

# Cryogenic CsI for Accelerator-based Dark Matter Search

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# CsI(Tl/Na) VS Pure CsI

## Doped CsI

- Light yield: 50~80% of NaI(Tl)
- Emission: ~ 550/420 nm
- R index: ~1.8 @ 500 nm
- Radiation hardness: weak
- Decay time: slow (~ $\mu$ s)

## Pure CsI

- Light yield: ~2% of NaI(Tl)
- Emission: ~ 315 nm
- R index: 1.95 @ 315 nm
- Radiation hardness: no damage up to  $10^5$  rads
- Decay time: fast (16 ns)

# Pure CsI as electromagnetic calorimeter

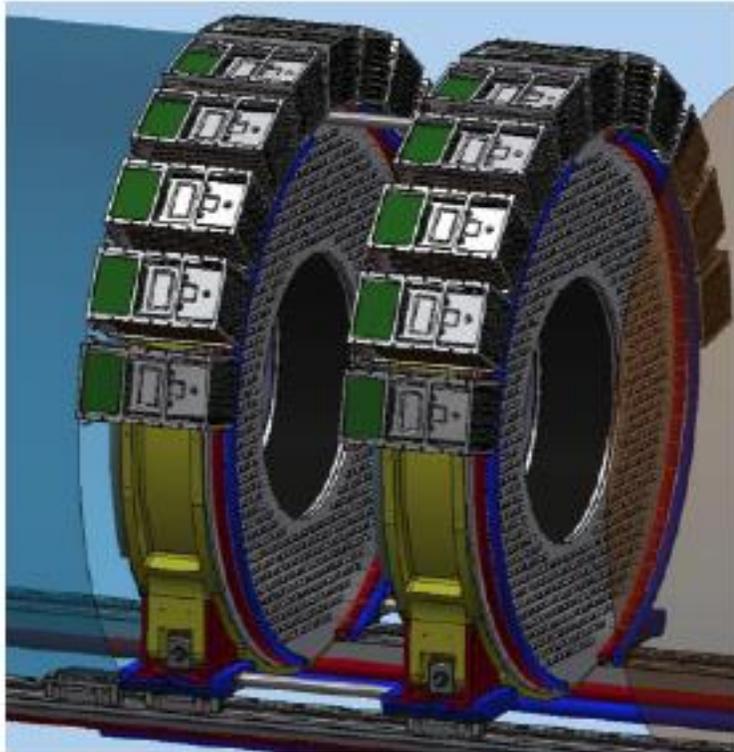
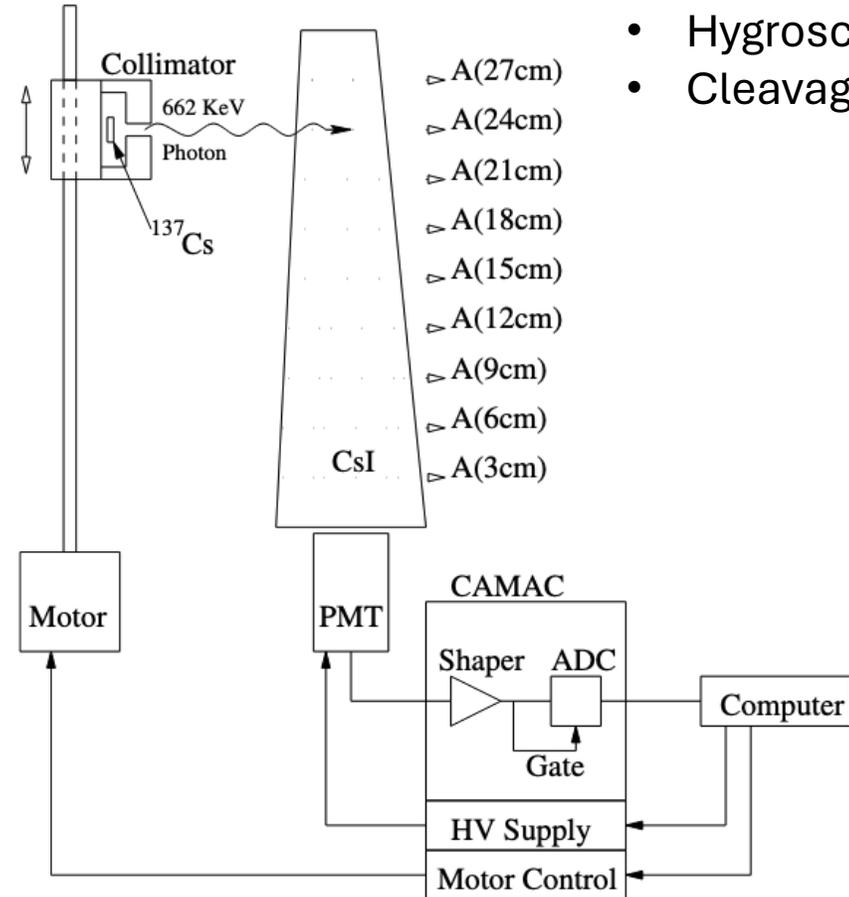


Figure 5. The Mu2e electromagnetic calorimeter.

JINST 12 C01061

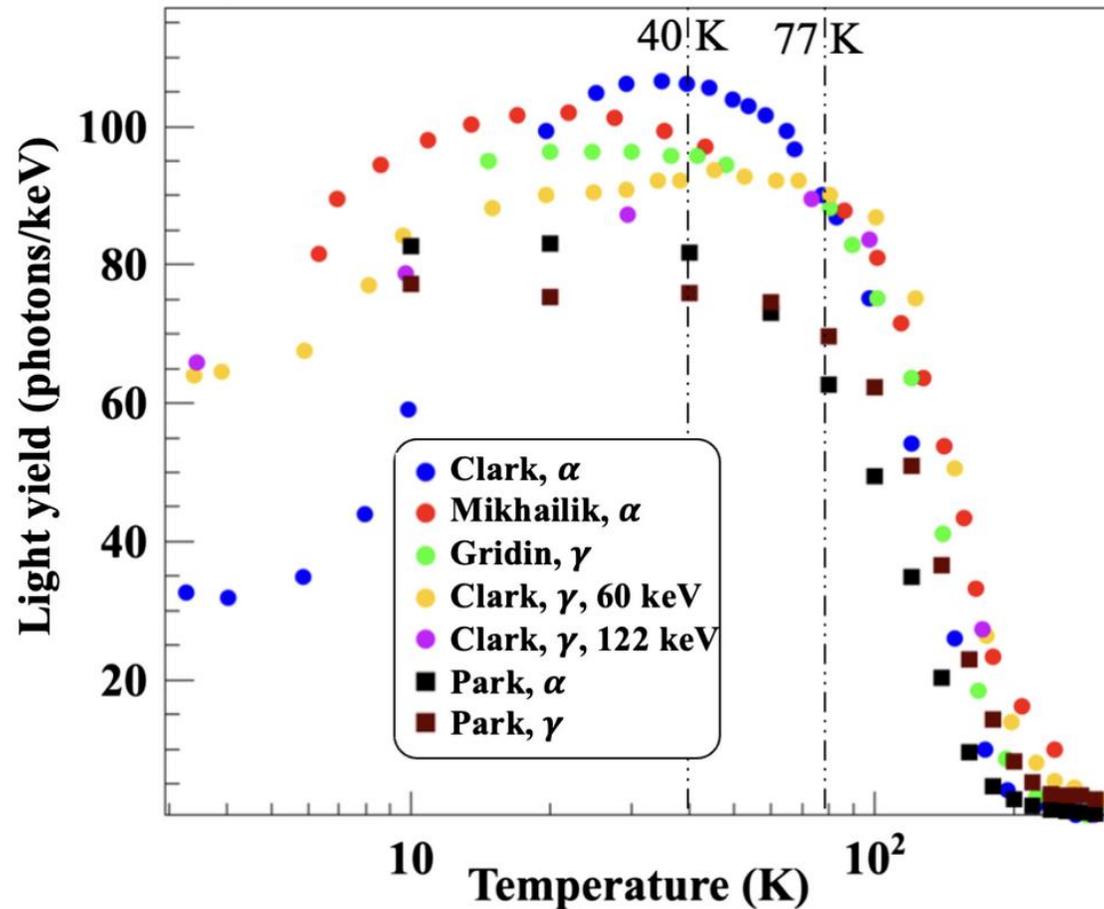


- Density: 4.51 g/cm<sup>3</sup>
- Hygroscopic: slightly
- Cleavage plane: none

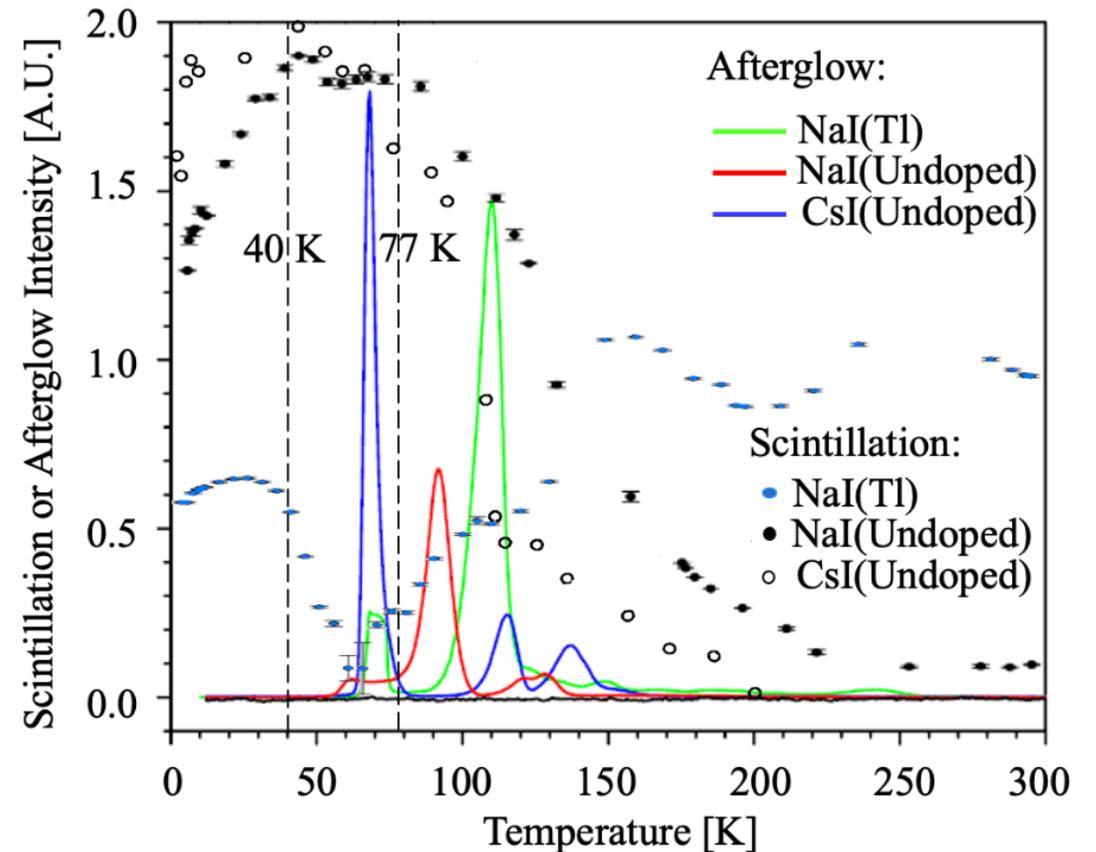
Study of radiation hardness of pure CsI crystals for Belle-II calorimeter, JINST 11 P03013

