



# Dual Calorimetry at JUNO

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# A reminder of JUNO

World's largest (20kt) liquid scintillator detector

Unprecedented energy resolution

$\sim 3\% @ 1\text{MeV}$

Sub-percent systematics control

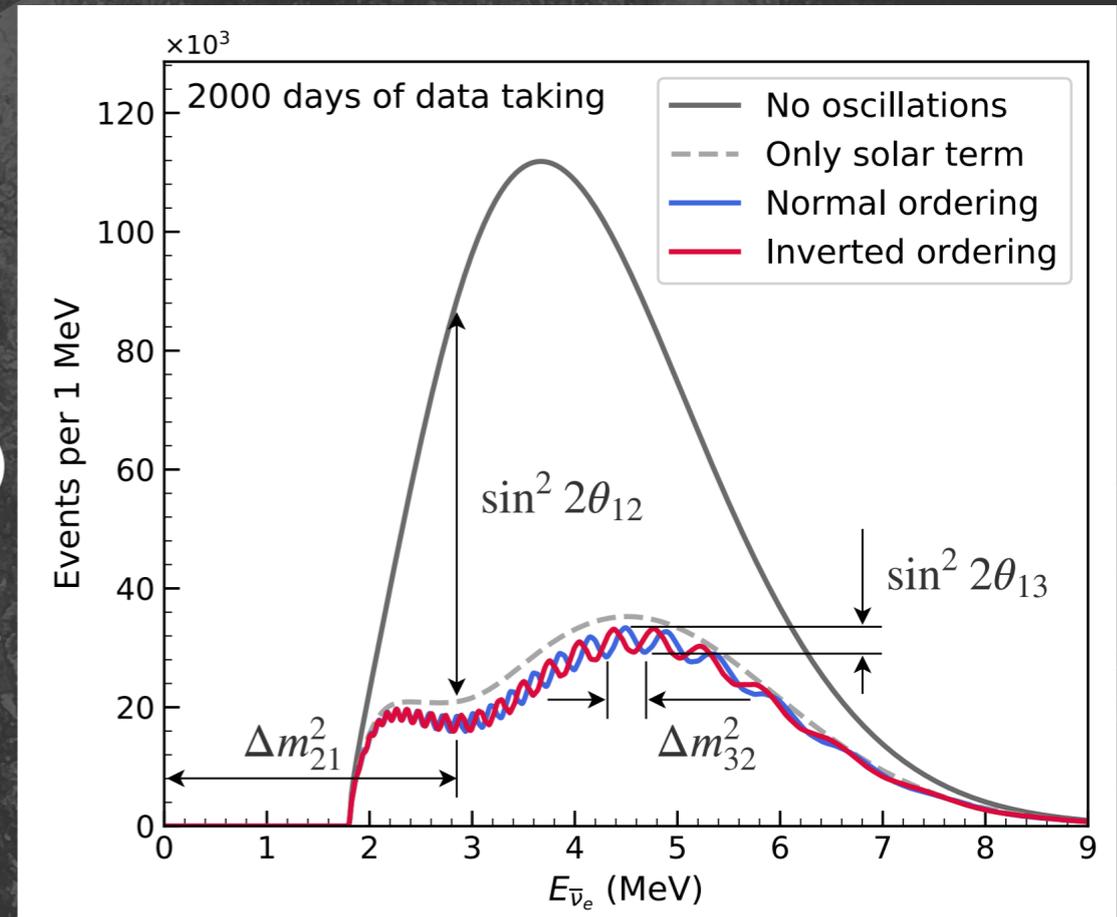
Primary Physics Topics:

Neutrino Mass Ordering (MO)

Sub-percent Precision Oscillation Parameters

( $\Delta m_{32}^2$ ,  $\Delta m_{21}^2$  and  $\sin^2 \theta_{12}$ )

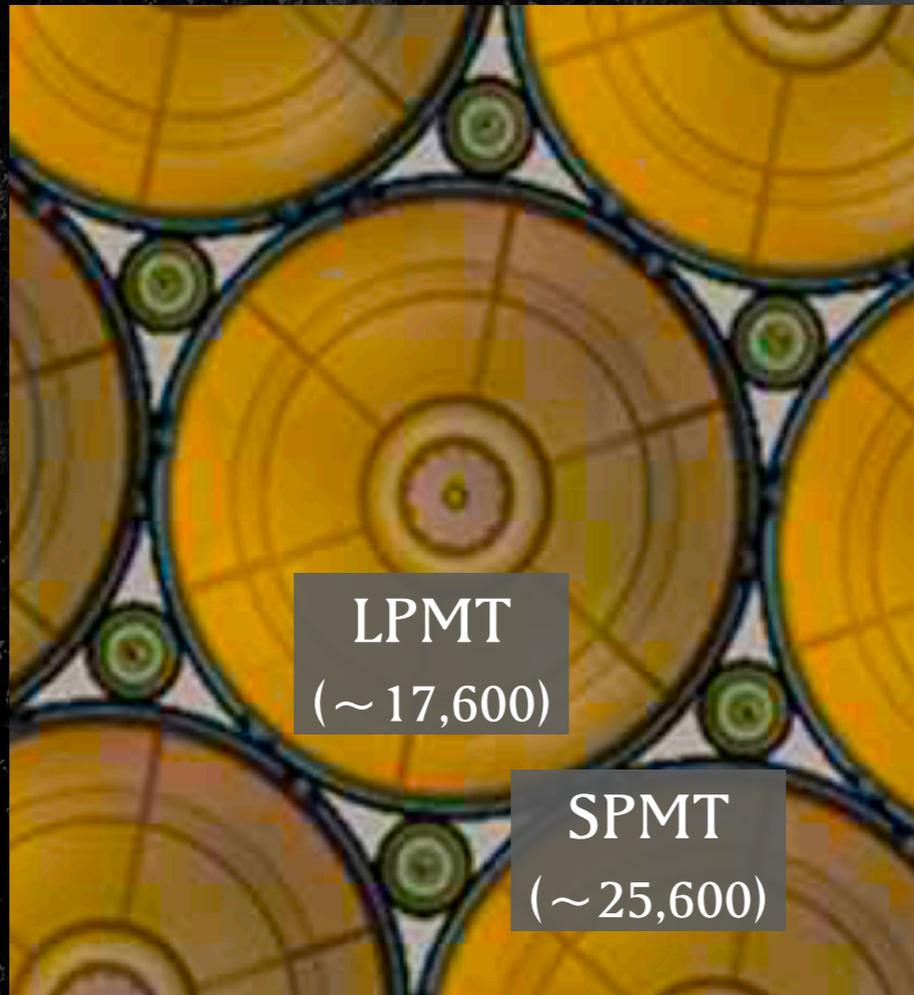
JUNO Reactor Neutrino Energy Spectrum



# What is Dual Calorimetry at JUNO?

2 sets of PMTs & electronics

JUNO  
Liquid  
Scintillator  
(LS)



