

**WORKFLOW** 1 Motivation & Detector status 2 Dataset and Event selection 3 Occupancy calculation 4 Optical model construction 5 LS attenuation-length fit

## 1 Motivation & Detector status

- The liquid scintillator attenuation length is a key factor for achieving JUNO's target energy resolution of 3% at 1 MeV.
- In-situ measurement reflects real detector optical properties.

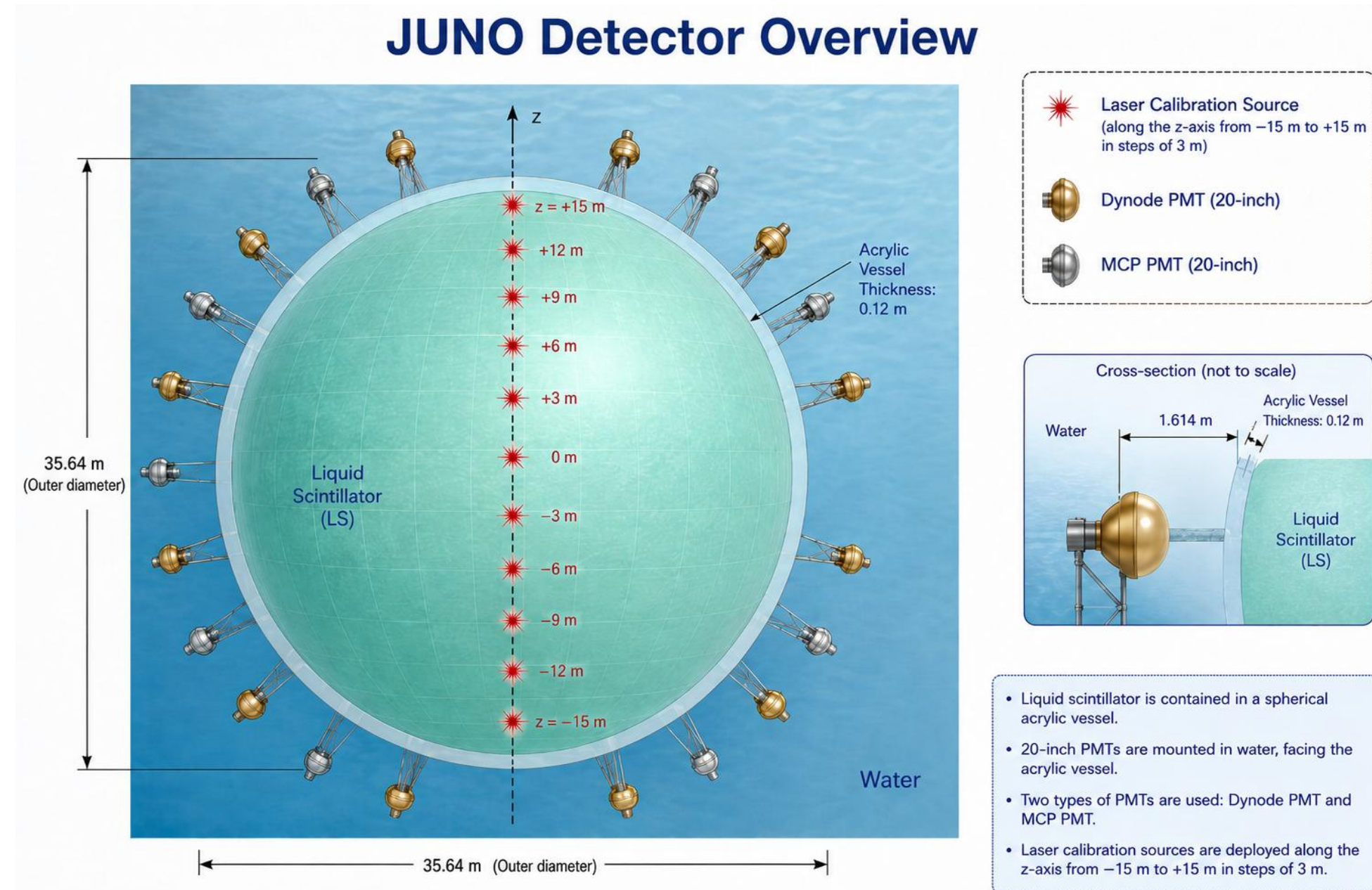


Fig. 1. JUNO detector status and laser scan;

## 2 Dataset and Event selection

- The dataset is based on Monte Carlo simulations of the JUNO 430 nm laser calibration system. Laser injection positions are scanned along the detector's z-axis, as shown in Fig. 1.
- After Time-of-Flight (TOF) correction and timing alignment, the PMT time-distribution peak is used as the reference. Laser events are selected within a  $\pm 1$  ns offset-time window.