# Pure CsI @ different temperatures

PRD 109, 092005 (2024)



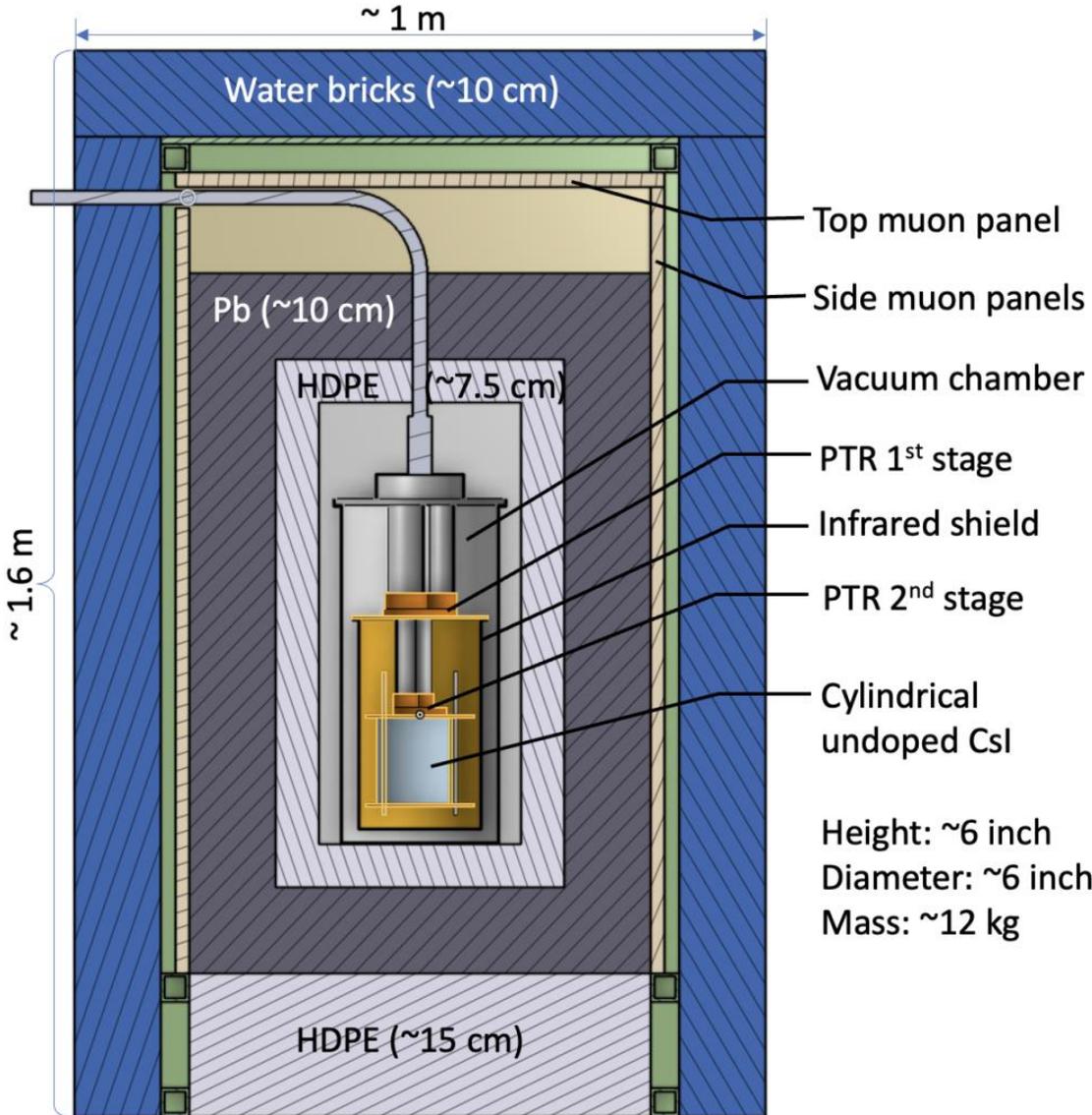
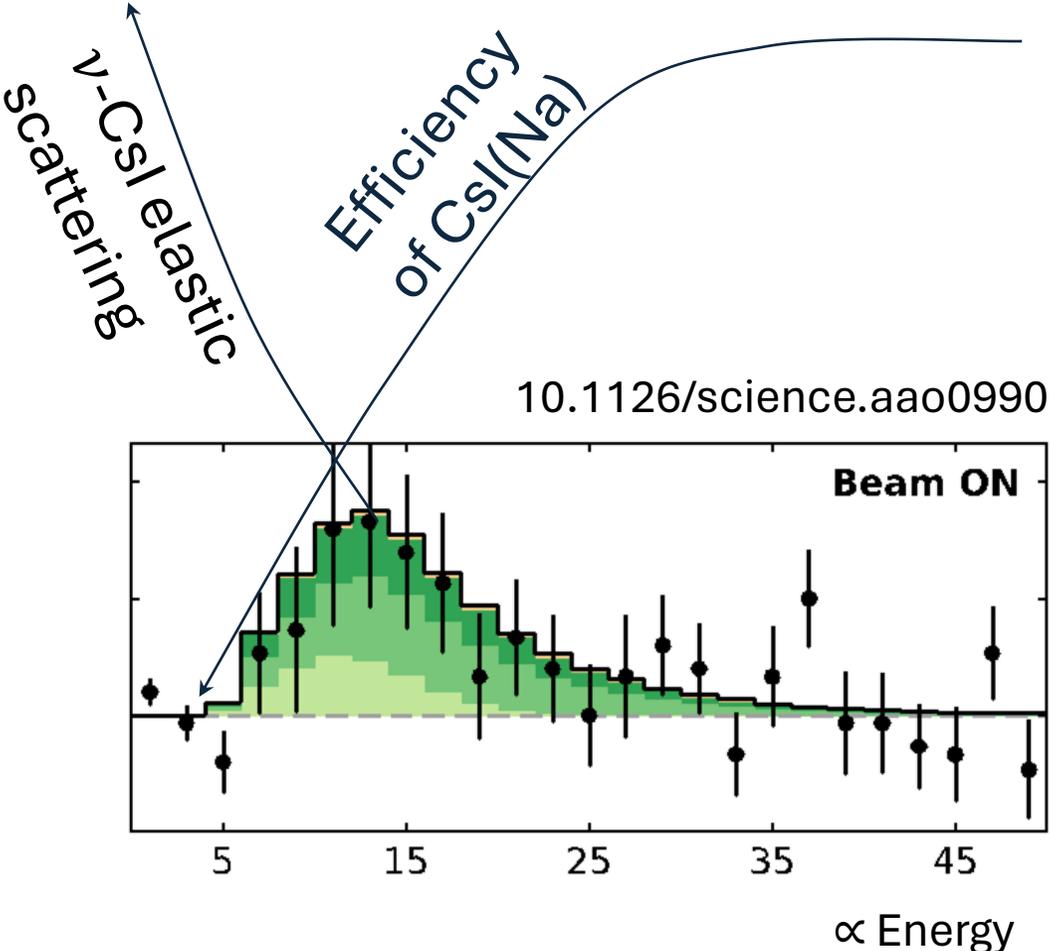
<https://doi.org/10.1140/epjc/s10052-020-8111-7>