Large PMT system (LPMT):  
20" PMT + Charge integration based electronics

Main calorimetry  
for 3% energy resolution@1MeV

Small PMT system (SPMT):  
3" PMT + Photon counting based electronics

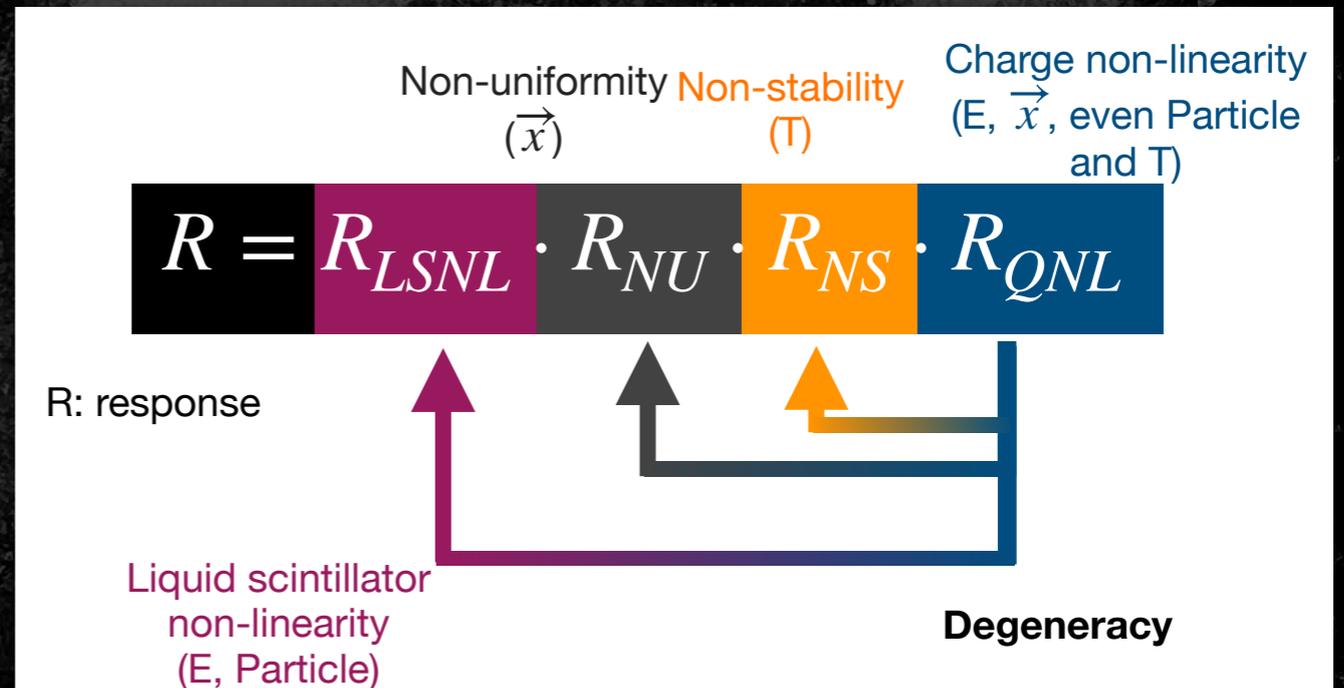
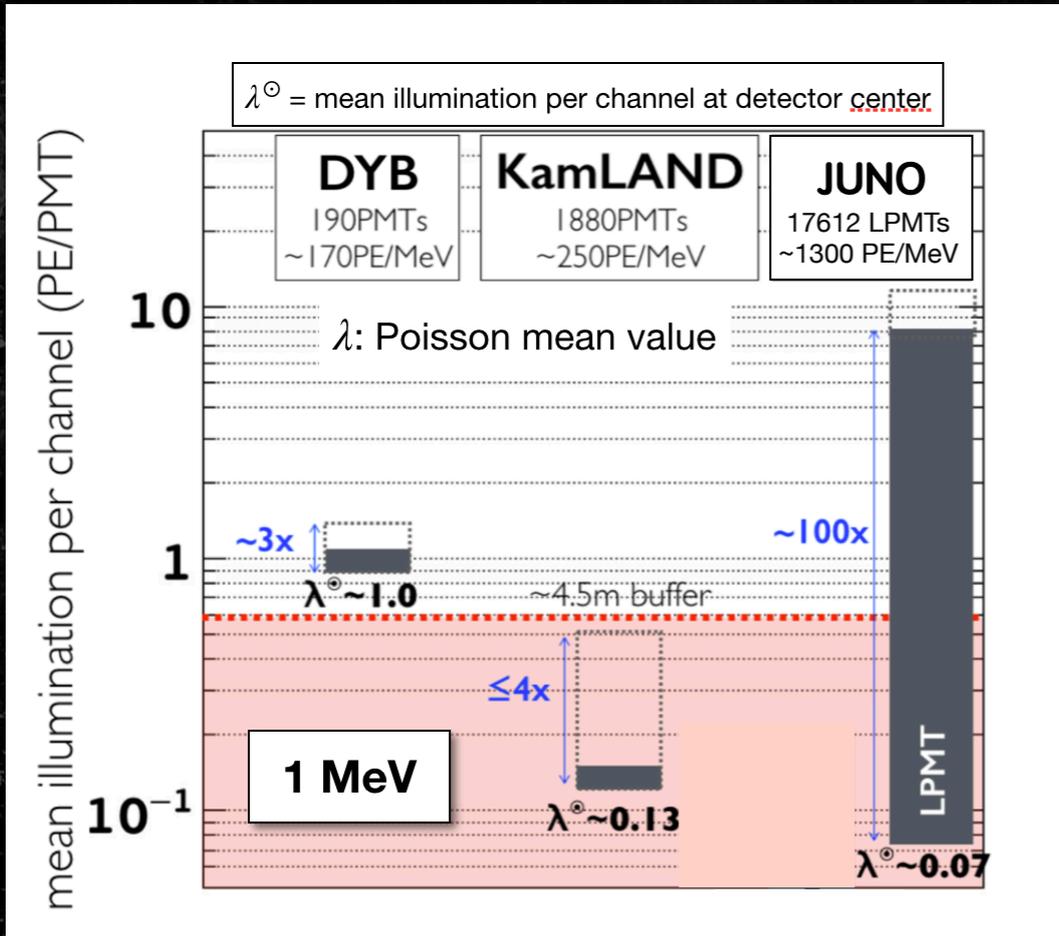
Second calorimetry  
to form Dual Calorimetry

