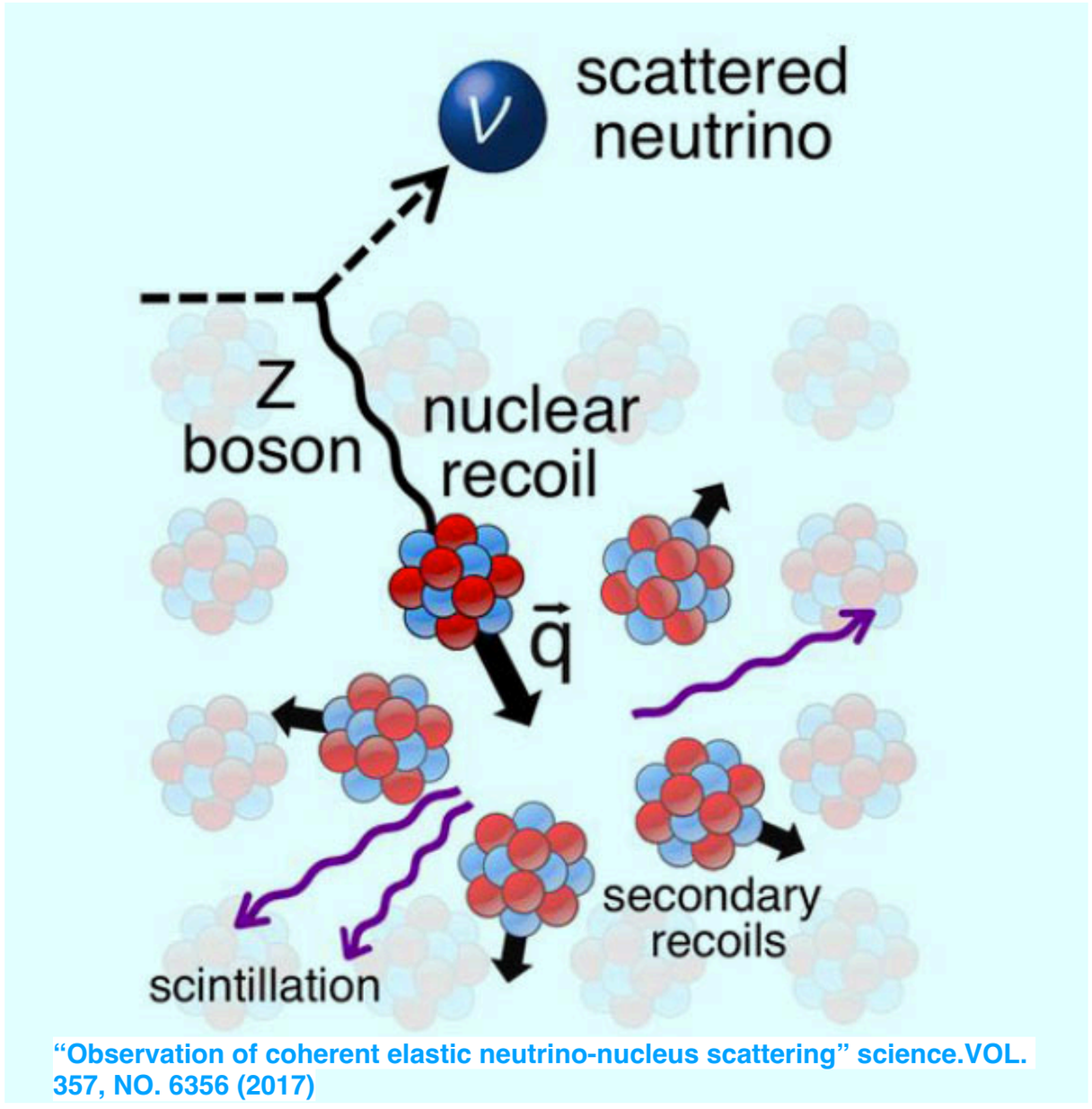
Status of Neutrino Elastic-scattering Observation with NaI(Tl) experiment (NEON)