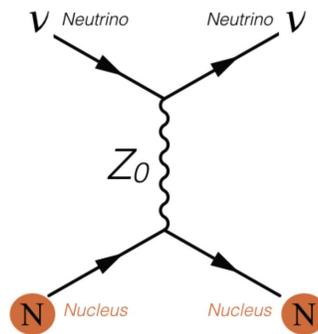
# Cryogenic operation of pure CsI

<https://sites.duke.edu/coherent/detectors>

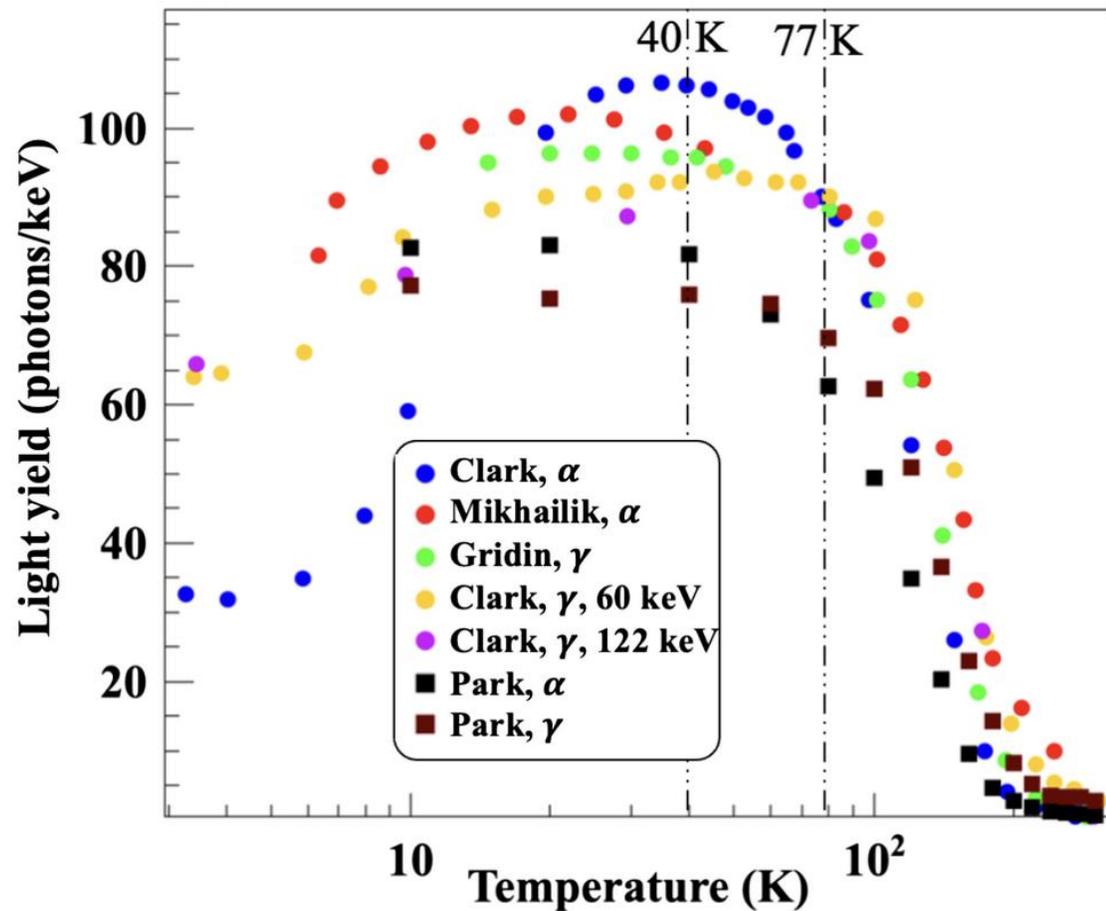
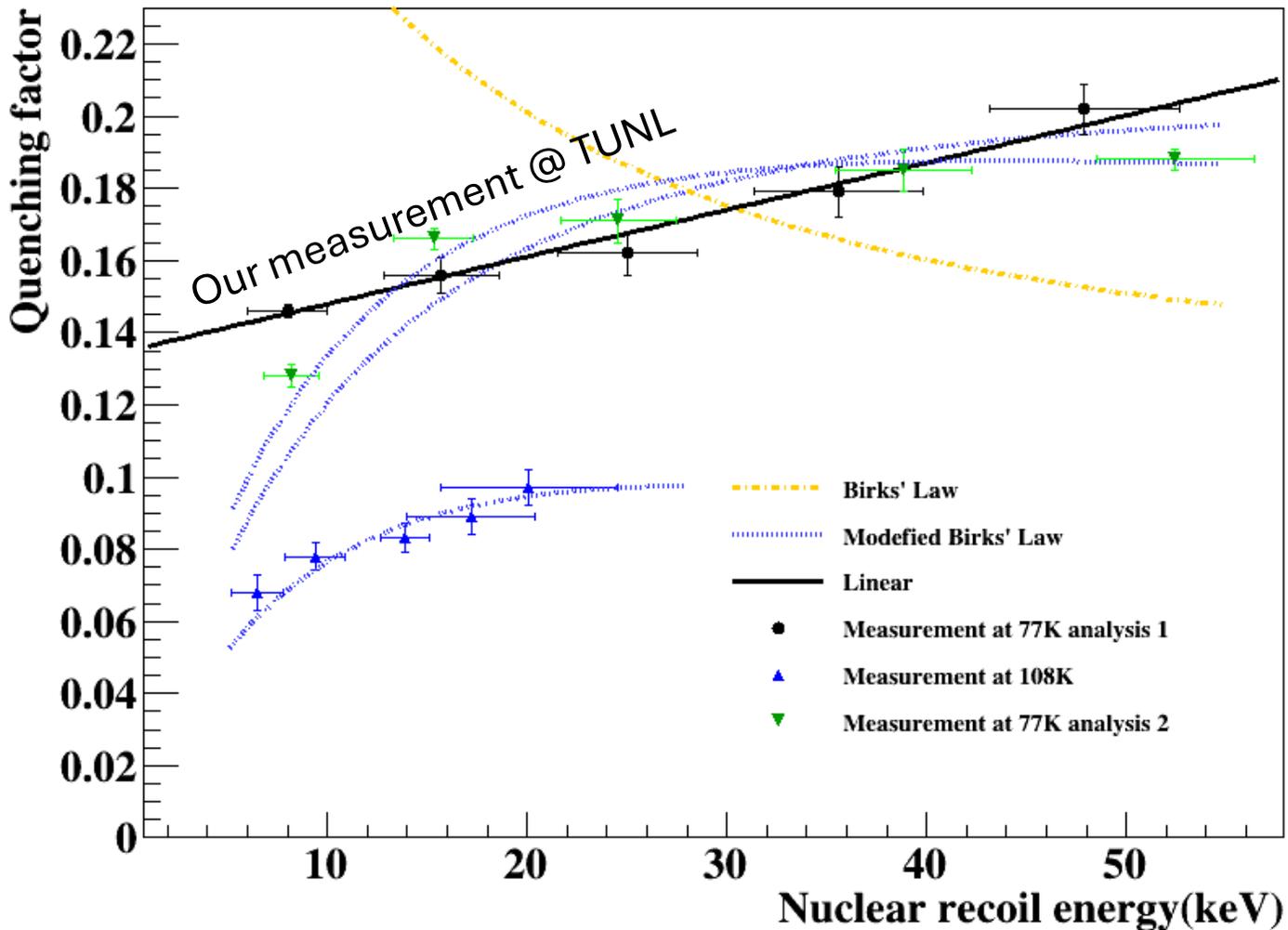


# Visible energy

LY(Nuclear)/LY(electronic)



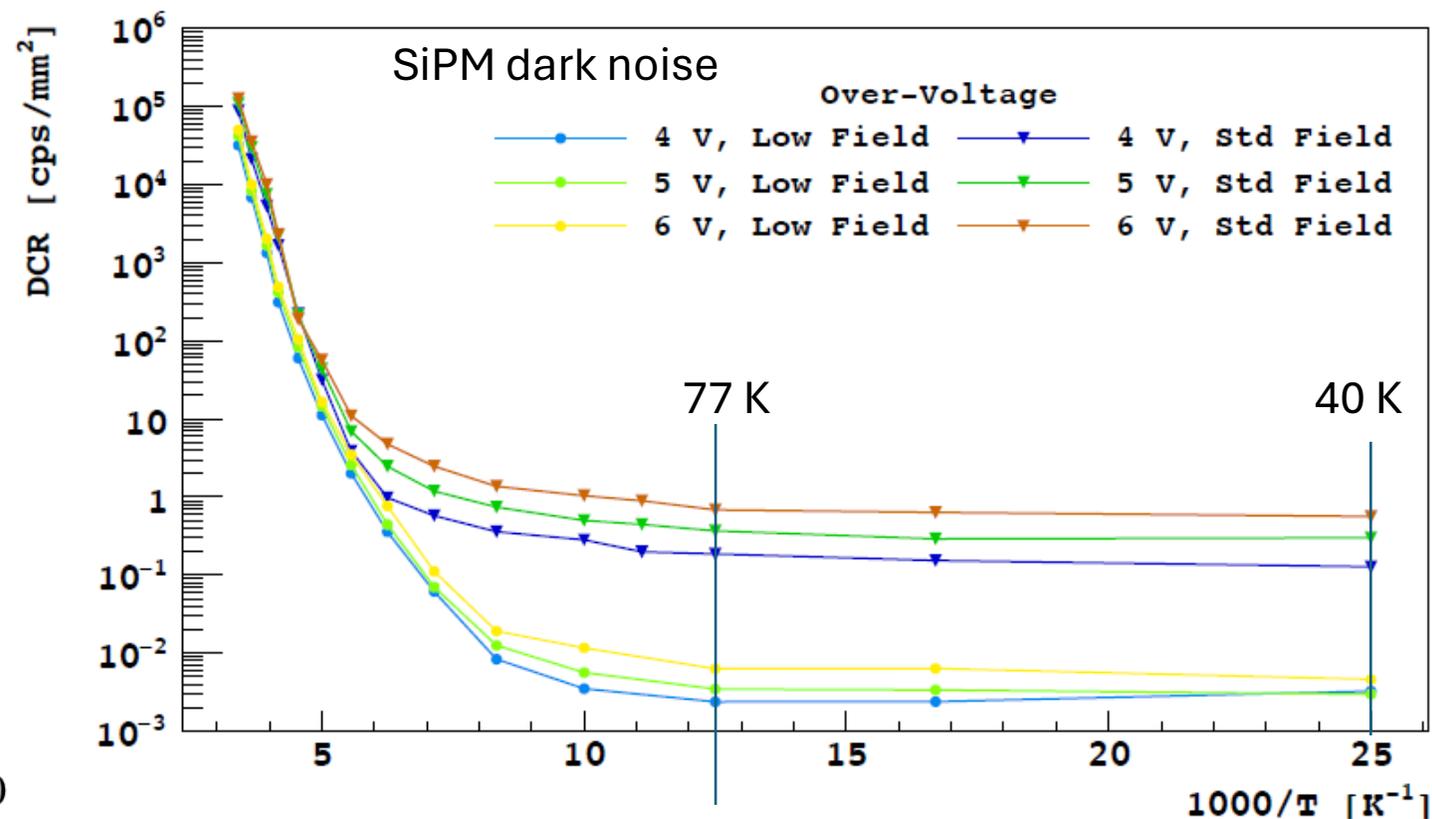
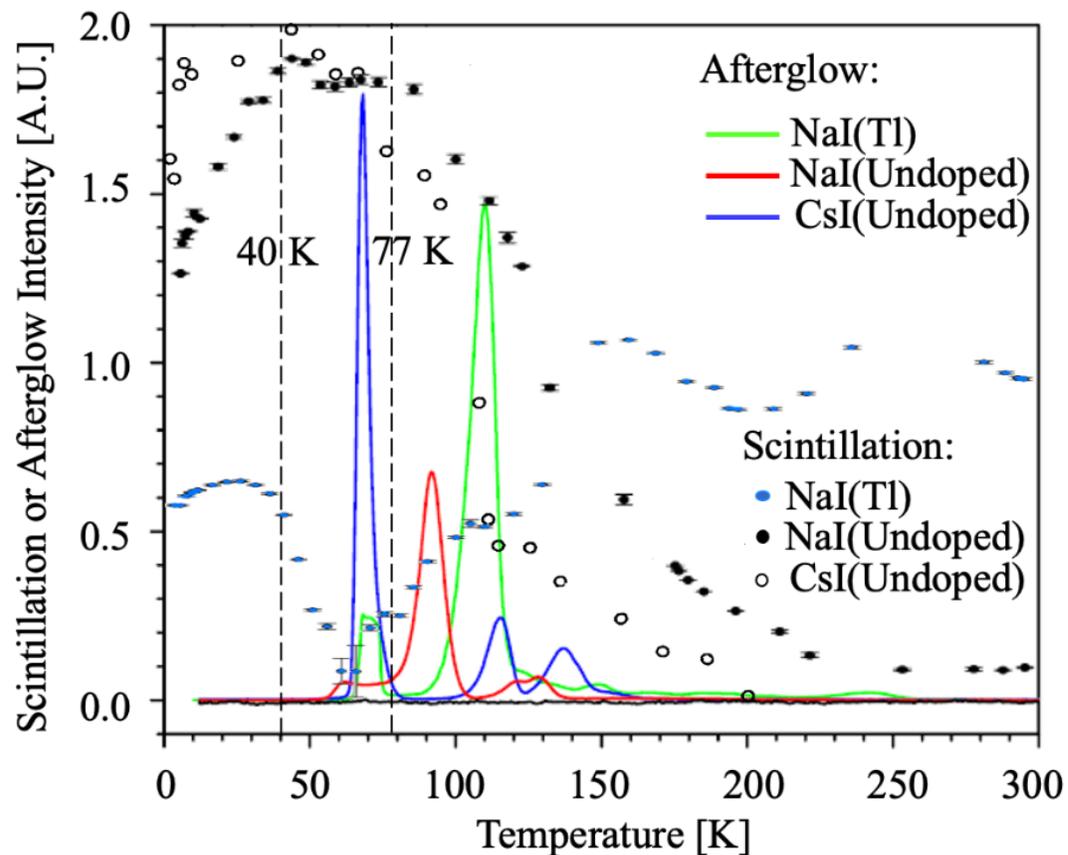
Obtained from electronic recoils:



# Cooling options

Cryocooler (down to  $\sim 40$  K): A bit more LY, a bit less afterglow, less SiPM DCR

In liquid nitrogen ( $\sim 77$  K): PMTs work just fine, less R&D



# Pure CsI + PMT @ 77 K

Eur. Phys. J. C (2020) 80:547

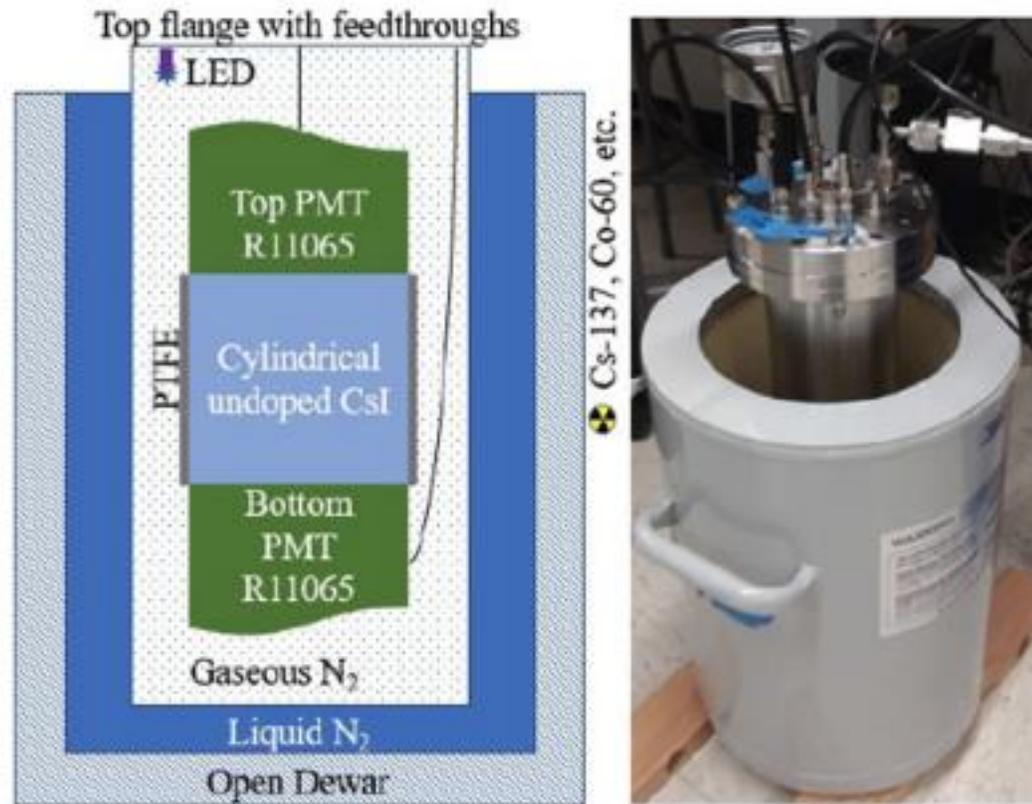


Fig. 1 A sketch (left) and a picture (right) of the experimental setup



Fig. 2 The detector assembly in a glove bag

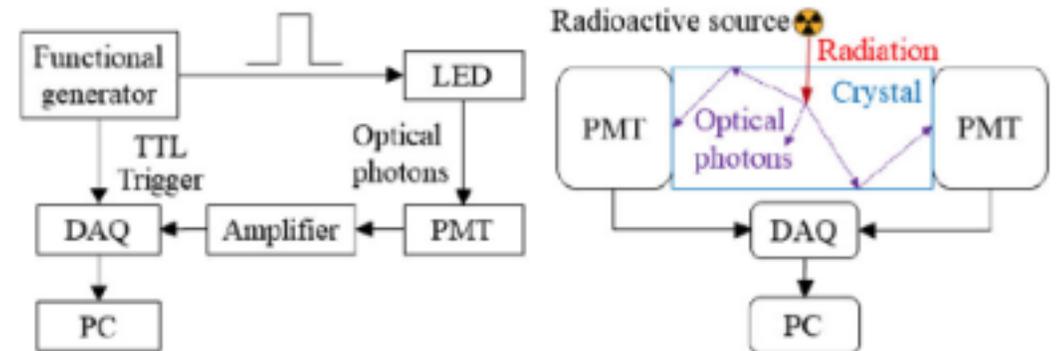


Fig. 3 Trigger logics for single-photoelectron response (left) and energy calibration (right) measurements

# Single PE spectrum

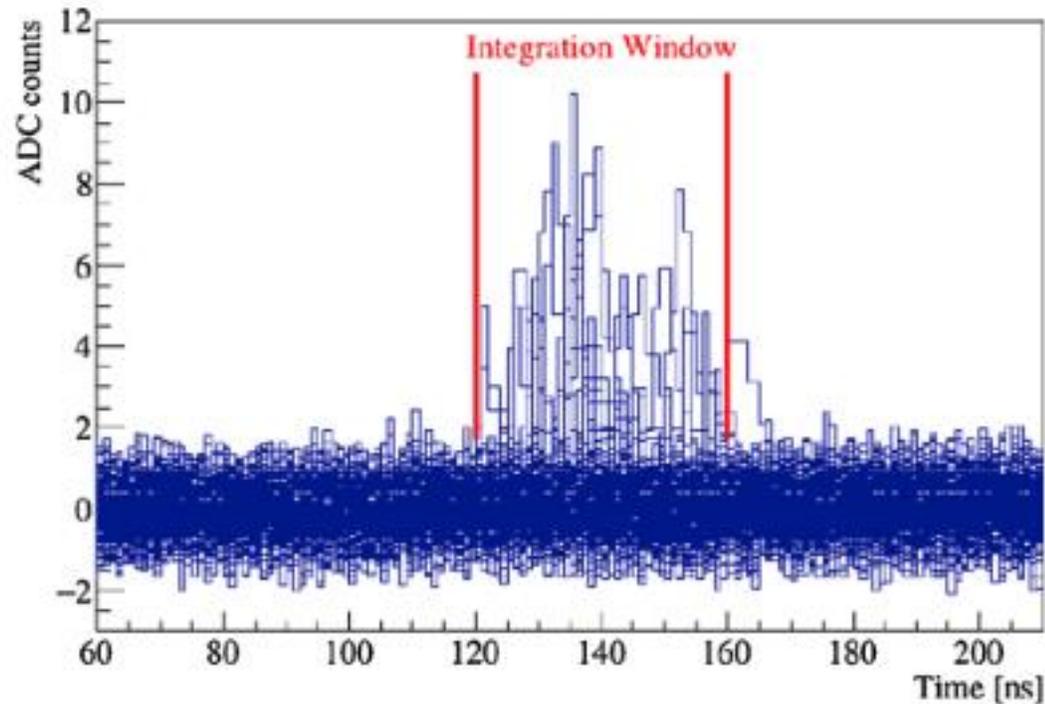


Fig. 4 Two hundred consecutive waveforms from the bottom PMT overlapped with each other