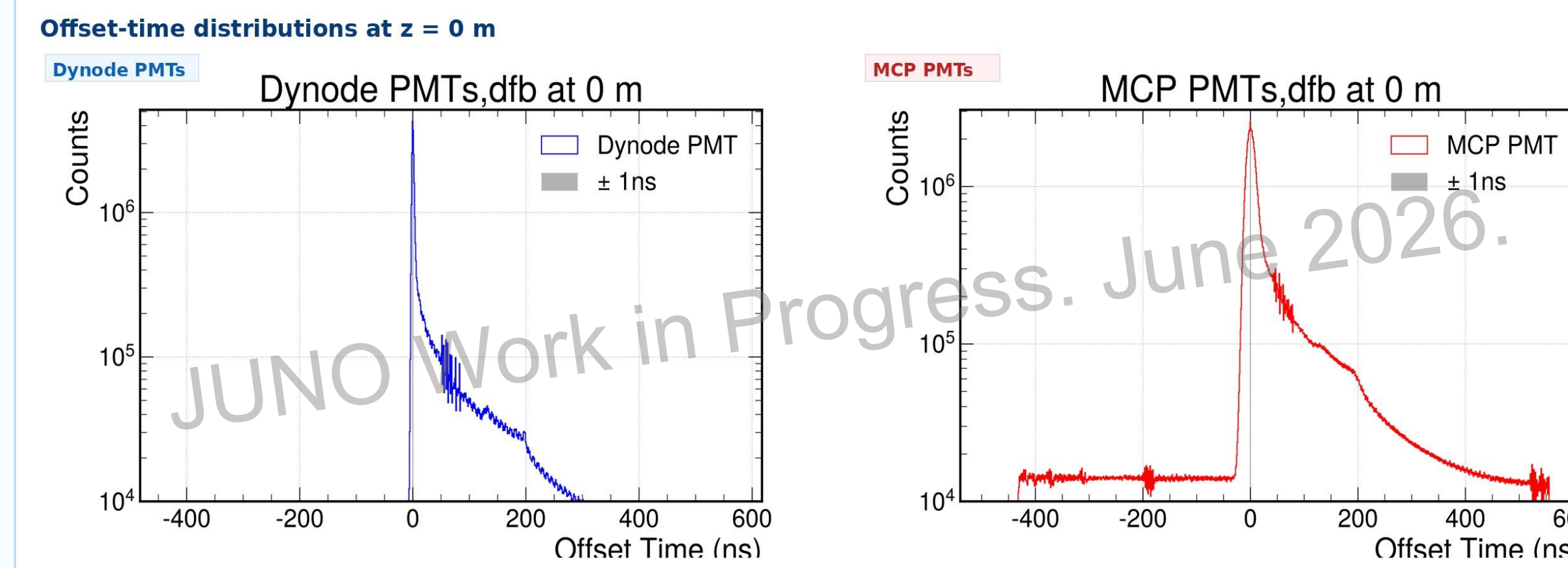


Fig. 2. z = 0 m offset-time distributions for Dynode and MCP PMTs.

## 3 Occupancy Response Across Source Positions

Panels are grouped by PMT type: Dynode on top, MCP on bottom.