# Why Dual Calorimetry?

## LPMT Calorimetry

Largest charge dynamic range

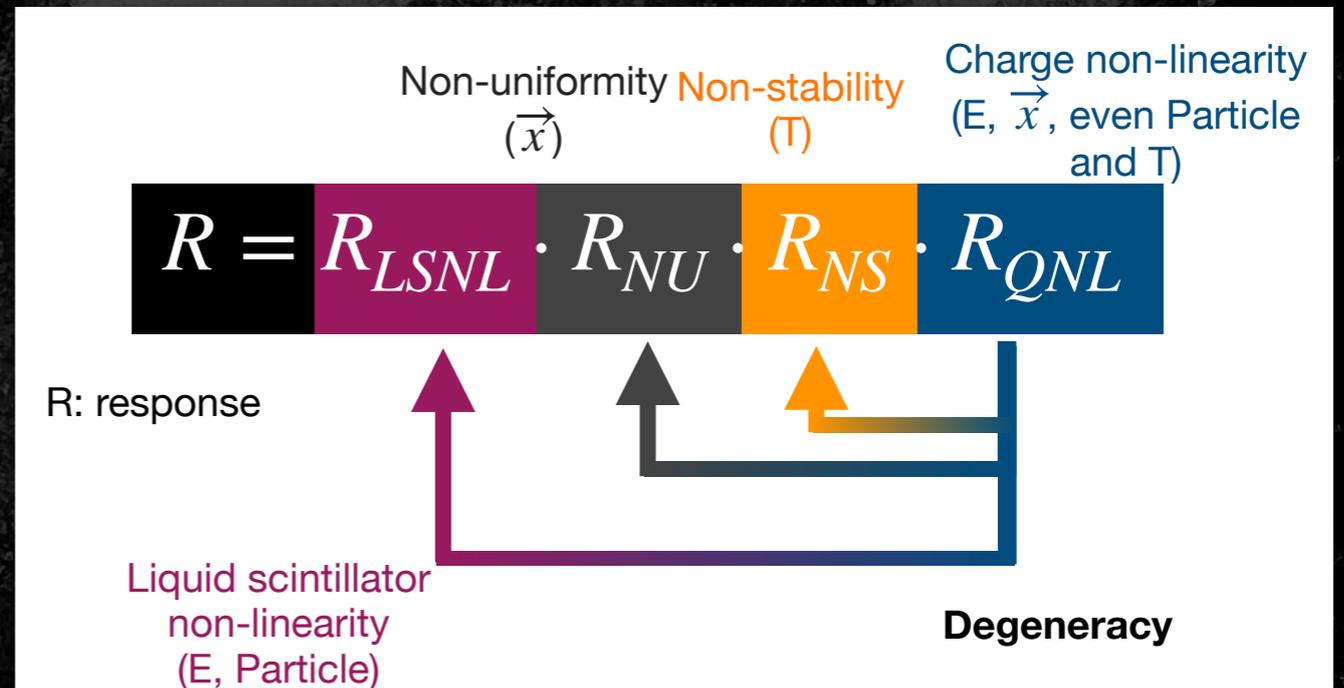
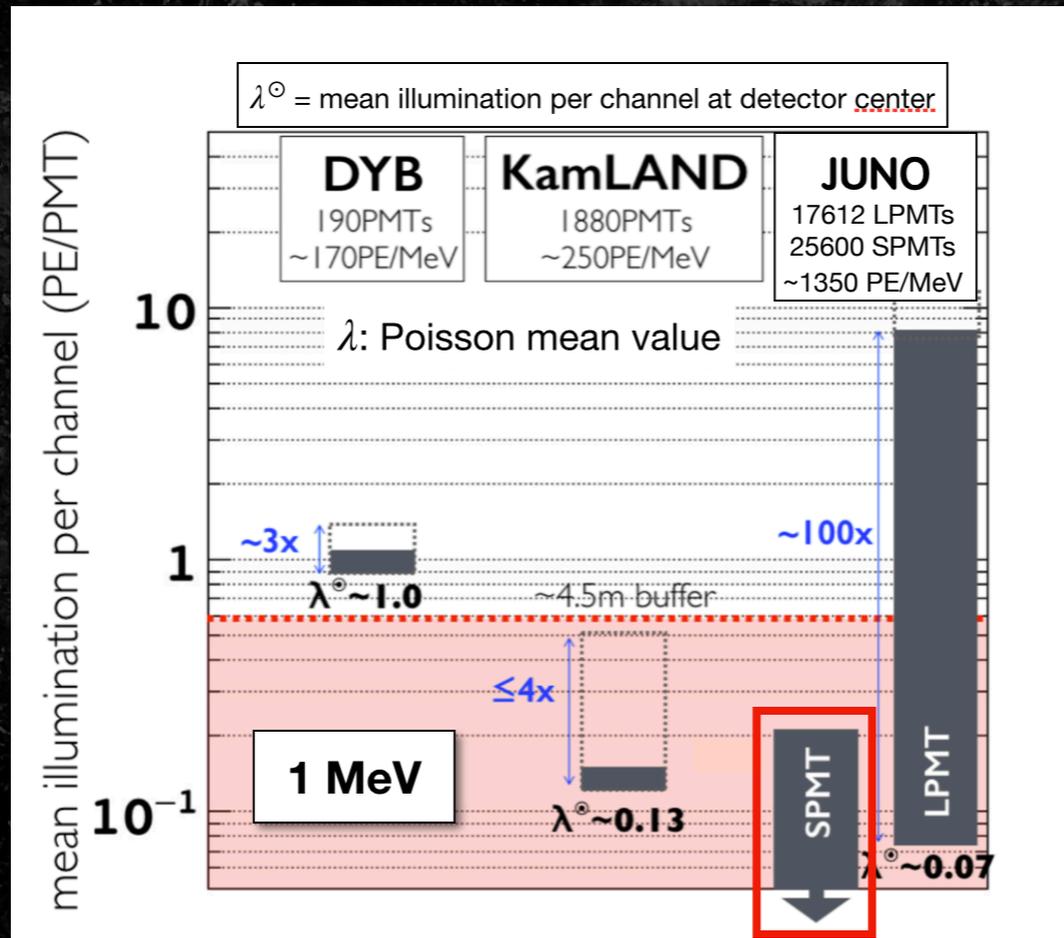
Detector response degeneracy  
(through readout charge response)



\*QNL is also called electronics/instrumental non-linearity

Critical: LPMT charge response/QNL control

# Why Dual Calorimetry?



\*QNL (charge non-linearity) is also called electronics/instrumental non-linearity

