35.4 m
- 75% PMT coverage by 17596 Large (20-inch) PMTs
- High efficiency 20-inch PMTs (~25-30% QE)
- Very transparent LS ($L_{att} \sim 20.6$ m)

Chin.Phys.C 50 (2026) 4, 043001

2 types of
Large PMTs

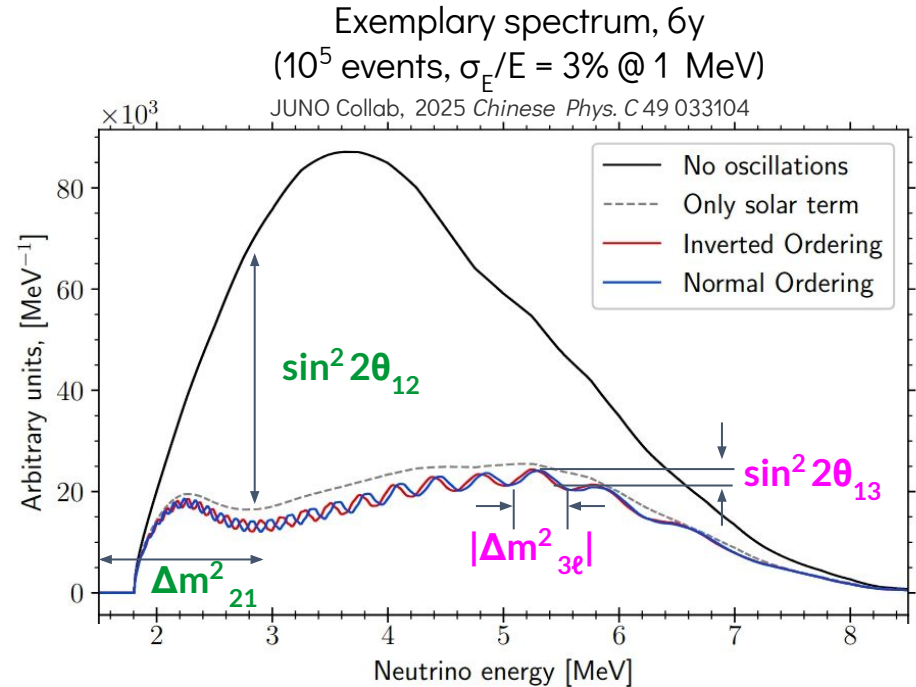


Why JUNO?

Spectroscopy of reactor $\bar{\nu}_e$ at medium baseline

First experiment to observe the interference of **fast** ($\sin^2\theta_{13}$, $|\Delta m^2_{3l}|$) and **slow** ($\sin^2\theta_{12}$, Δm^2_{21}) oscillations **in vacuum**

→ interference pattern depends on NMO



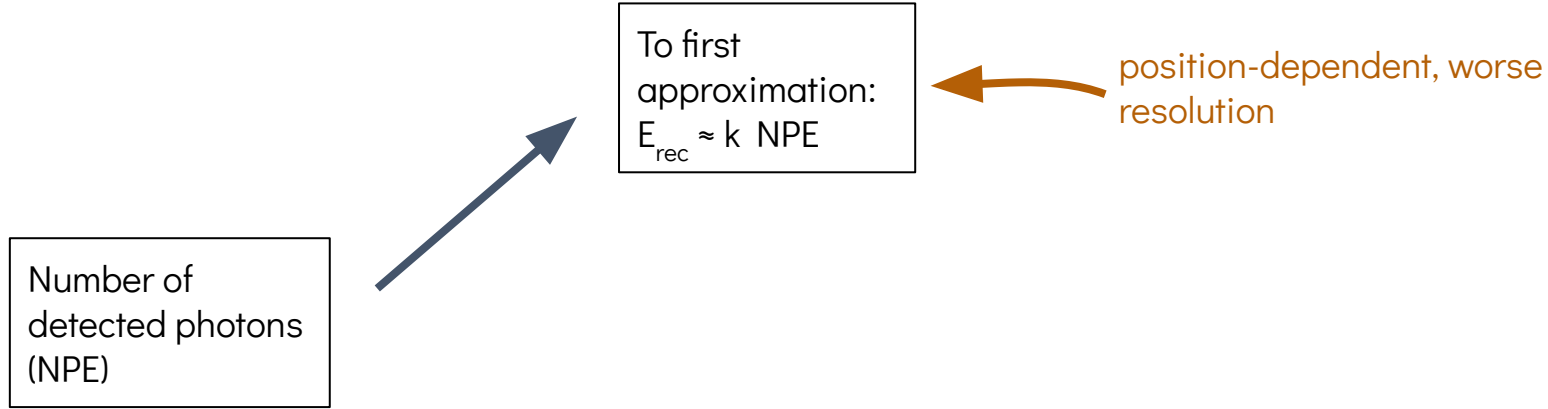
Detector response goals

Precision measurements require deep understanding of detector & excellent performances