Byungju Park

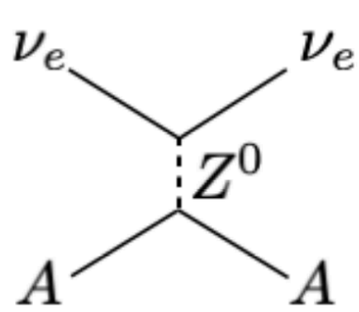
On behalf of the NEON Collaboration

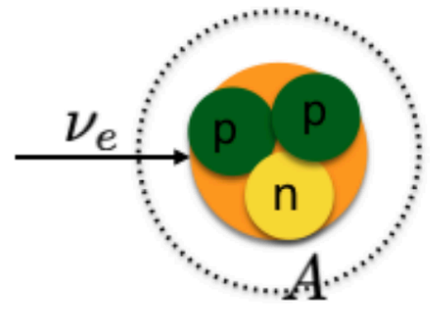
Magnificent CEvNS 2023
March 22, 2023

Coherent elastic neutrino-nucleus scattering (CEvNS)

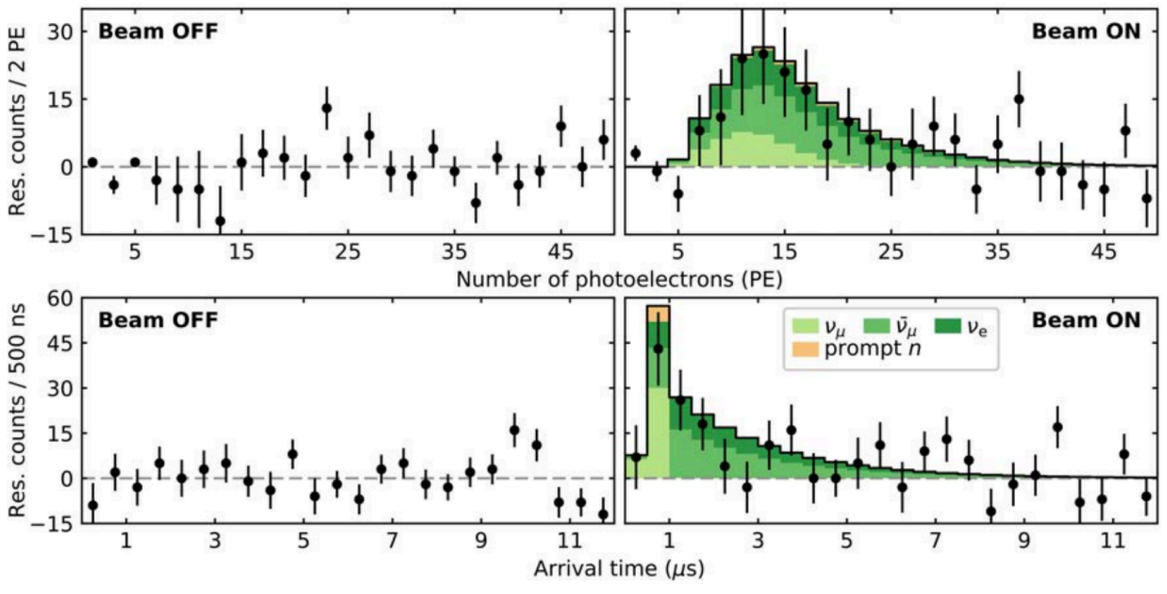


"Observation of coherent elastic neutrino-nucleus scattering" science.VOL. 357, NO. 6356 (2017)





Coherent effects of a weak neutral current
Daniel Z. Freedman (PRD 9,1389, 1974)