Single photoelectron (PE) dominant  
Digital PE (or photon) counting

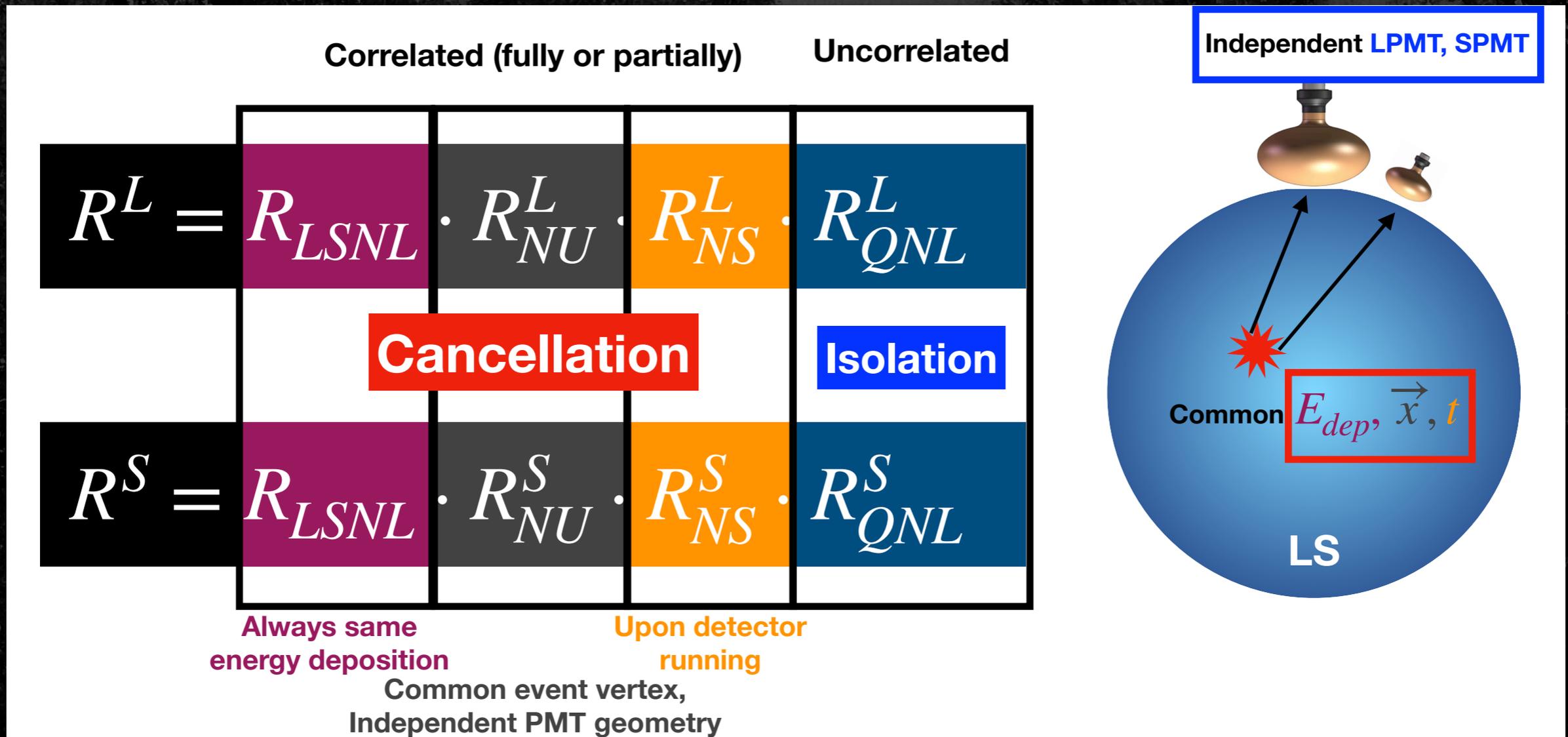
~“Zero” Charge Non-Linearity (QNL)  
~“Zero” degeneracy

SPMT Calorimetry

SPMT serves as linear charge reference.

# Dual Calorimetry Principle

Calorimetry response comparison between LPMT and SPMT



# Dual Calorimetry Principle

Calorimetry response comparison between LPMT and SPMT



Direct charge response comparison:

$$R_{QNL}^L : R_{QNL}^S$$



20-inch PMT



Flash ADC based electronics  
(charge integration)