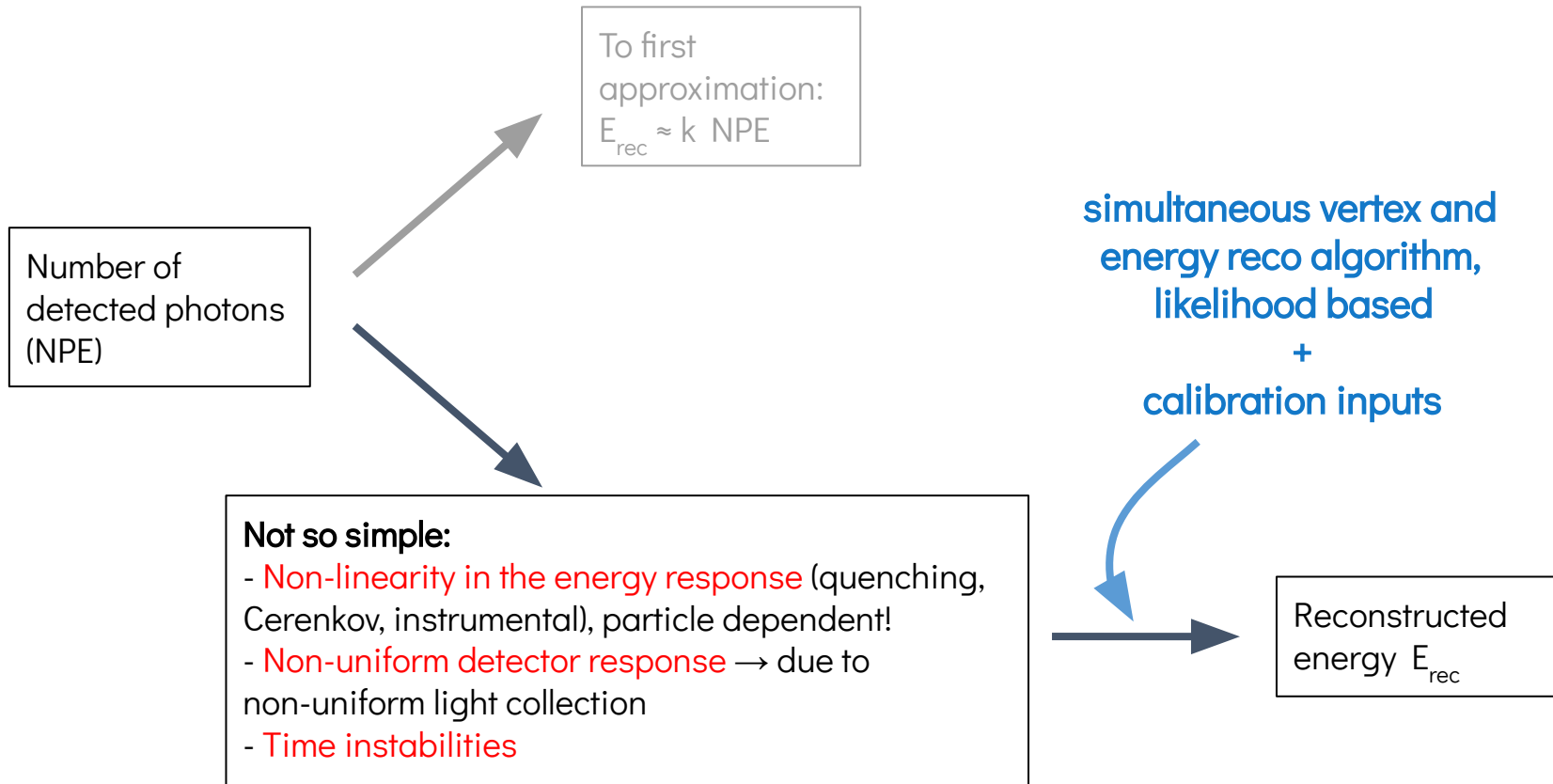
Key requirements

- 1) excellent energy resolution
 - can be lowered via calibrations
 - goal 3.1% @1 MeV
- 2) sub-percent control of the detector response
 - must be controlled via calibrations & reconstruction
 - low level calibrations (LPMTs), high-level calibrations