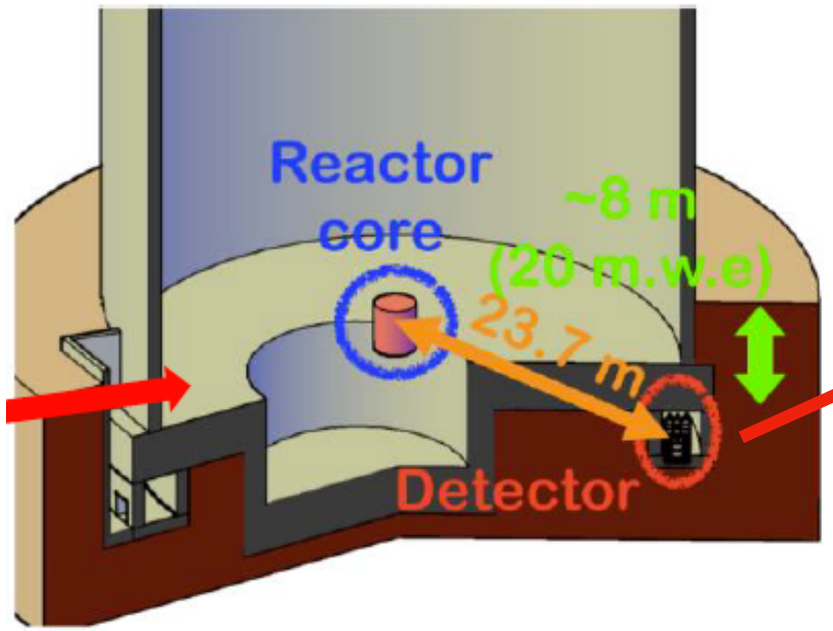
CEvNS was observed by COHERENT experiment (2017)

NEON collaboration

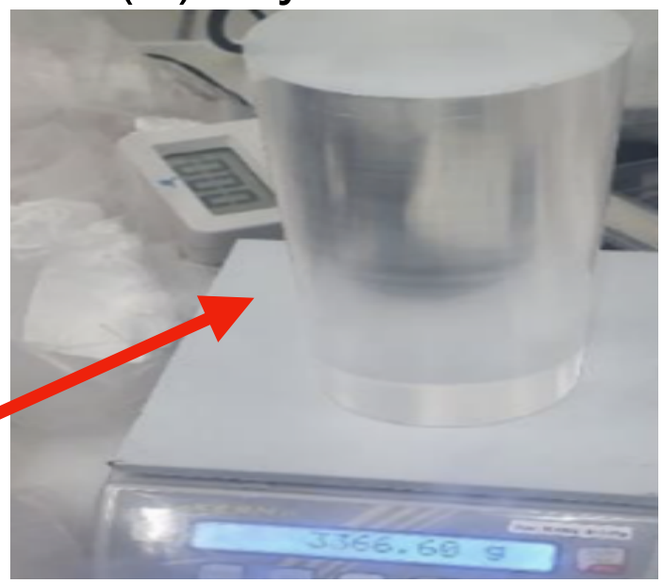
Neutrino Elastic scattering Observation with **NaI** (**NEON**) **is an experiment that aims to observe CEvNS from the reactor anti-electron neutrinos.**