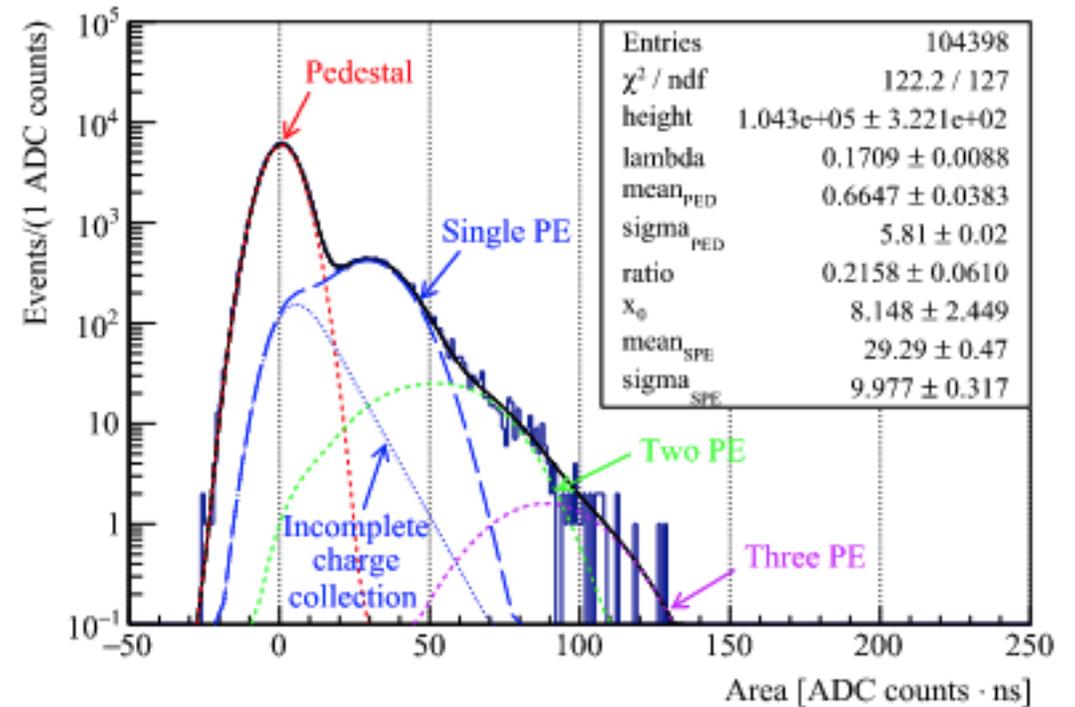


Fig. 5 Single-PE response of the top PMT in logarithmic scale

# Light yield with PMT @ 77 K

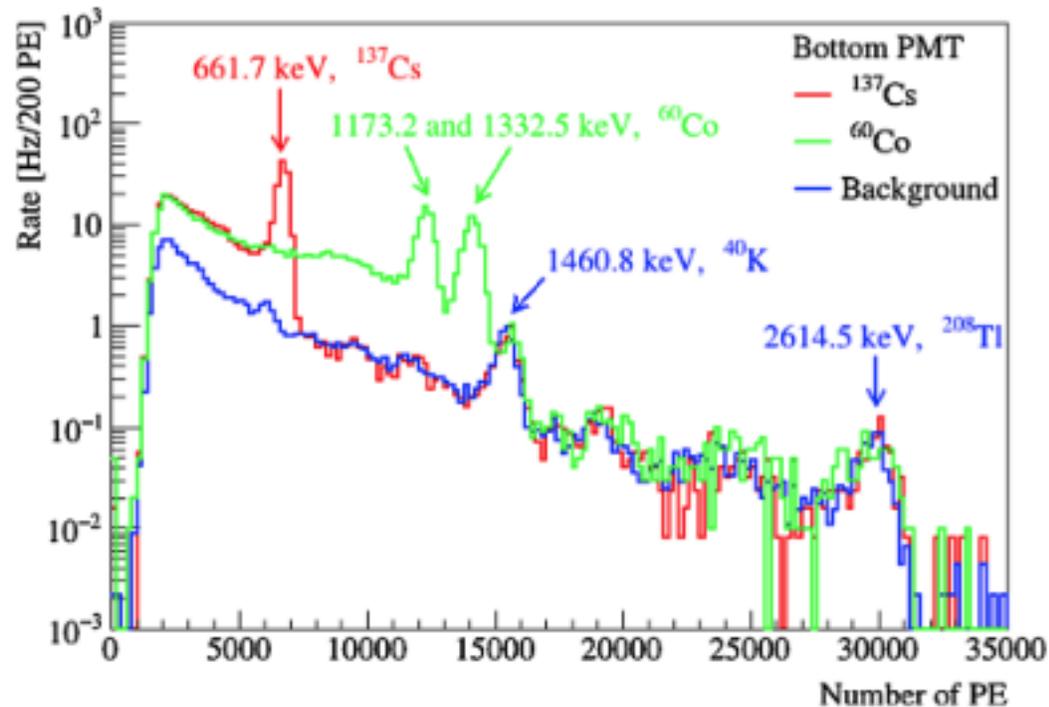


Fig. 7 Energy spectra of the bottom PMT at 80 K

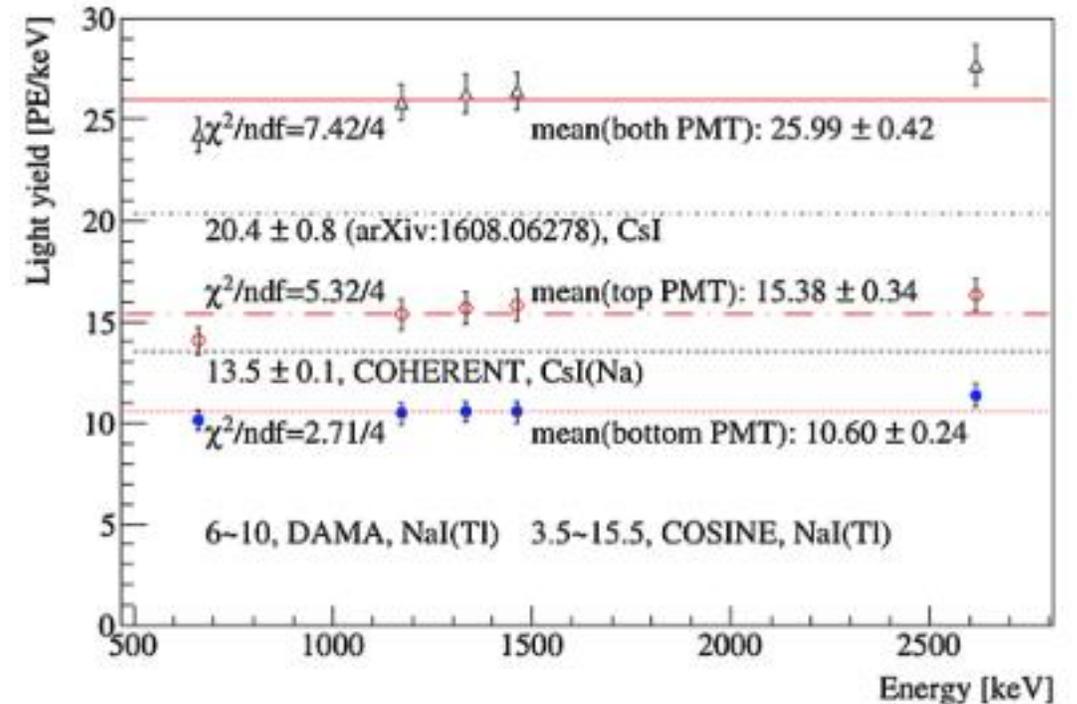
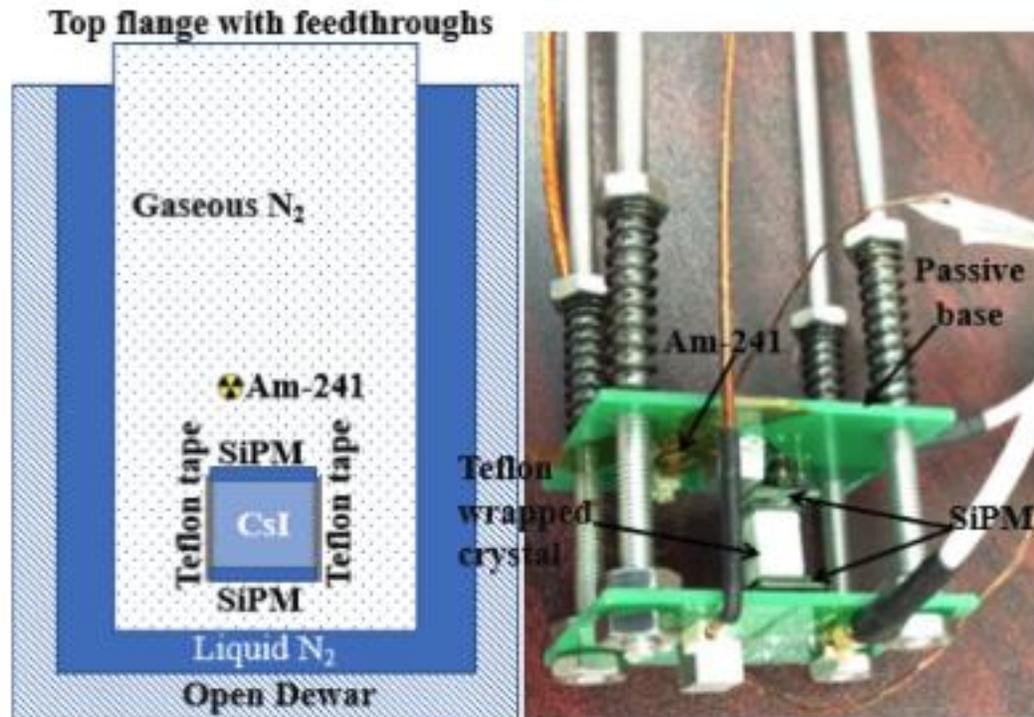


Fig. 9 The obtained light yields for the top (empty circles), the bottom (filled squares) and both (empty triangles) PMTs, compared to those achieved by other experiments [15, 17, 21] and an earlier measurement with a smaller crystal [49]