Energy reconstruction



Energy reconstruction



Calibration sources

Laser calibrations

LPMT gain, timing, DCR

Gamma calibrations

Energy scale, non linearity, resolution

Cosmogenic isotopes

Energy scale, non linearity, resolution

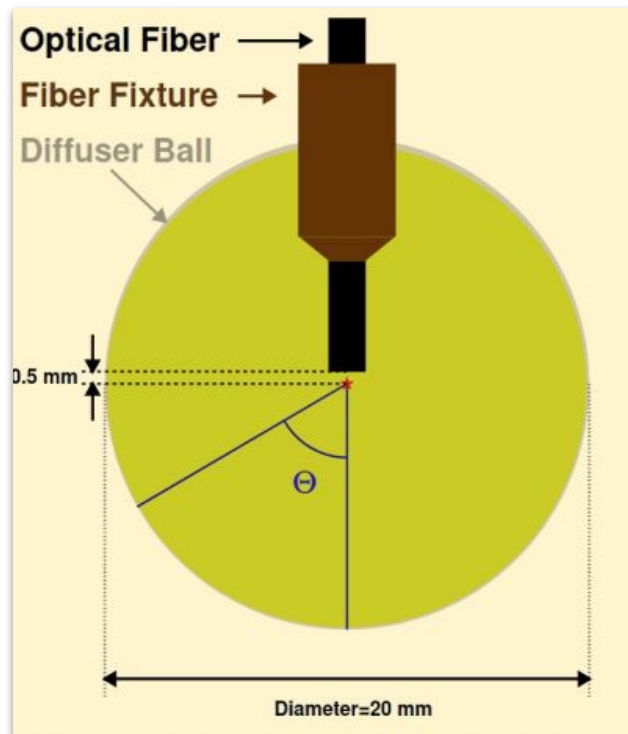
^{214}Po α decays

Energy scale, time-stability

spallation neutrons

Energy scale, time-stability, non-uniformity

Laser system for LPMT calibrations



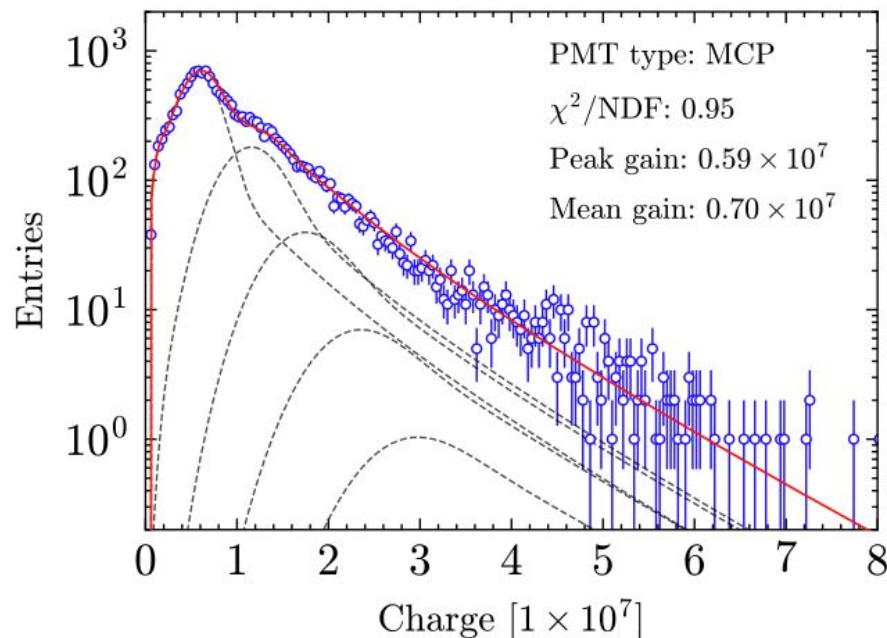
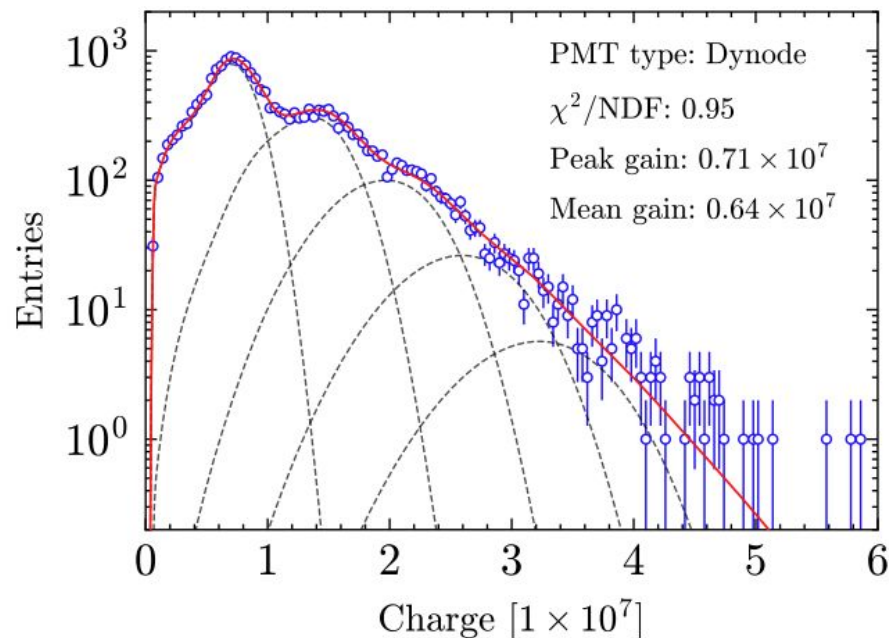
- Laser: 266 nm (UV) or 420 nm or 532 nm (help to understand the light propagation without LS effect)
- Plastic (PTFE) diffuser ball for uniform light distribution
- Diffuser deployed along the central vertical axis of CD
- Weekly calibration: external trigger, 50 Hz rate.