NaI(Tl) target detector

NEON in reactor site

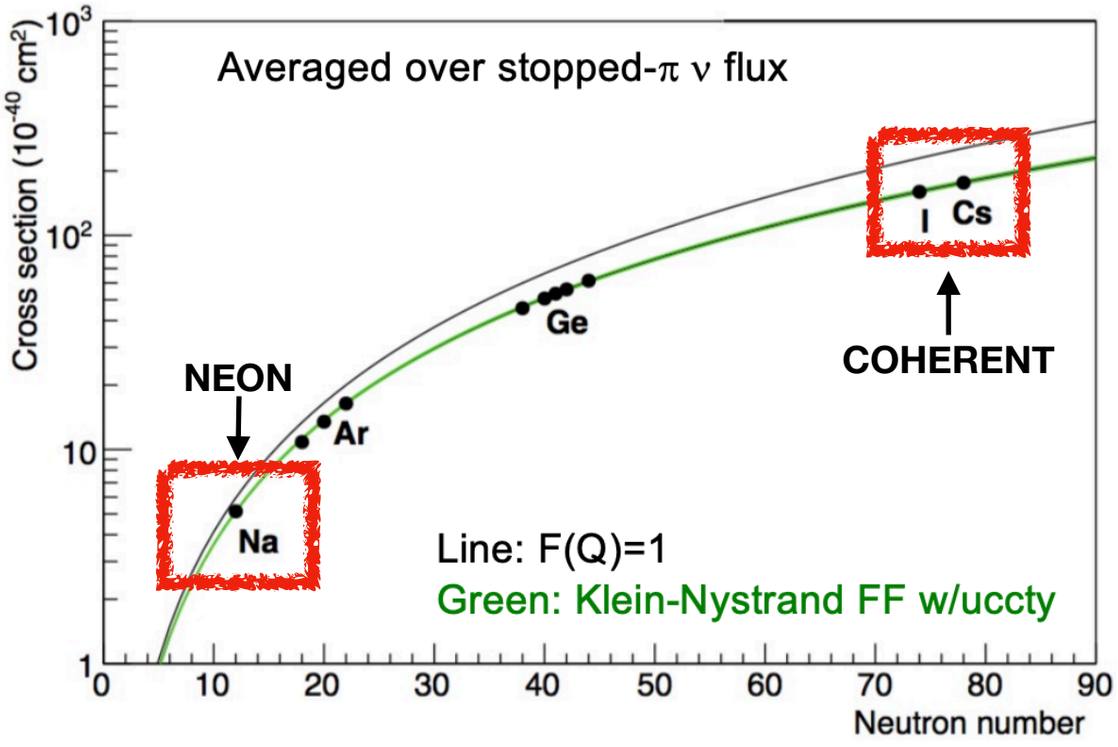


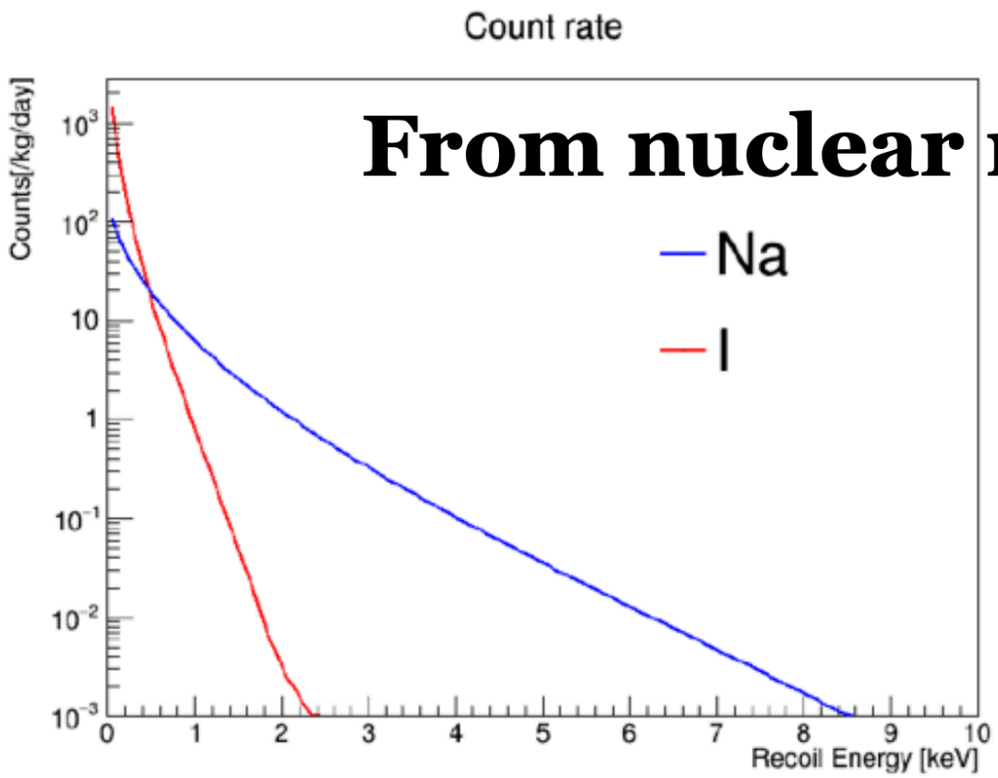
NaI(Tl) Crystal detector



Required detector performance

- Enough size of detector
- Low background
- Low energy threshold
- High light yield (LY)