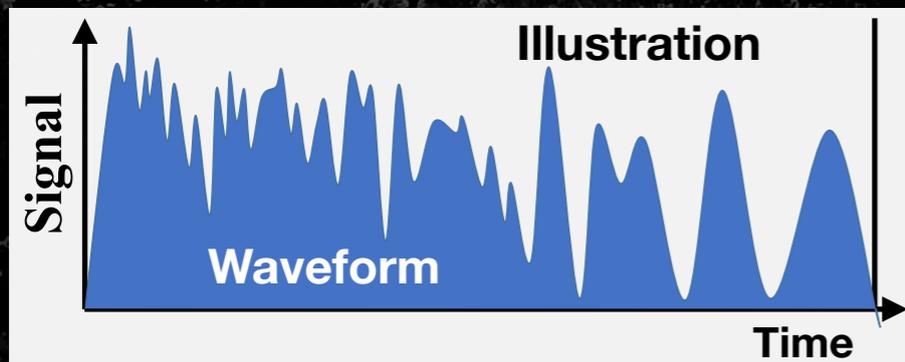
VS



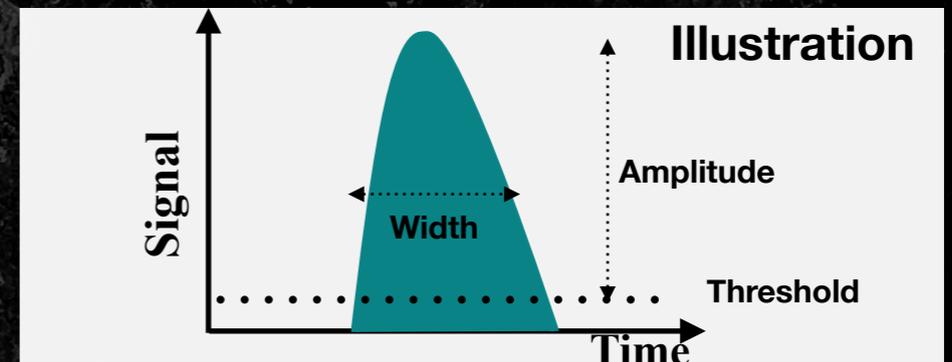
3-inch PMT



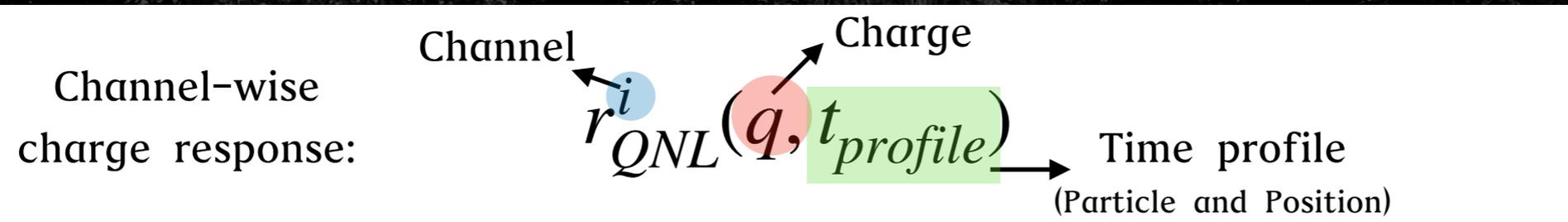
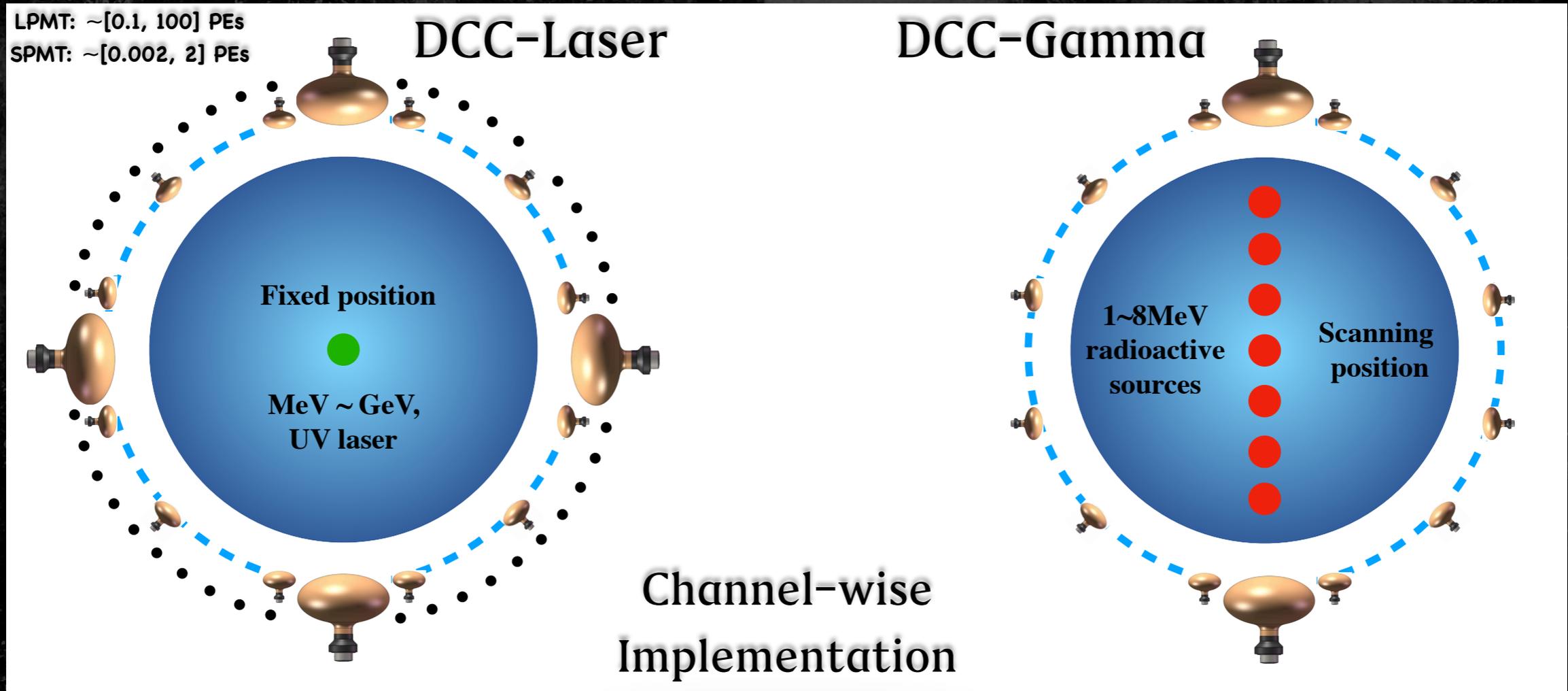
Photon counting based electronics  
(digital ⊕ analog)



Linear charge reference



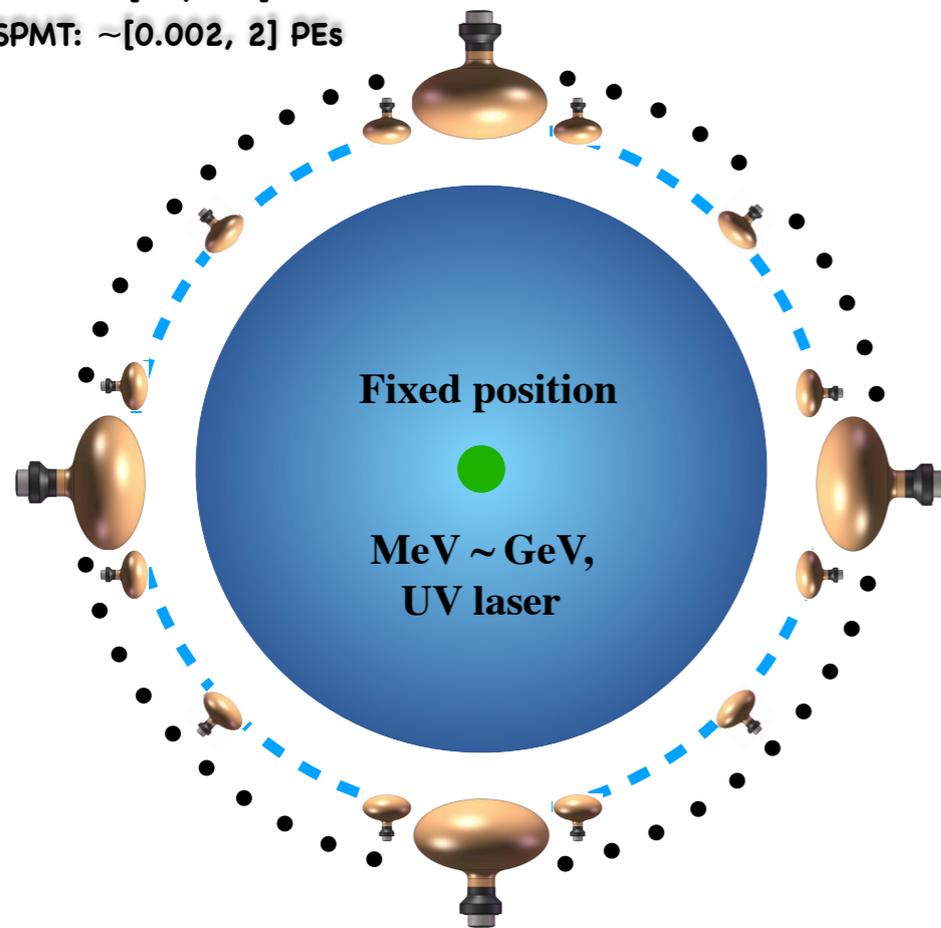
# Novel calibration method for JUNO: Dual Calorimetry calibration (DCC)



Physics target: reactor neutrino inverse beta decay signals ( $e^+$ , uniform) & all channels

# DCC-Laser

LPMT:  $\sim[0.1, 100]$  PEs  
SPMT:  $\sim[0.002, 2]$  PEs



UV laser:

Tunable intensity MeV~GeV

→ Full charge dynamic range  
for all LPMTs

Fixed source position:

Perfect QNL isolation

$$r_{QNL}^i(q, t_{profile})$$

# DCC-Gamma

LPMT:  $\sim [0.1, 100]$  PEs

SPI:  $\sim [0.002, 21]$  PEs

Gamma sources:

$\gamma \sim e^+$  (1~8MeV)  $\rightarrow$  Particle

Scanning source position:

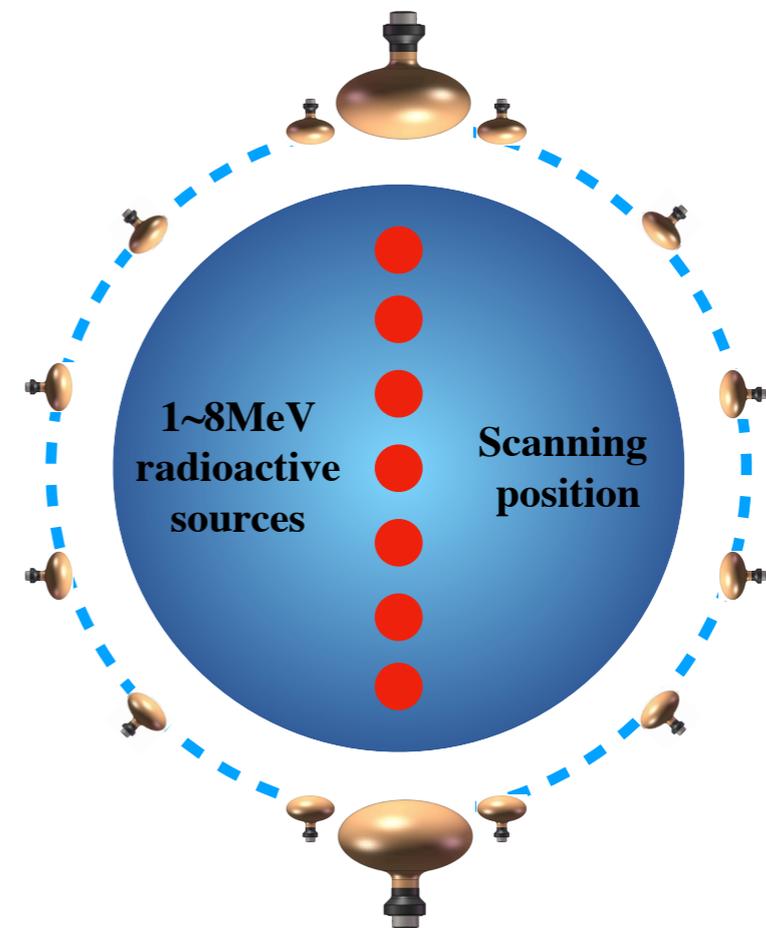
$\sim$  Uniform distributed signals

$\rightarrow$  Position

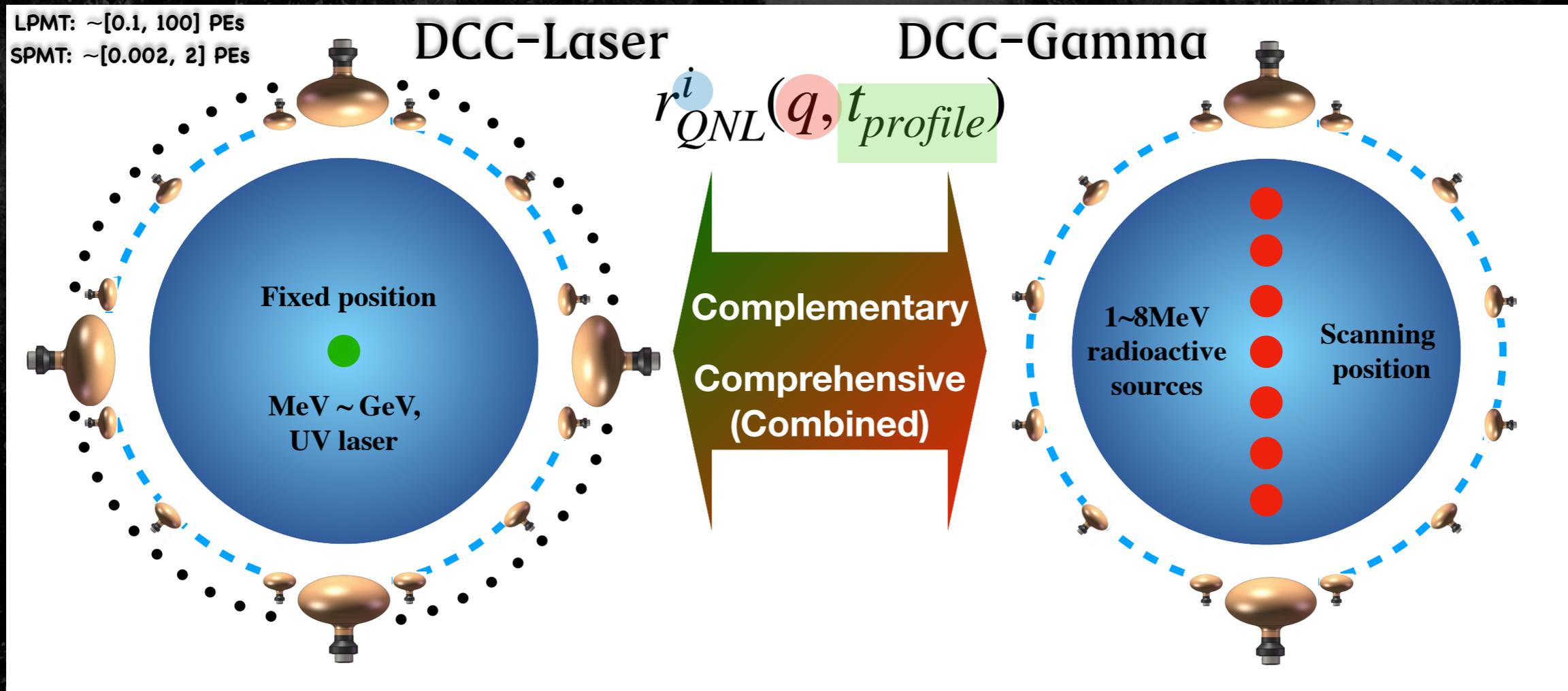
MeV ~ GeV,  
UV laser

$$r_{QNL}^i(q, t_{profile})$$

(Particle and Position)



# DCC Strategy



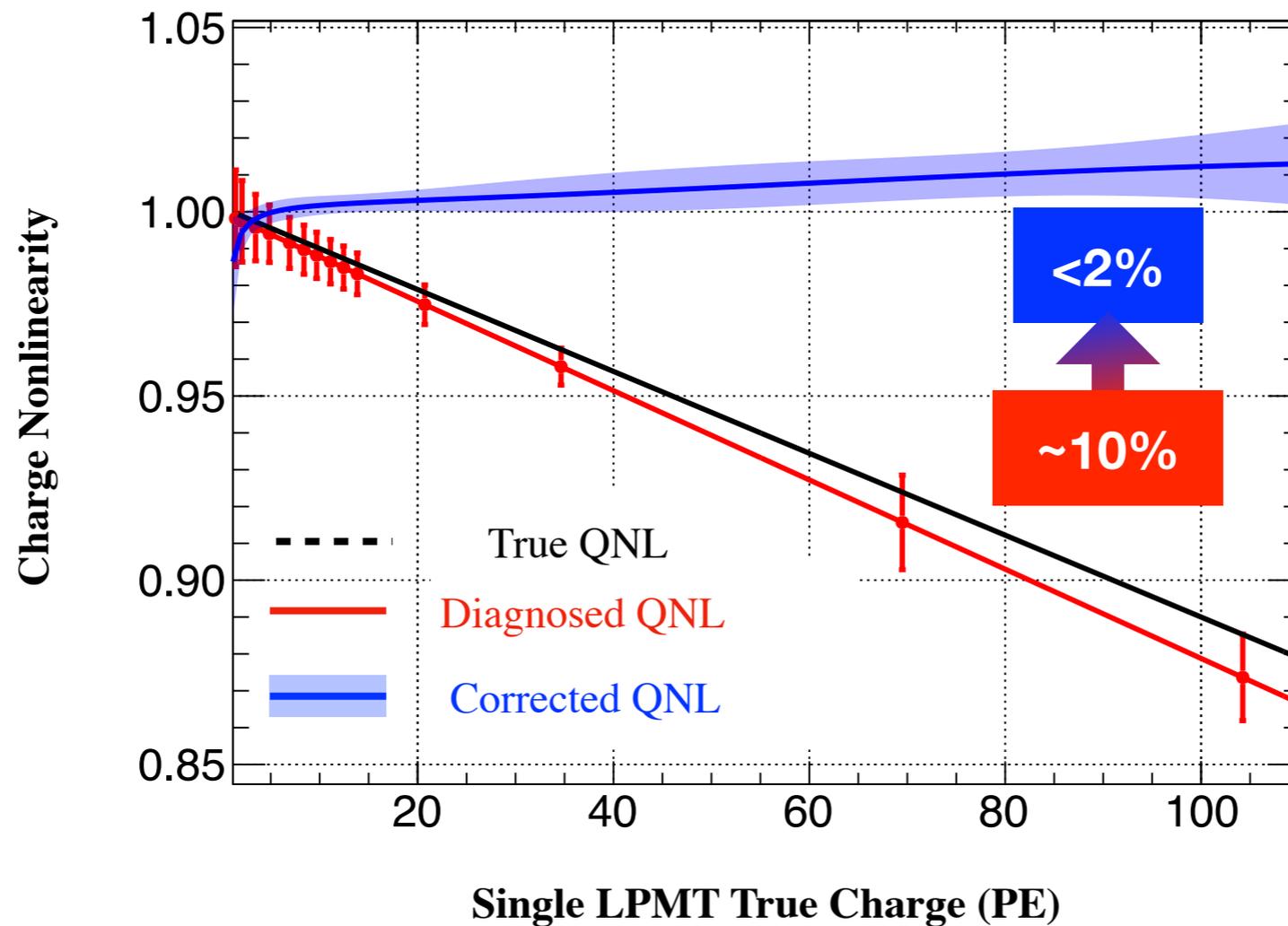
Direct calibration of potential QNL of LPMT  
 at every single channel level\*