Performance:

- Timing precision <1 ns, stability of 1%.
- Light intensity tunable.
- LPMT and SPMT nonlinearity can be corrected by laser data

LPMT calibrations: gain

- Necessary to characterize the single-photoelectron (SPE) charge distribution
- Fitting the charge spectra for laser runs
- Stable in time at < 0.2% level



LPMT timing

Timing calibration is a key ingredient for the event reconstruction

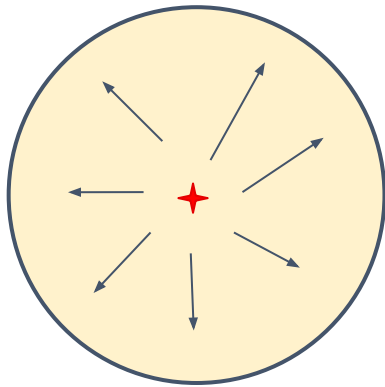
LPMT timing

Timing calibration is a key ingredient for the event reconstruction

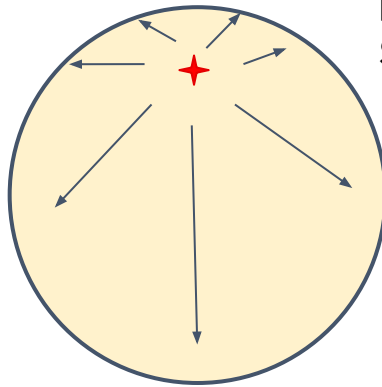
Vertex reco:

- 1) requires time-aligned PMTs
- 2) performed via time-of-flight triangulation for the fired PMTs

all PMTs fired ~ same time



North PMTs fired earlier than
South PMTs



★ : event → : scint. photons

LPMT timing

Timing calibration is a key ingredient for the event reconstruction

Vertex reco:

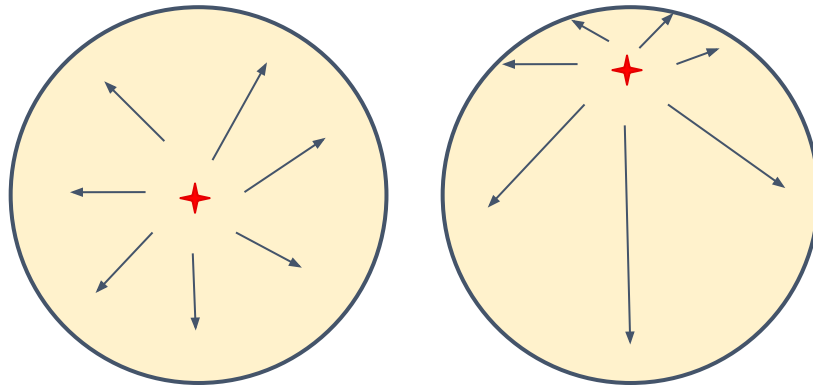
- 1) requires time-aligned PMTs
- 2) performed via time-of-flight triangulation for the fired PMTs