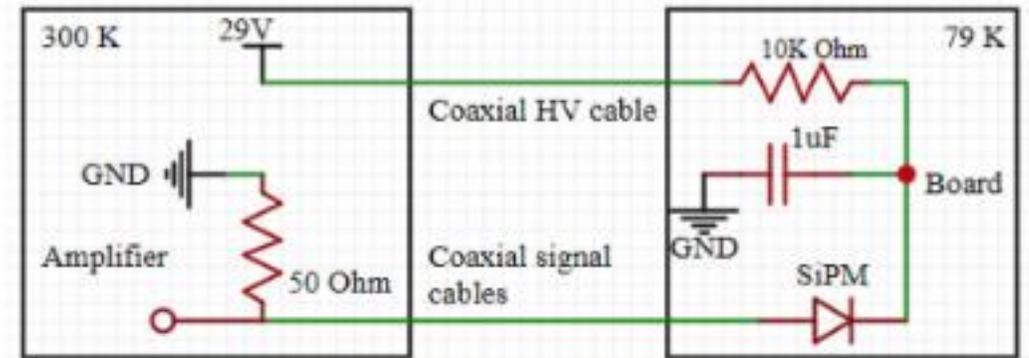
# Pure CsI + SiPM @ 77 K



**Fig. 1** A sketch and a picture of the experimental setup

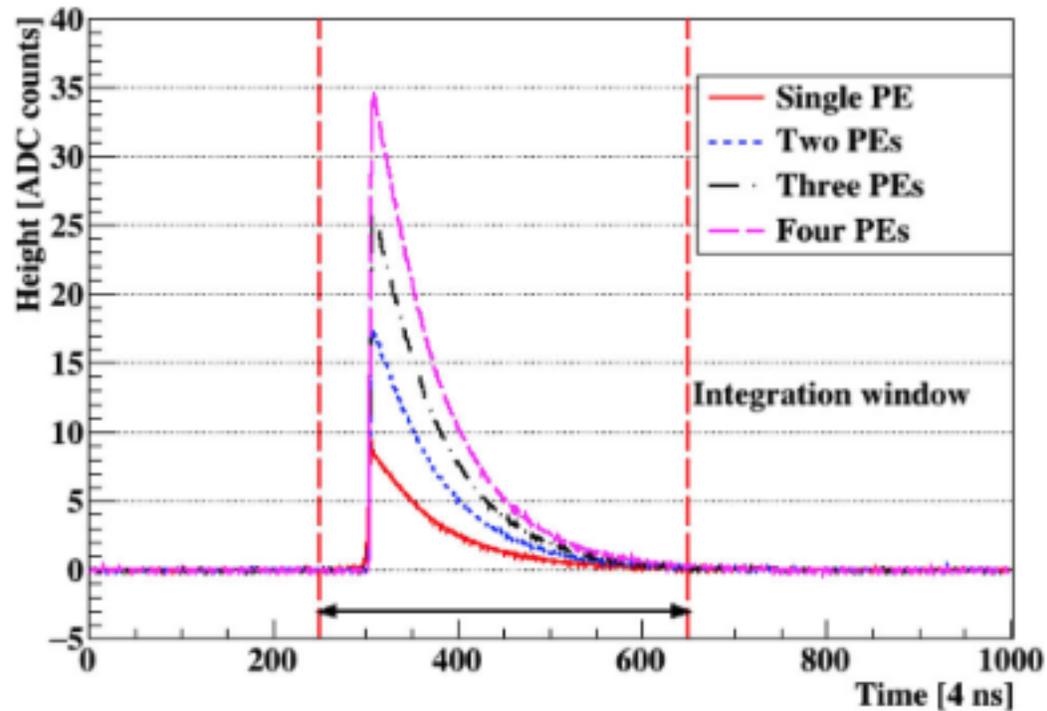
Eur. Phys. J. C (2022) 82:344

<https://doi.org/10.1140/epjc/s10052-022-10289-x>

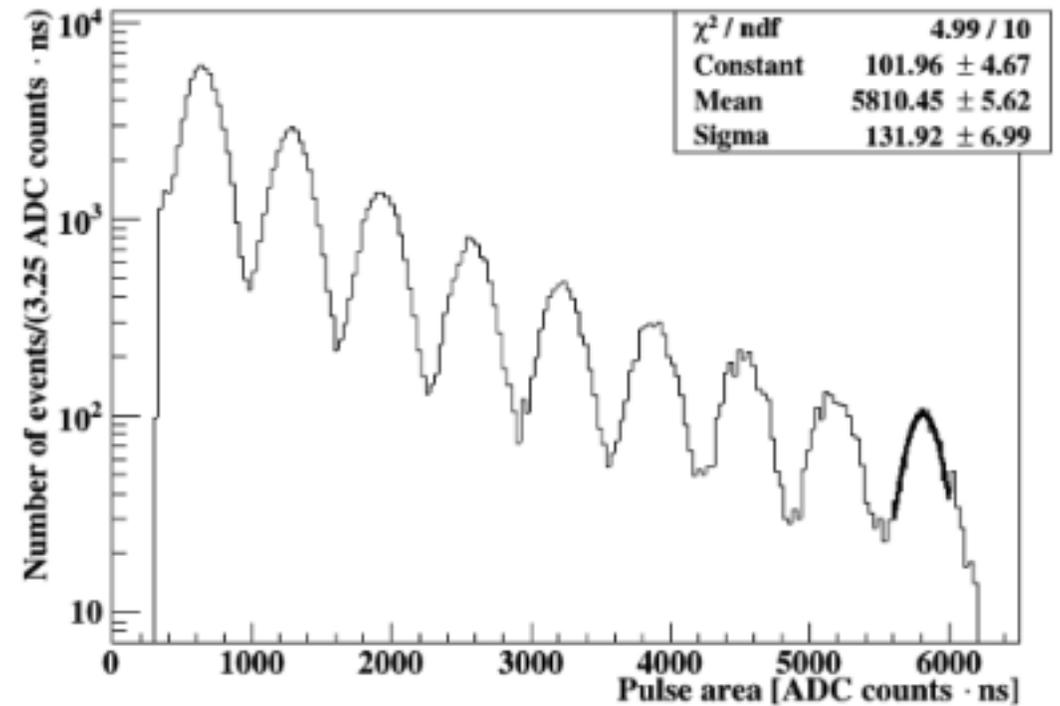


**Fig. 2** Circuit diagram of the passive base (right) and its wiring to room-temperature devices (left)

# SPE spectrum

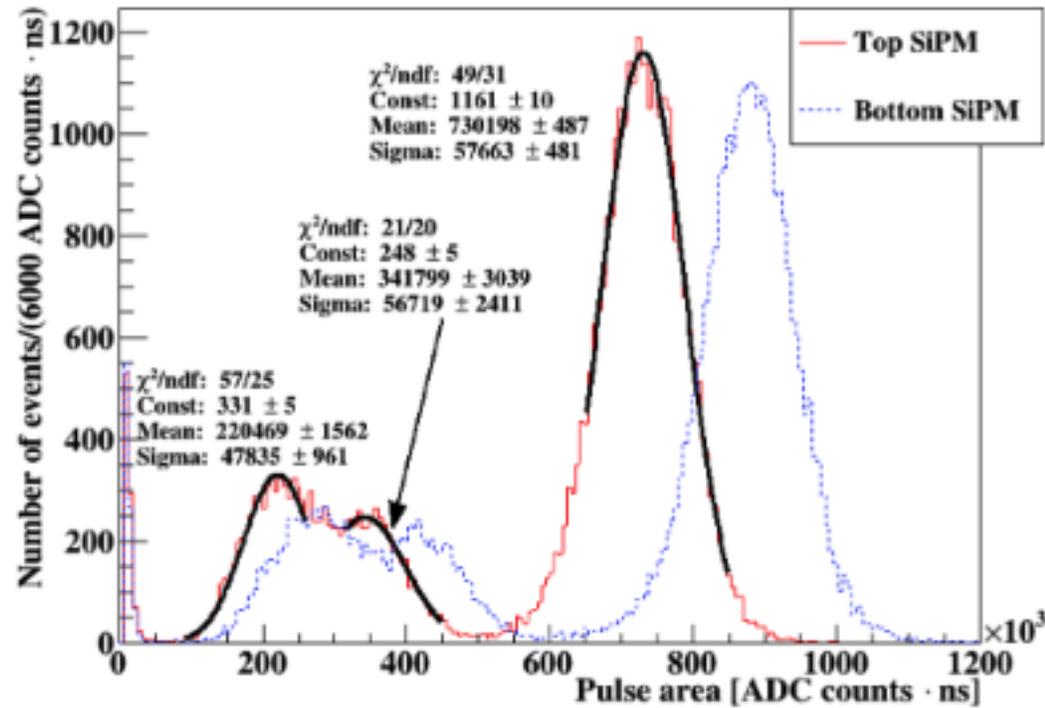


**Fig. 5** Average waveforms of different PEs from the top SiPM. The ones from the bottom SiPM are very similar

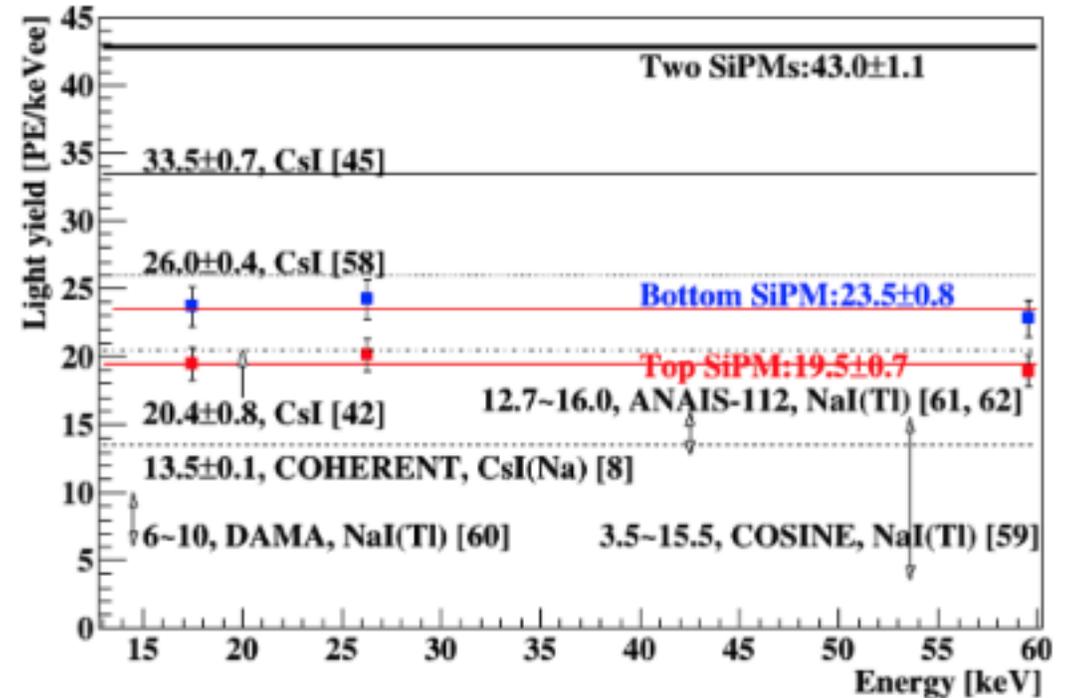