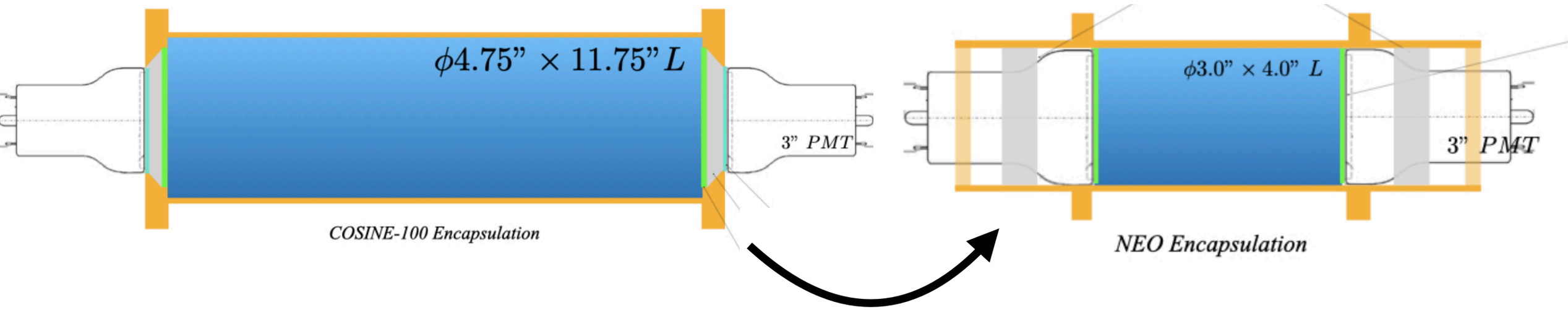




From nuclear reactor

$$E_{max} = 2E_\nu^2/M_N$$

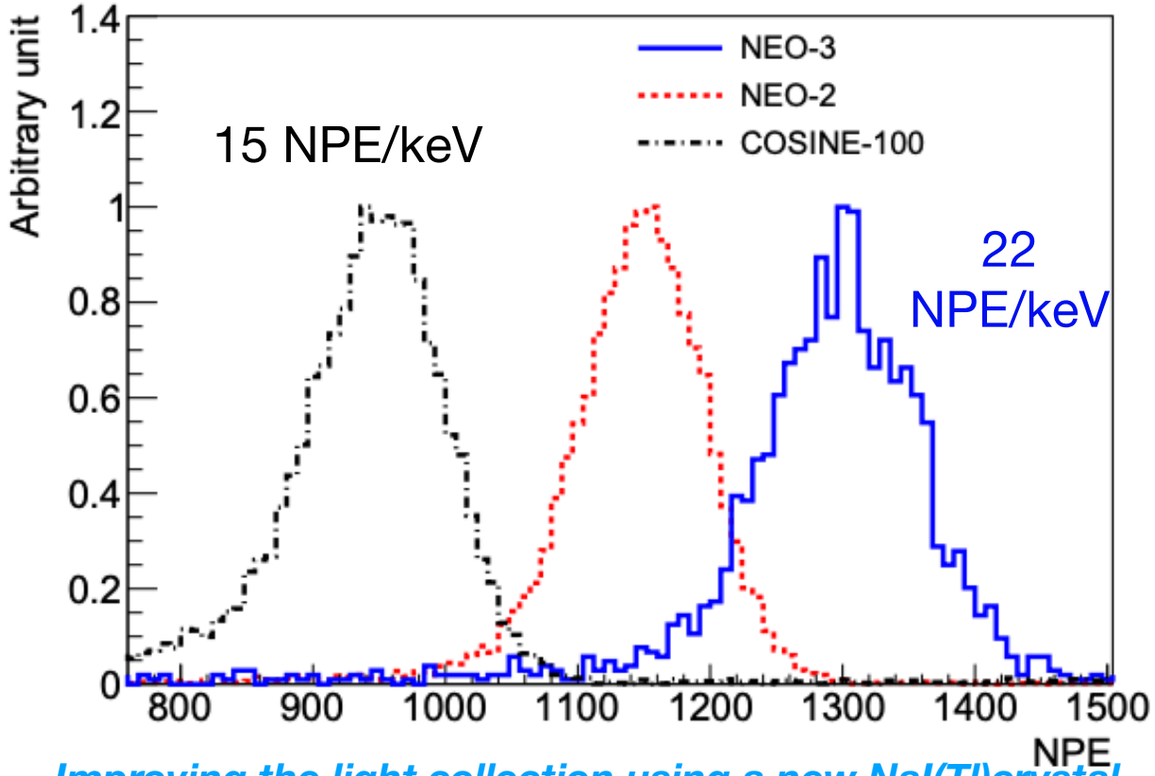
Improving light collection of the NaI(Tl) crystal