Energy reco requires as input a vertex-dependent charge-map to “account for” light collection non-homogeneities



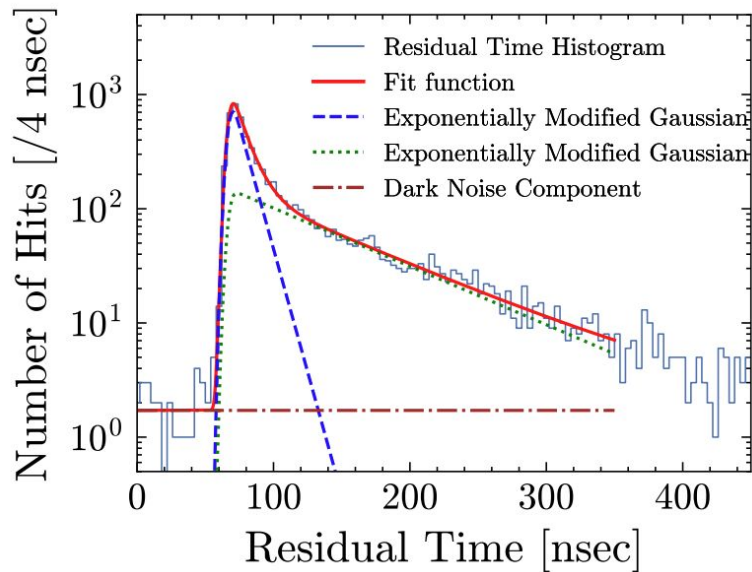
Biased or non-performant vertex reco also impacts on the energy reco!