Included in "Calibration Strategy of the JUNO experiment", JHEP 03 (2021) 004

# Channel-wise QNL control with DCC

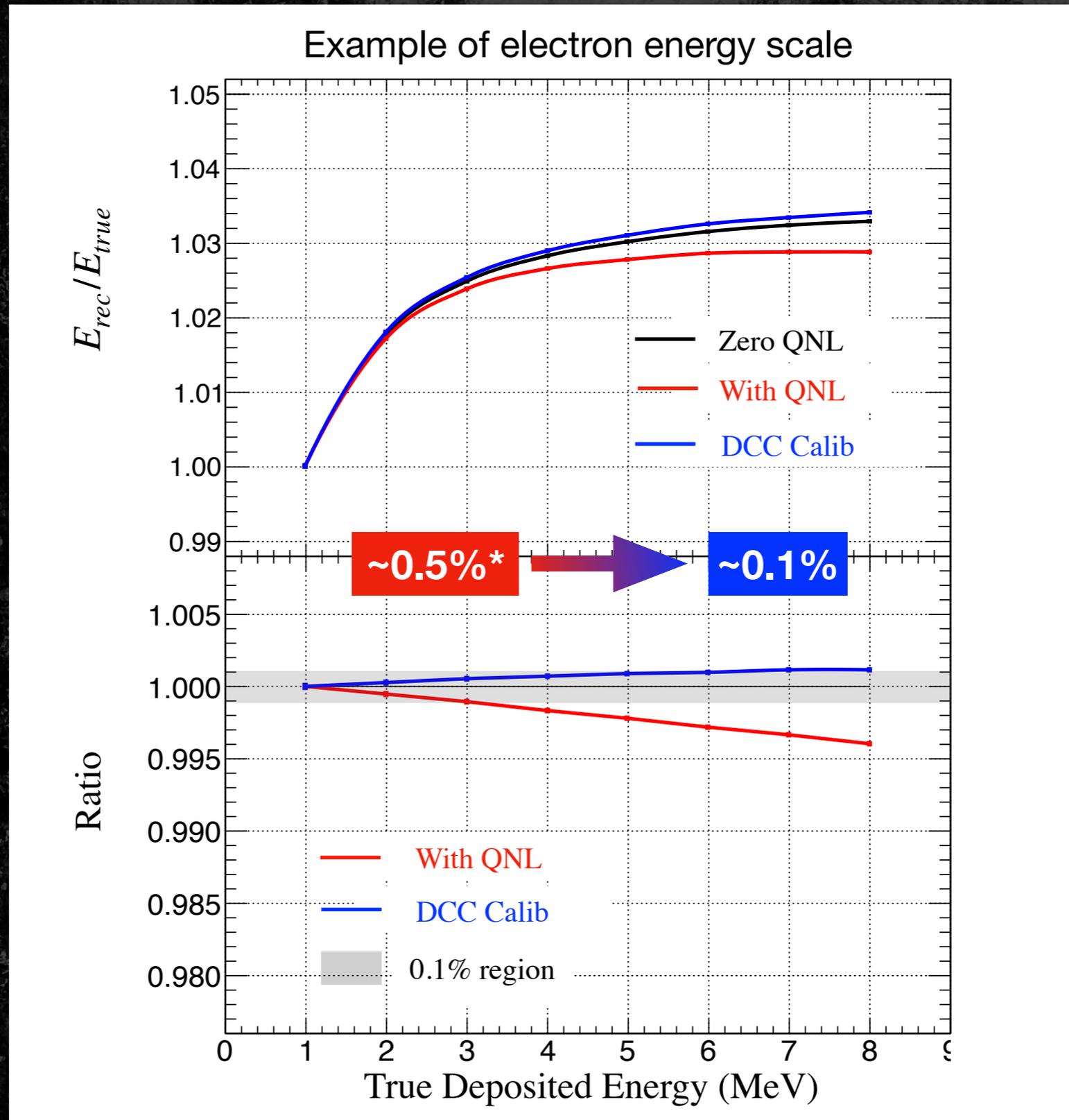
Assuming a  $\sim 10\%$  QNL in  $[1, 100]$ PE range (JUNO LPMT)