Attached without quartz window

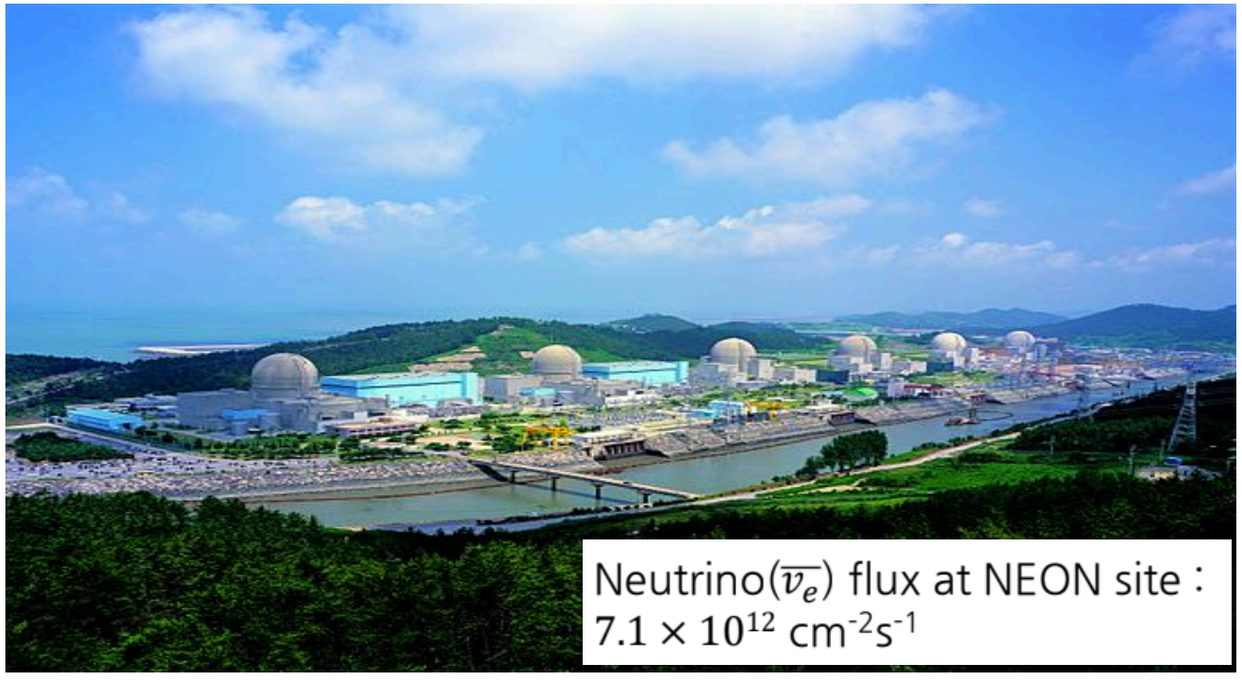
- We can increase light collection by attaching Photomultiplier tube(pmt) directly to the crystal in the encapsulation.