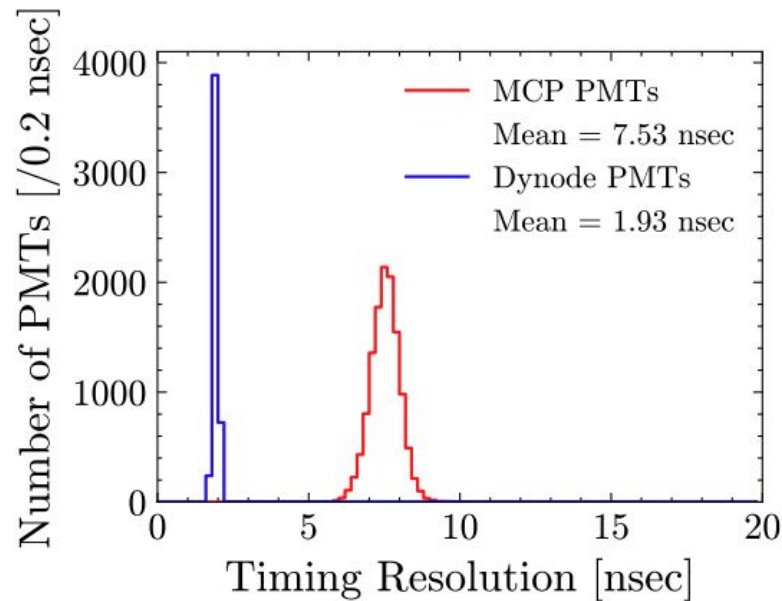
★ : event → : scint. photons

LPMT timing: laser runs

$$t = t_{\text{first-hit}} - t_{\text{TOF}} - t_{\text{ref-PMT}}$$



one of model
parameters
proportional to



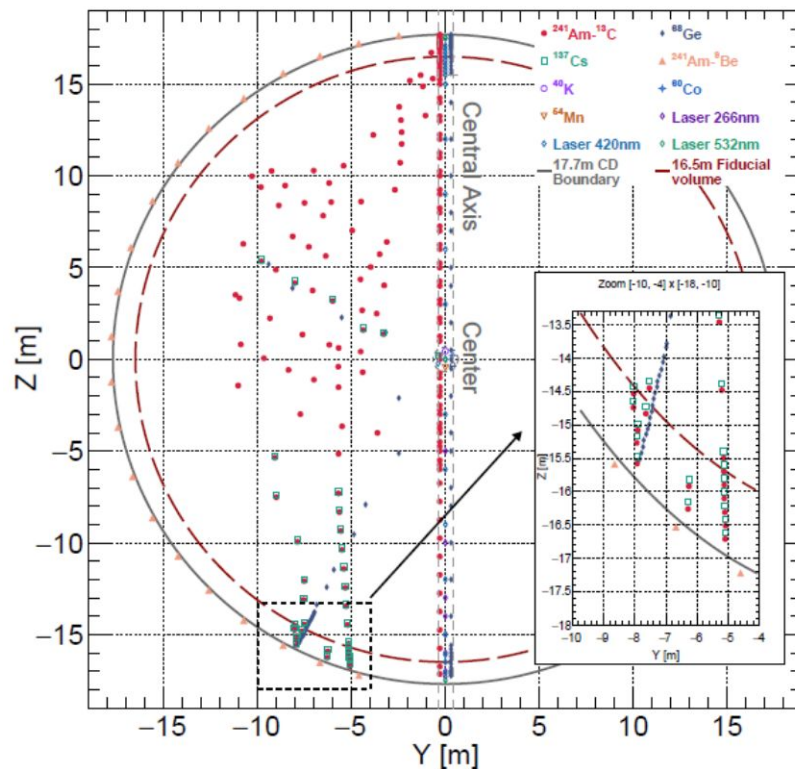
+ times aligned to better than 1 ns, that is the ADC sampling time.

γ sources campaign

Artificial sources deployed in multiple positions via mechanical 1D (vertical axis) and 2D systems

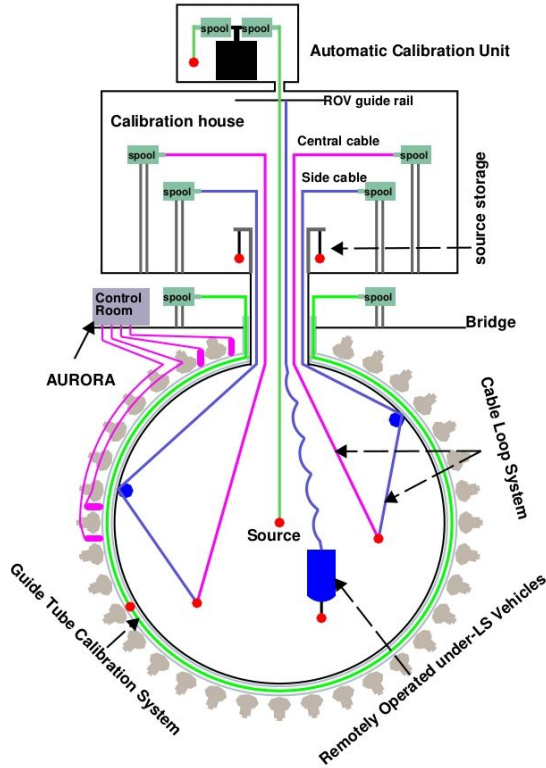
Source	Energy	Activity
Gamma Sources		
^{68}Ge	$0.511 \times 2 \text{ MeV}$	595 Bq ^a
^{137}Cs	0.662 MeV	140 Bq ^b
^{54}Mn	0.835 MeV	521 Bq ^a
^{40}K	1.460 MeV	13 Bq
^{60}Co	1.173+1.333 MeV	165 Bq ^b
Neutron Sources		
$^{241}\text{Am}-^{13}\text{C}$	neutron + 6.13 MeV ($^{16}\text{O}^*$)	
	(n, γ)p 2.223 MeV	130 Bq
	(n, γ) ^{12}C 4.94 MeV	100 Bq
	(n, γ) ^{56}Fe 7.63 MeV, etc.	
$^{241}\text{Am}-^9\text{Be}$	neutron + 4.43 MeV ($^{12}\text{C}^*$)	
	(n, γ)p 2.22 MeV	30 Bq