**Fig. 6** Single PE response of the top SiPM in logarithm scale. The ones from the bottom SiPM are very similar

# Light yield

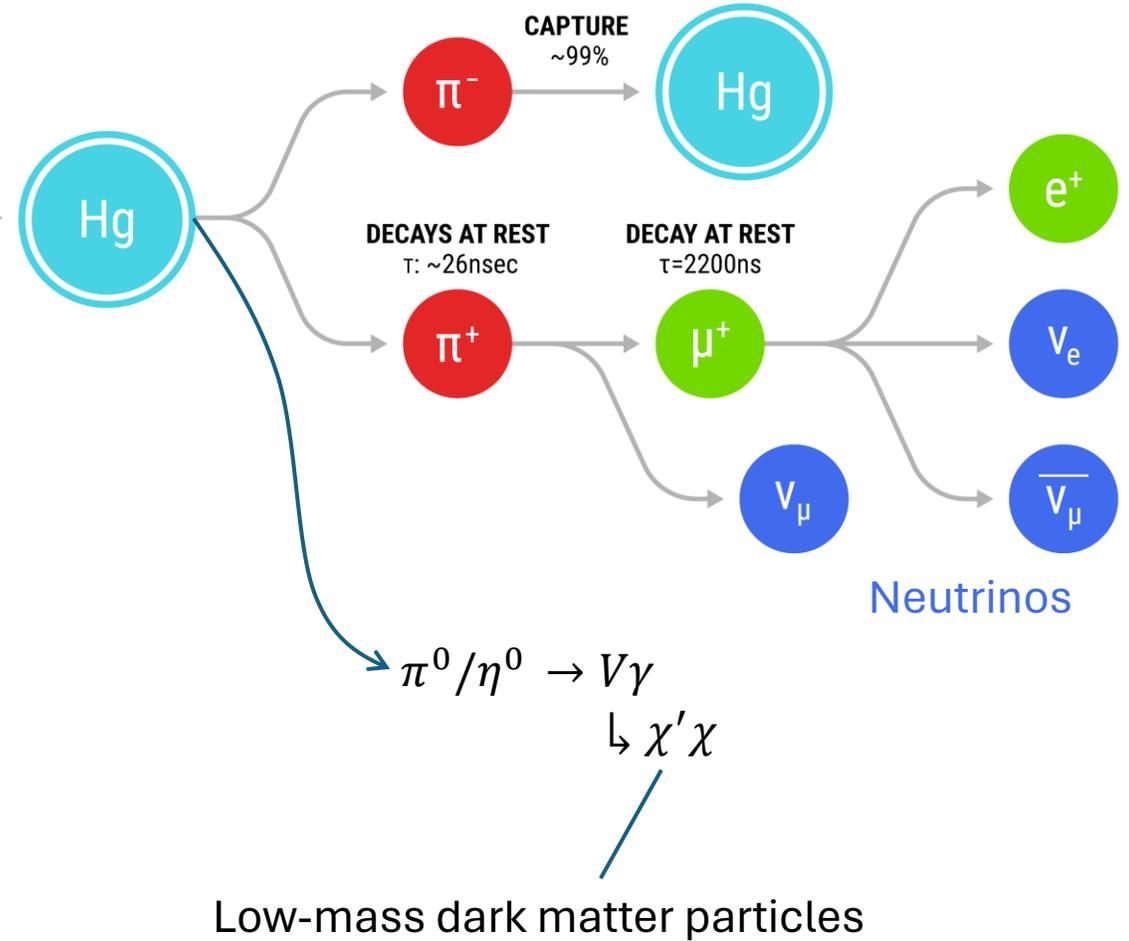
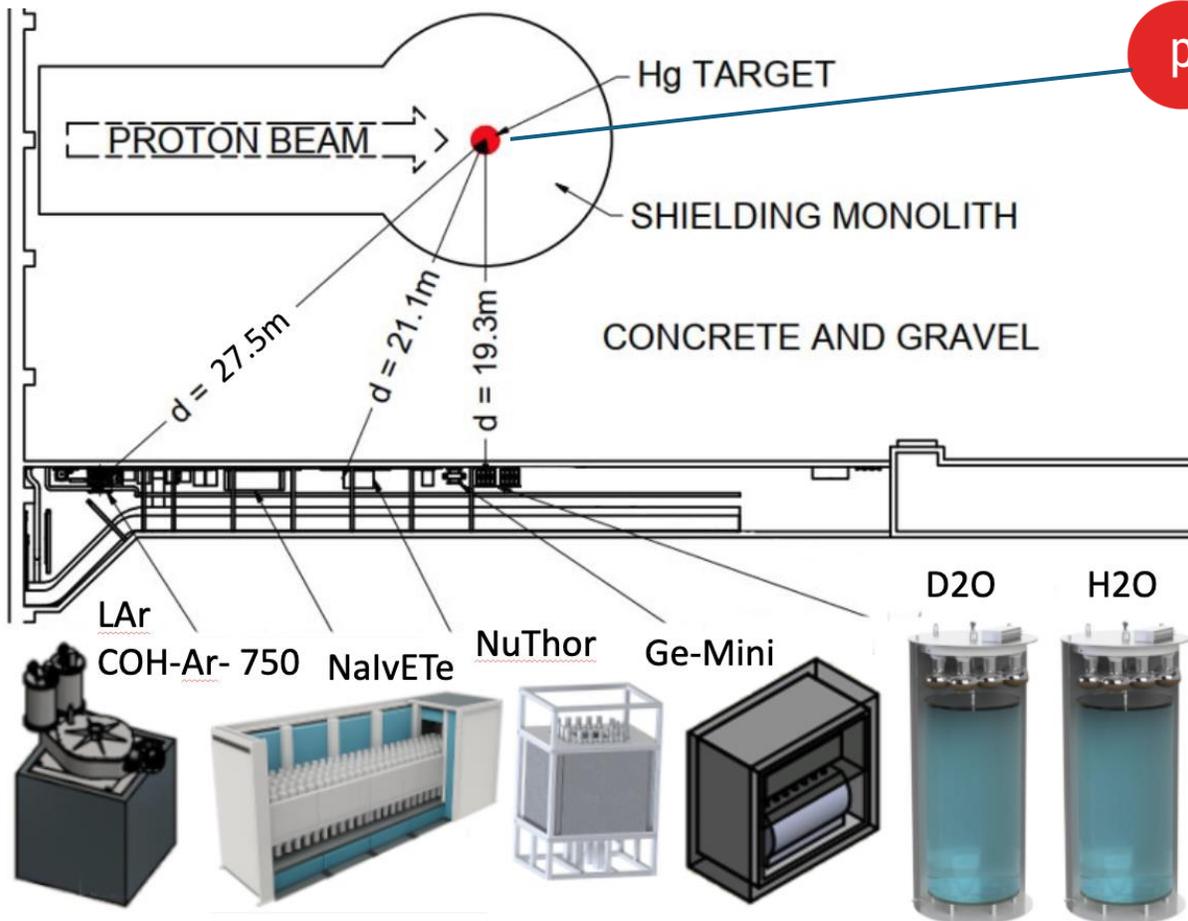


**Fig. 10** Energy spectrum of  $^{241}\text{Am}$  as the distribution of pulse areas in units of ADC counts·ns



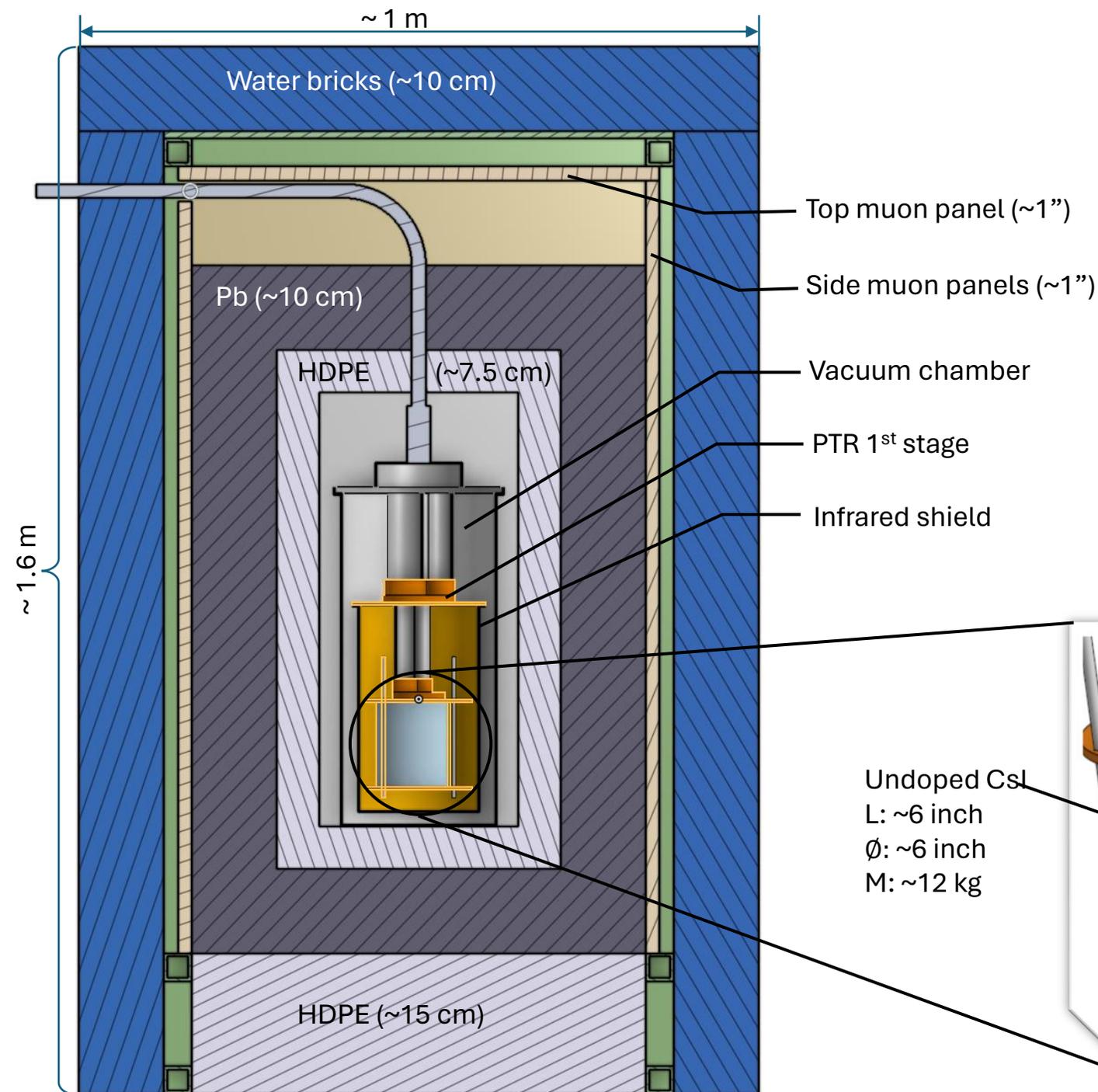
**Fig. 12** Light yields measured for scintillators made of iodide compounds from various experiments [8,42,45,58–62]. All were measured with PMTs except for the one in this work. The arrows only represent ranges of light yields, their locations do not indicate energies where measurements were done