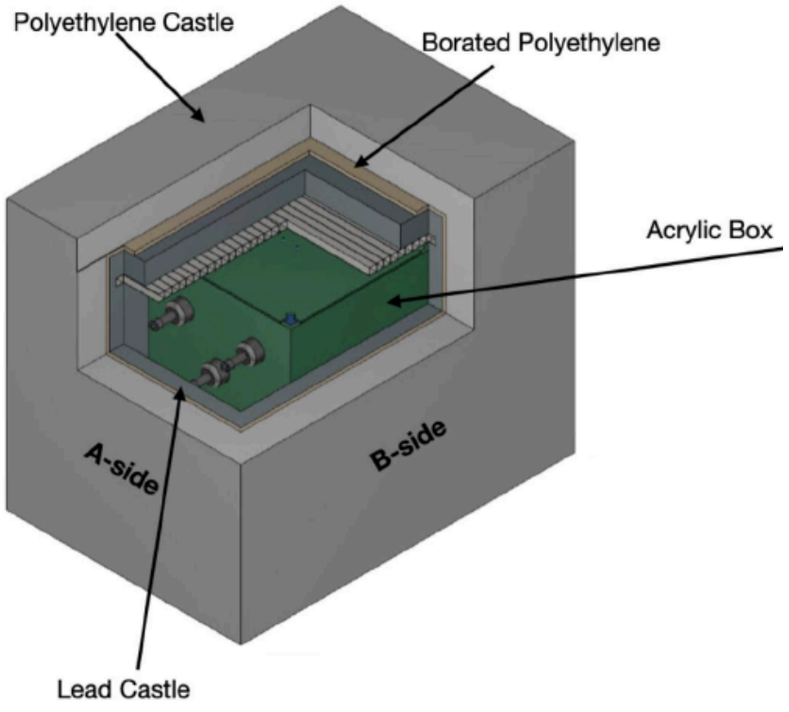
- Achieve about 22 Number of photoelectron(NPE)/keV light collection (15 NPE/keV for previous design).

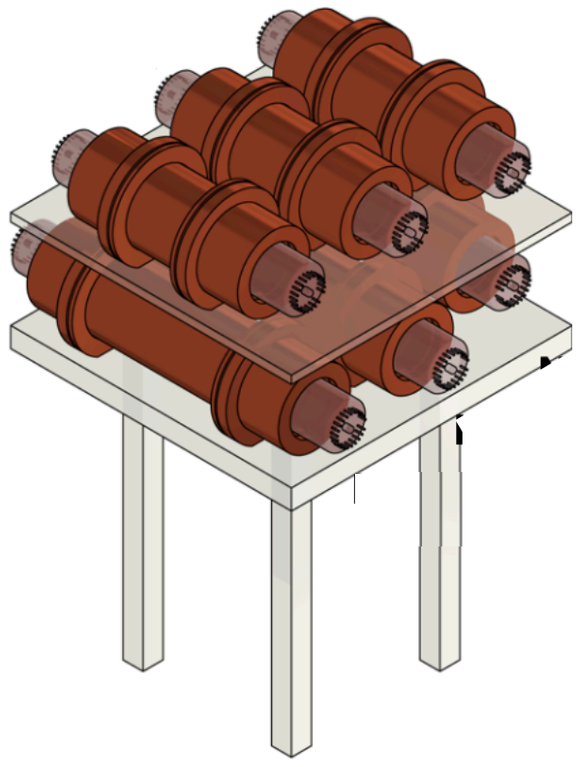


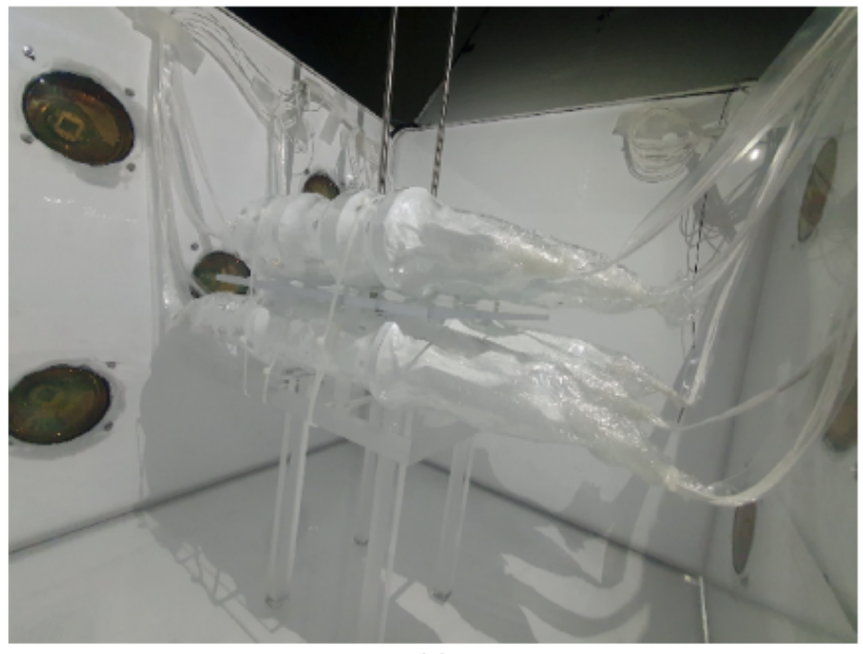
Improving the light collection using a new NaI(Tl)crystal encapsulation.” Nucl. Instrum. Meth. A 981 (2020)