No ^{222}Rn leakage or other contaminants introduced during calibration

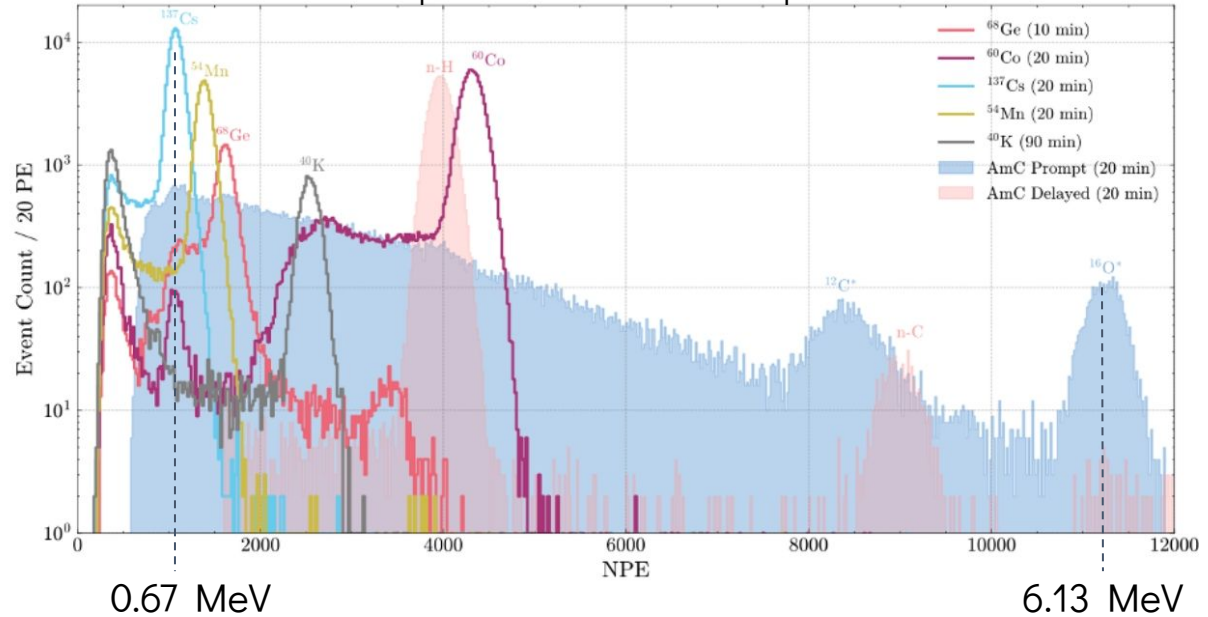


γ sources campaign

Artificial sources deployed in multiple positions via mechanical 1D (vertical axis) and 2D systems



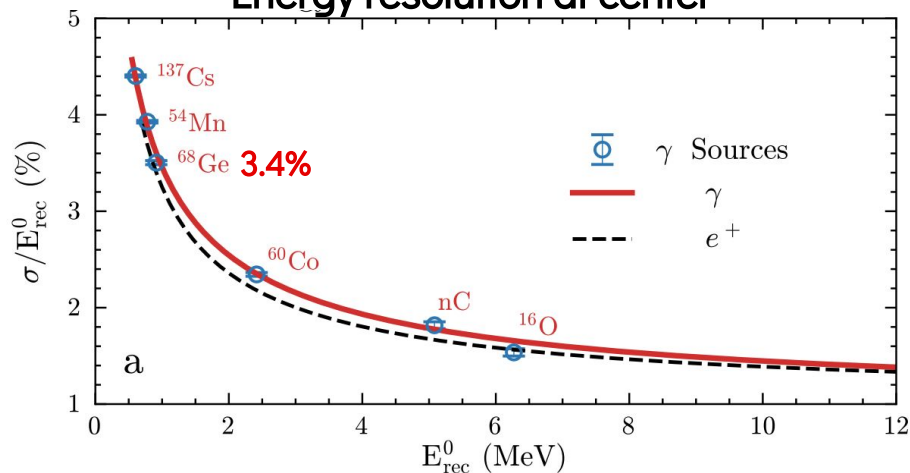
Energy spectrum for calibration runs
(unit: photoelectrons collected per event)



Reconstruction performances

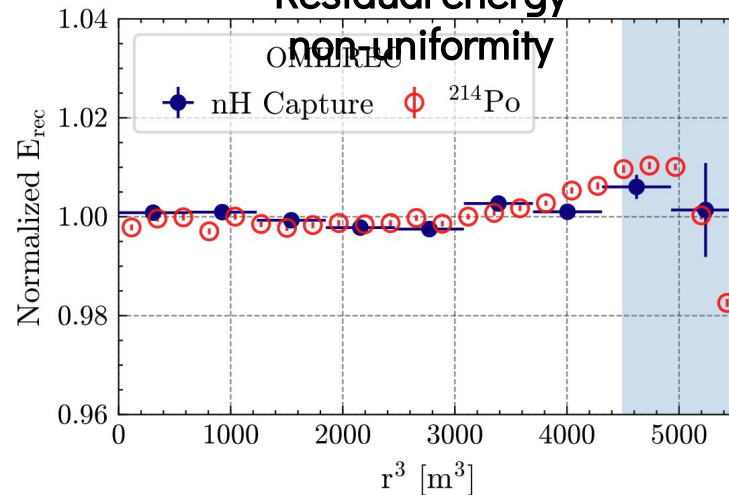
inputs from calibrations: PMTs timing and gain, non-uniformity map for PE collection