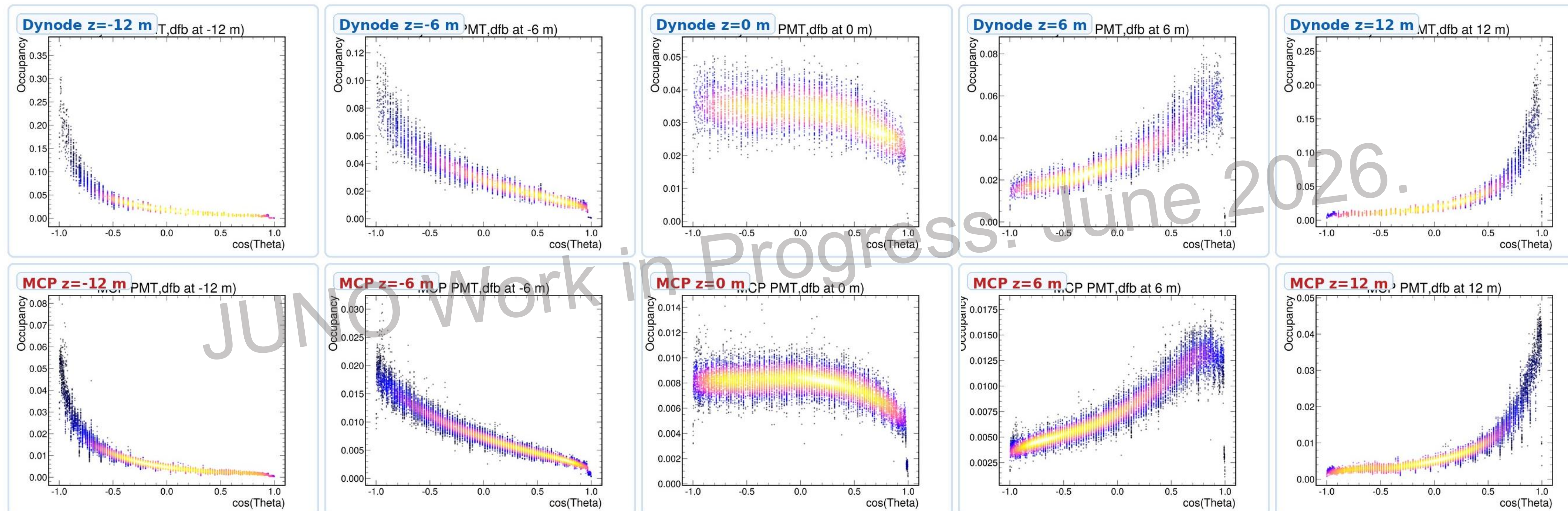


Fig. 3. Occupancy versus  $\cos(\Theta)$  after event selection for five representative source positions per PMT type.

- Multiple photoelectrons (MPE) :  $N_{MPE} = -N_{pulse} \log(1 - N_{hit}/N_{pulse})$
- Occupancy:  $O = \frac{N_{MPE}}{N_{pulse}} = -\log(1 - \frac{N_{hit}}{N_{pulse}})$

## 4 Model Construction: Equations & Parameters

### 1 Model for Expected Observables

$$O_{ij}^{model} = N_i \frac{\Omega_{ij}}{4\pi} T_{ij} \exp\left[-\left(\frac{d_{ij}^{w,int}}{L_{LS,int}} + \frac{d_{ij}^a}{L_a} + \frac{d_{ij}^{w,ext}}{L_{w,ext}}\right)\right] P(\cos\theta^{DB}) \epsilon_j$$

Expected occupancy includes geometry, transmission, attenuation, angular response, and PDE.

### 2 Normalized Observable

$$\tilde{O}_{ij}^{model} = \frac{O_{ij}^{model}}{(\Omega_{ij}/4\pi) T_{ij} \epsilon_j \exp\left[-\left(\frac{d_{ij}^a}{L_a} + \frac{d_{ij}^{w,ext}}{L_{w,ext}}\right)\right]} = P(\cos\theta^{DB}) N_i \exp\left(\frac{d_{ij}^{w,int}}{L_{LS,int}}\right)$$

$$\log \tilde{O}_{ij}^{model} = \log P(\cos\theta^{DB}) + \log N_i - \frac{d_{ij}^{w,int}}{L_{LS,int}}$$

### 3 Angular Acceptance Model

$$P(\cos\theta^{DB}) = a_0 + a_1 \cos\theta^{DB} + a_2 (\cos\theta^{DB})^2 + a_3 (\cos\theta^{DB})^3$$

### 4 $\chi^2$ Minimization

$$\chi^2(L_{LS,int}^{PMT\ type}, N_i^{PMT\ type}) = \sum_{i=1}^{11} \sum_{n \in PMT\ layers} \frac{(\tilde{O}_{ij}^{data} - \tilde{O}_{ij}^{model})^2}{\sigma_{stat,n}^2 + \sigma_{acrylic}^2 + \sigma_{w,ext}^2 + \sigma_{PDE}^2}$$

### Variables & Parameters

Observables & Normalization	Uncertainties
$O_{ij}$ : occupancy	$\sigma_{stat,n}$ : statistical uncertainty for layer n
$\tilde{O}_{ij}$ : normalized observable	$\sigma_{acrylic}$ : acrylic systematic uncertainty
$N_i$ : source normalization for run i	$\sigma_{w,ext}$ : external-water systematic uncertainty
$\Omega_{ij}$ : solid angle	$\sigma_{PDE}$ : PDE systematic uncertainty
$T_{ij}$ : transmission factor	
$\epsilon_j$ : PMT detection efficiency (PDE)	
Angular Responses	Other
$d_{ij}^{w,int}$ : optical distance in internal LS	i : run index
$d_{ij}^a$ : optical distance in acrylic	j : PMT index
$d_{ij}^{w,ext}$ : optical distance in external water	n : PMT layer index
Attenuation Lengths	PMT type : Dynode or MCP
$L_{LS,int}$ : attenuation length in internal LS	
$L_a$ : attenuation length in acrylic	
$L_{w,ext}$ : attenuation length in external water	

Fig. 4. Forward model, normalized occupancy, diffuser-ball anisotropy and  $\chi^2$  minimization. The formula figure is enlarged and placed next to the workflow steps to make the model role explicit.