Controlled  $< 2\%$  with DCC



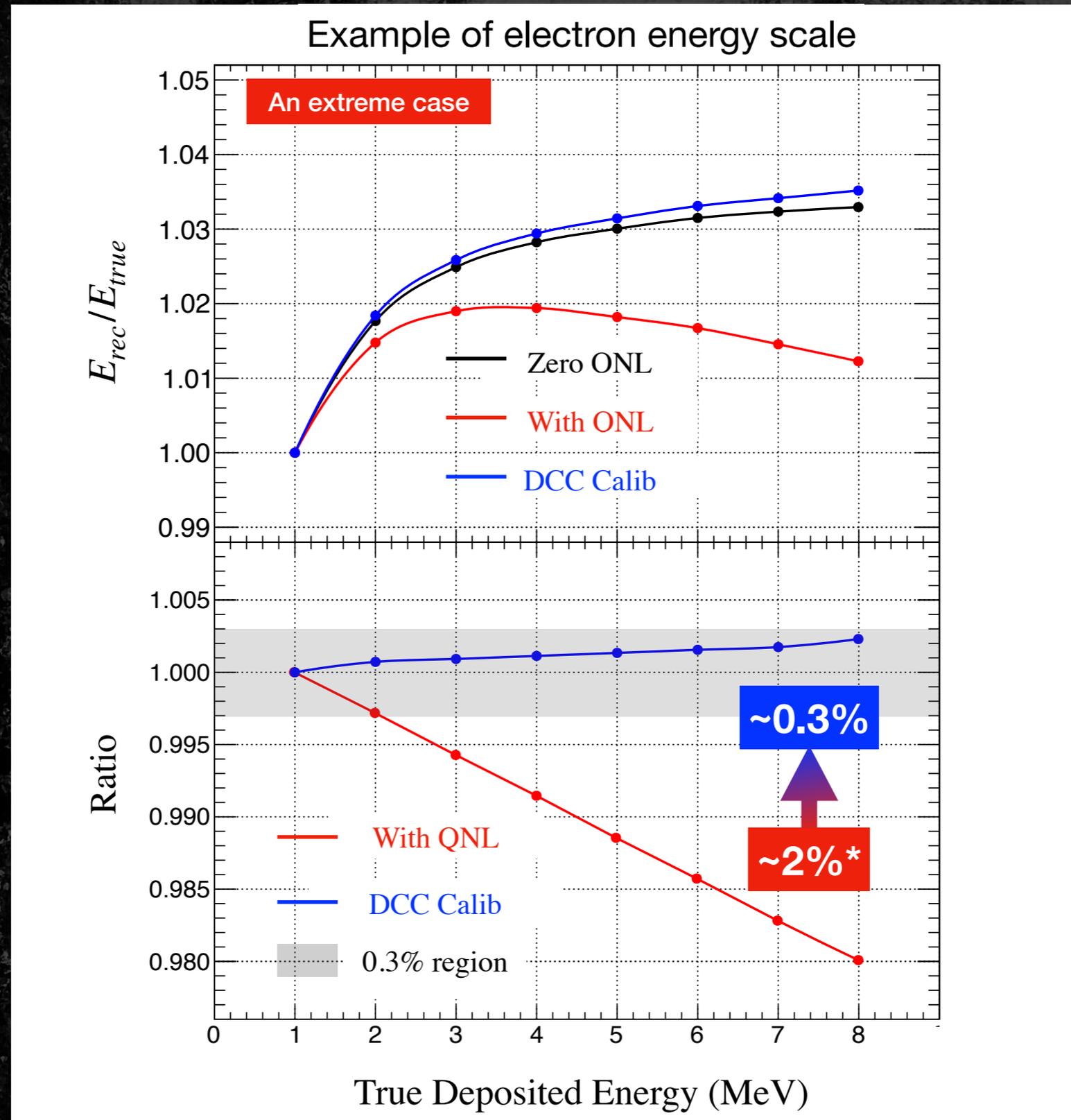


# DCC potential performance — Energy scale control



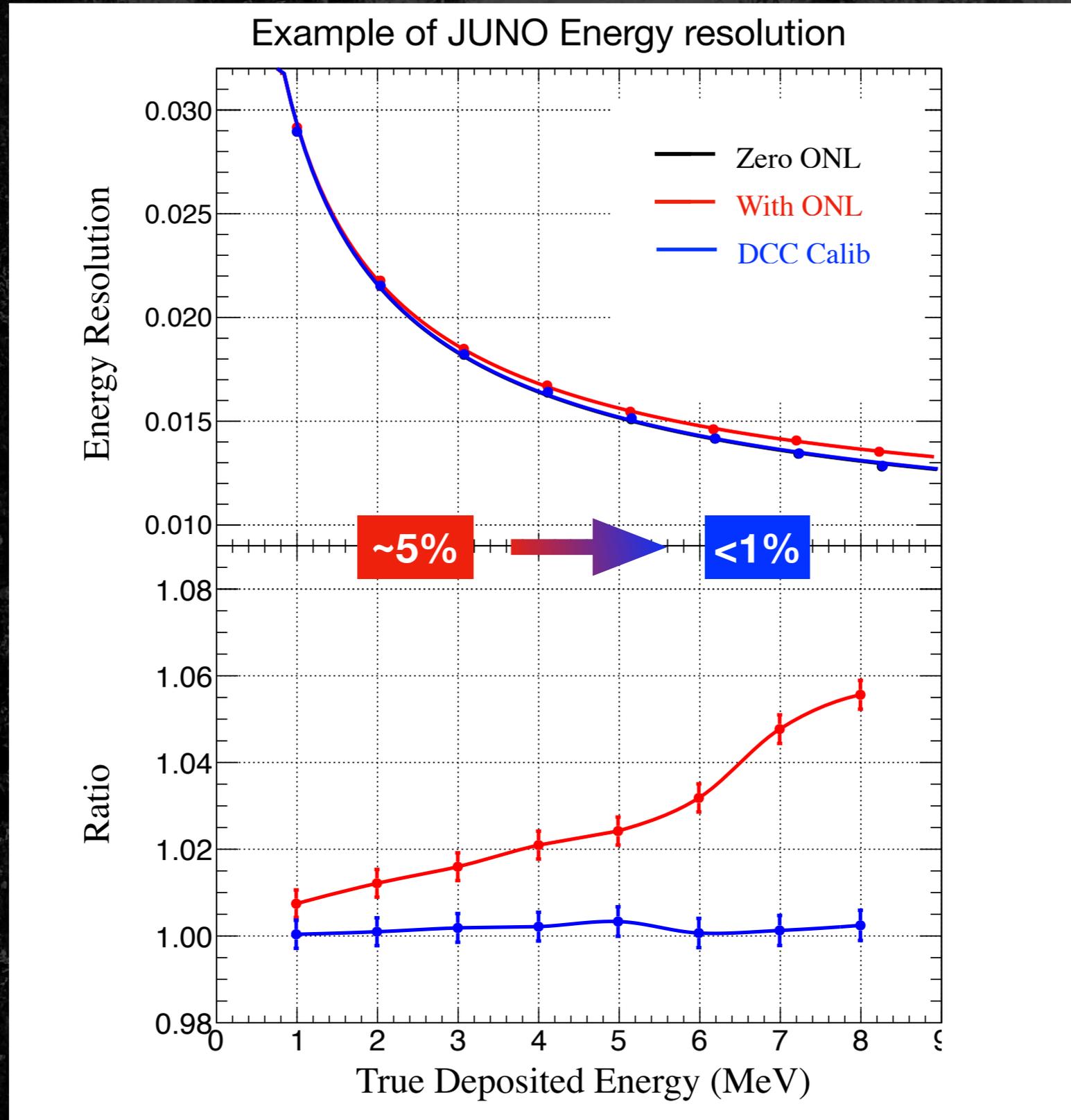
\*assumed QNL effect in energy resolution (~10% channel-wise QNL up to 100 PE).

# DCC potential performance — Energy scale control (extreme case)



\*assumed QNL effect in energy resolution (~50% channel-wise QNL up to 100 PE).

# DCC potential performance — Energy resolution control



\*assumed QNL effect in energy resolution (~10% channel-wise QNL up to 100 PE).

# Conclusions

Dual Calorimetry at JUNO:

Initiated for improving detector response systematics control

DCC: Novel calibration method

Improving the control of JUNO energy detection systematics  
(sub-percent level)

through LPMT QNL calibration.

Ensuring the necessary conditions for JUNO high precision measurements