# COHERENT @ the SNS

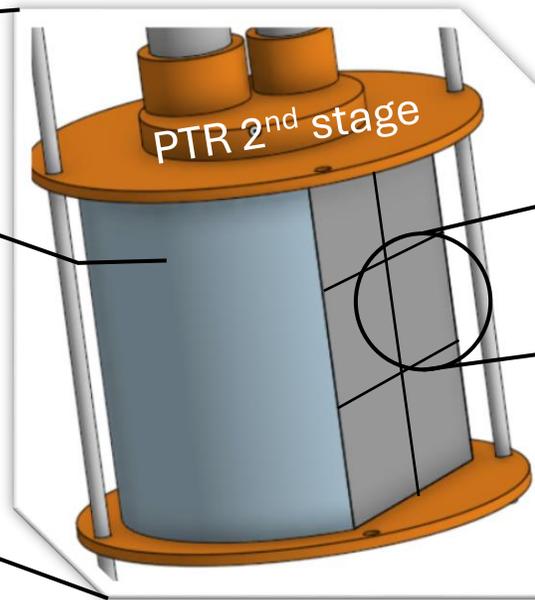


# 40 K cryostat

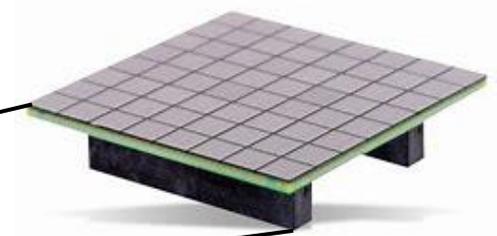
- 6x6 mm<sup>2</sup> single SiPM
- 300 ~ 800 SiPM channels
- Cold FPGA to reduce cables
- Or combining channels



Undoped CsI  
L: ~6 inch  
Ø: ~6 inch  
M: ~12 kg



2 × 3 50 × 50 mm<sup>2</sup> SiPM arrays  
or  
4 × 6 25 × 25 mm<sup>2</sup> SiPM arrays



# Sensitivity

PHYS. REV. D **109**, 092005 (2024)

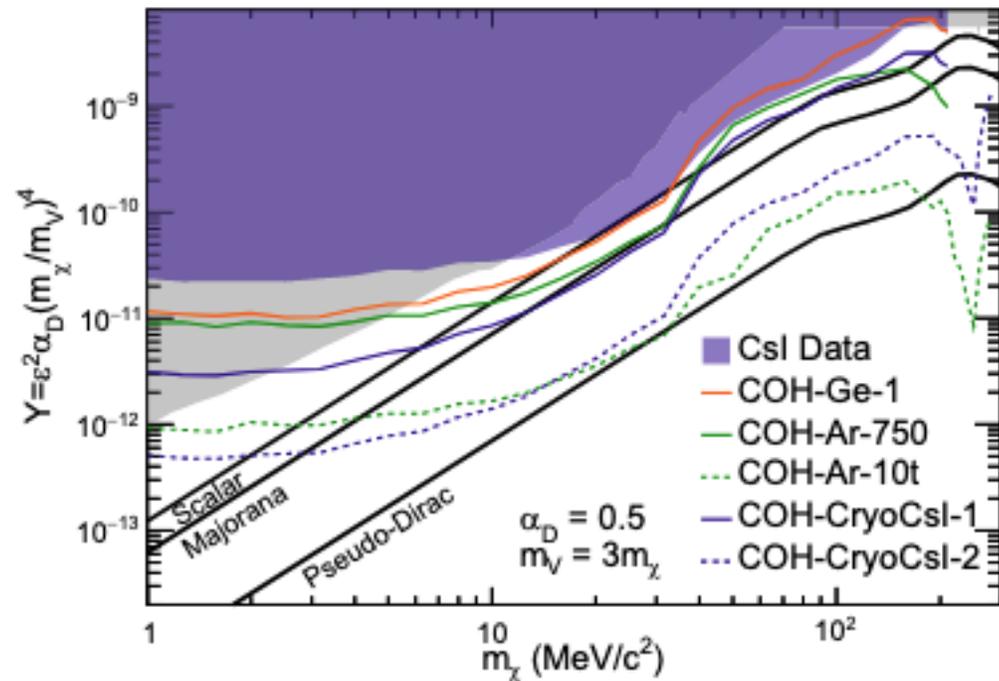
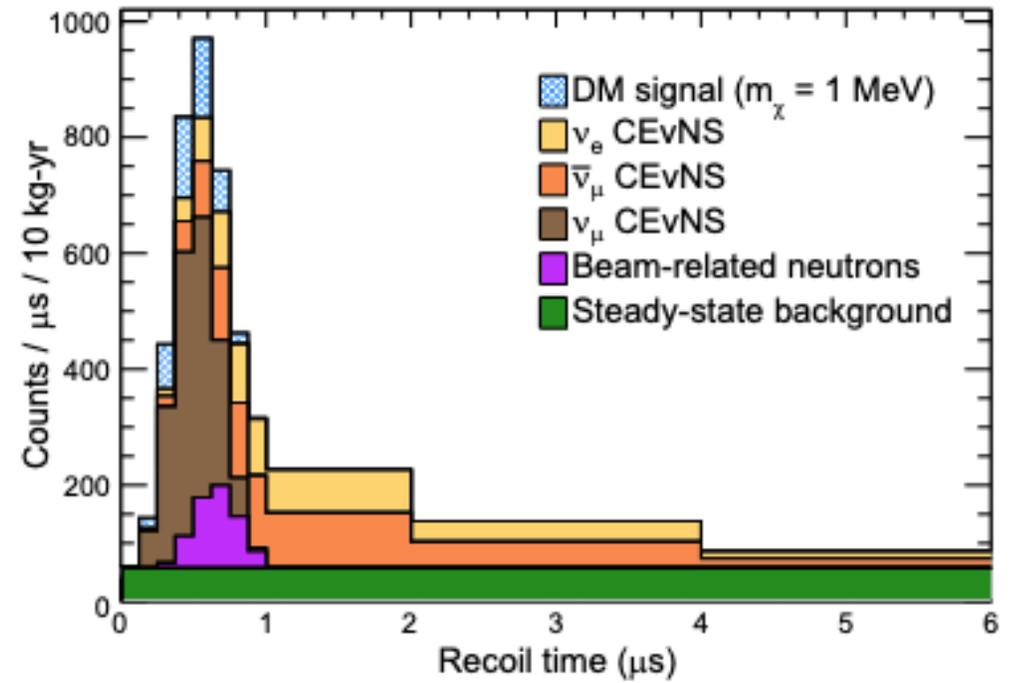
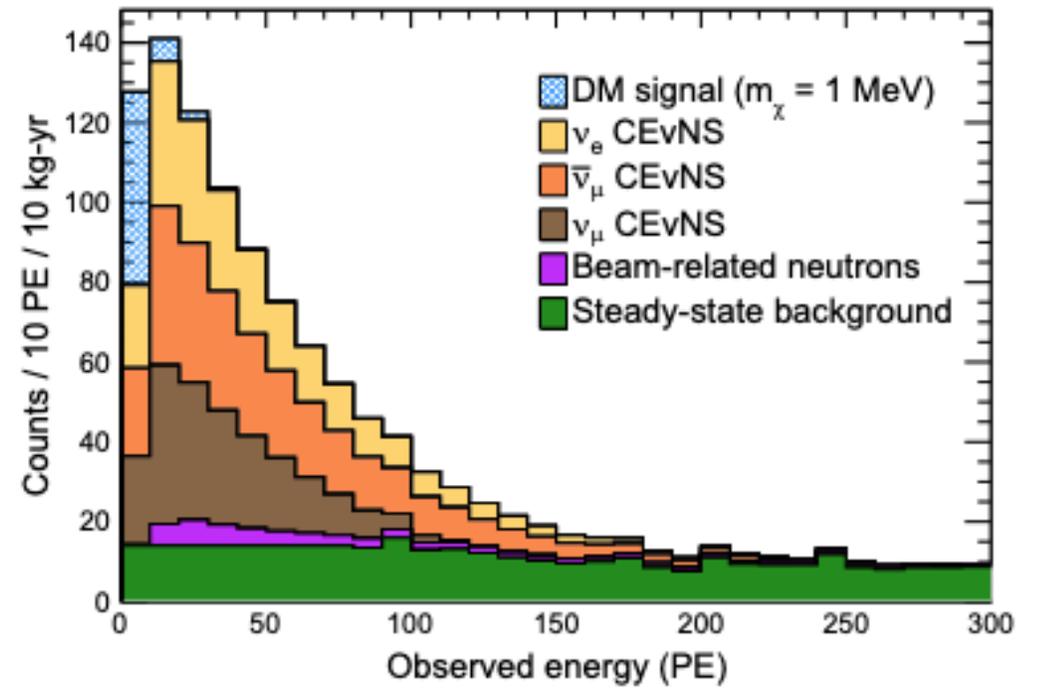


FIG. 10. Calculated sensitivities to new parameter space testable with future CEvNS detectors at the SNS. Cryogenic CsI detectors perform well, particularly at low dark-matter masses.



# Summary

## Pure CsI VS Doped CsI

- Different pro's & con's
- Pure CsI is perfect as electromagnetic calorimeter

## Pure CsI @ different T

- Twice brighter than doped CsI @ 40 ~ 77 K
- CsI + SiPM offers best light yield

## Physics

- Probe accelerator-produced low-mass dark matter elastically scattered with CsI