## 5 Attenuation-Length Fitting & Main Results

**Dynode PMTs** : consistent with 20.6 m reference  
 **$20.82 \pm 0.28$  m**

**MCP PMTs** : higher than reference expectation  
 **$28.16 \pm 0.33$  m**

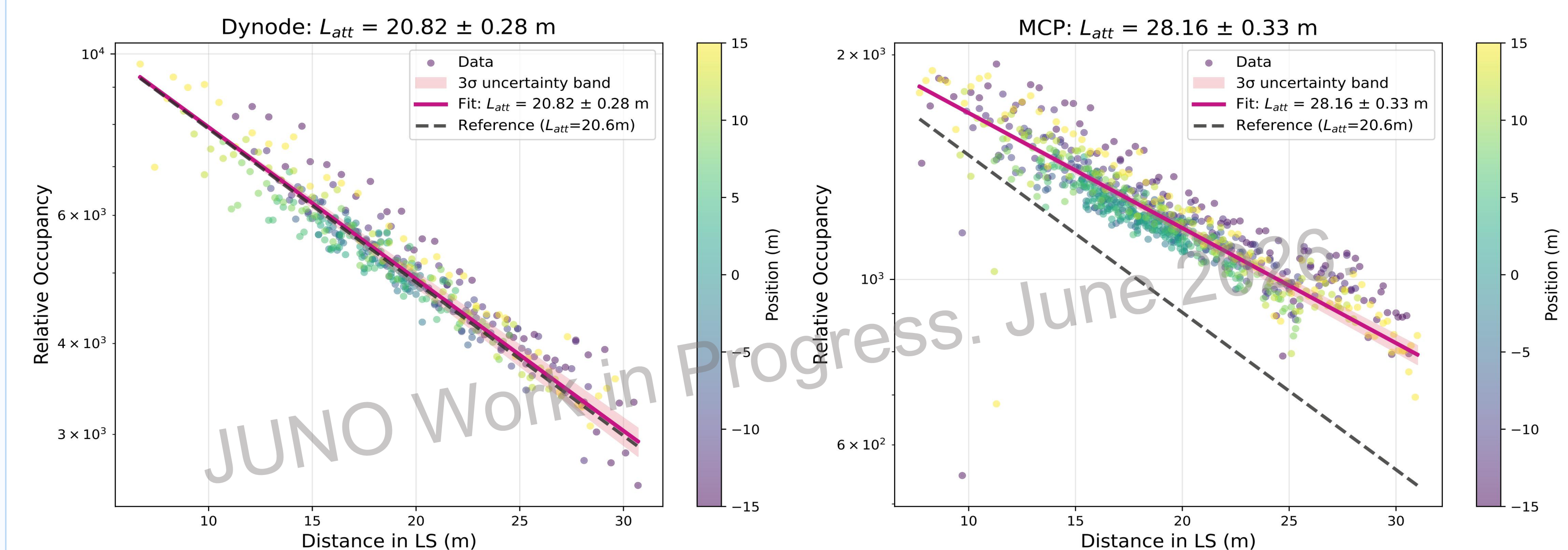


Fig. 5. Combined attenuation-length results. The Dynode PMT result agrees well with the reference within uncertainties, while the MCP PMT result shows a larger deviation. The better timing resolution of Dynode PMTs enables a higher signal-to-noise ratio in time-based event selection.

## 6 Summary & Outlook

This poster presents a method for measuring the **liquid scintillator attenuation length** and validates it using JUNO 430 nm laser simulation data. The attenuation length obtained with Dynode PMTs,  **$(20.82 \pm 0.28)$  m**, is in good agreement with the simulated reference value of **20.6 m** within uncertainties, demonstrating the effectiveness and precision of the method. The discrepancy between the Dynode and MCP results suggests that the method is sensitive to detector performance, particularly the **timing resolution**. In future work, the method will be applied to **real JUNO laser calibration data** to measure the liquid scintillator attenuation length.

### Reference:

- Rigan, M. (2021). Optical calibration of the SNO+ detector in the water phase with deployed sources. Journal of Instrumentation. <https://doi.org/10.1088/1748-0221/16/10/P10021>
- An, Fengpeng. (2016). Neutrino physics with JUNO. Journal of Physics G: Nuclear and Particle Physics. 43. 10.1088/0954-3899/43/3/030401.

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