Energy resolution at center



~3.4% for ^{68}Ge

Residual energy

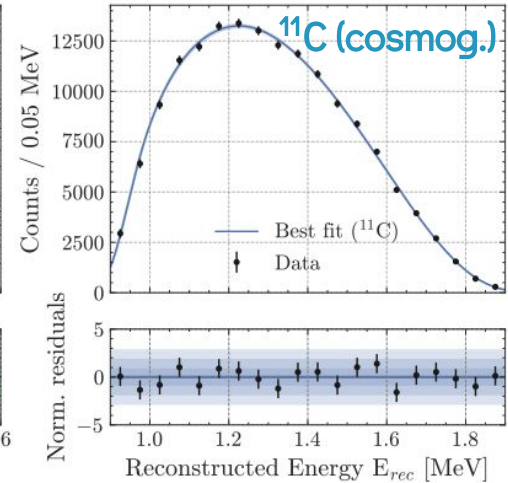
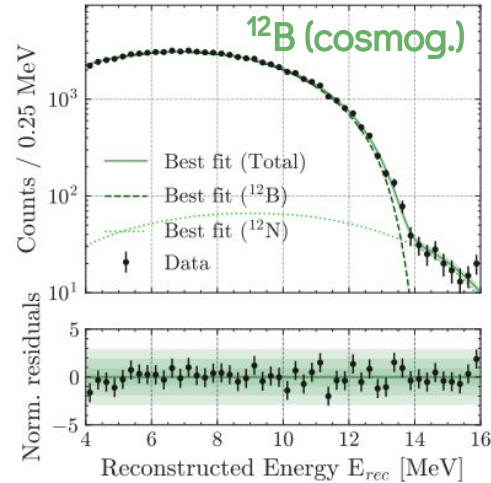
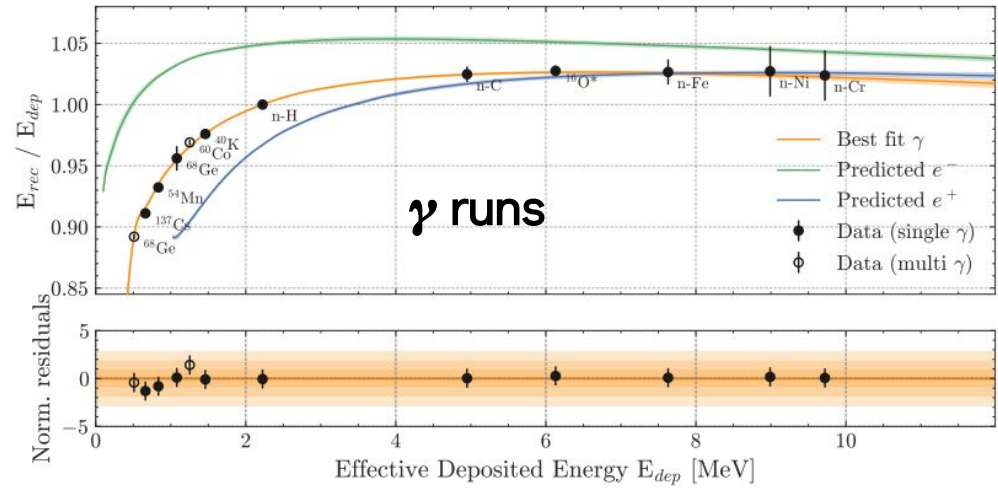


Via ^{214}Po events, controlled at <1% level

Energy response

Energy scale is intrinsically **non-linear** and **particle dependent** : modelling of ionisation quenching + Cherenkov light + instrumental non-linearity

→ characterized with <1% precision with γ sources, cosmogenic isotopes, spallation neutrons



Conclusion & future plans

- Detector characterization performed in very short time span, stable and regularly taking data
- Most of the initial detector performance parameters exceed the design values.
- Energy resolution nearly at the design value, improvements expected from enhanced calibrations (new extensive campaign planned) and event reconstruction.





Thanks!