NEON experiment Site





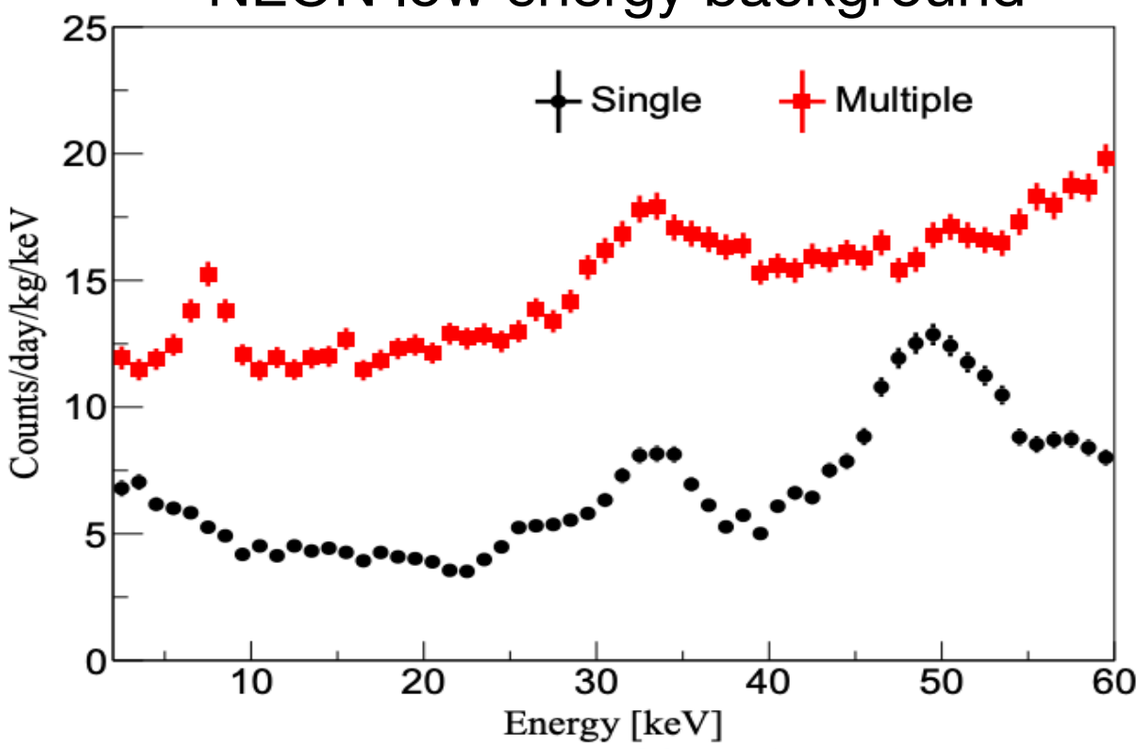




Installed in Nov. 2020

NEON engineering run

NEON low energy background



Eur. Phys. J. C **83**, 226 (2023)

NEON detector mass and LY

Crystal	Mass (kg)	Size (inch, D × L)	Light yield (NPE/keV)
NEO-1	1.62	3 × 4	20.5±0.9
NEO-2	1.67	3 × 4	19.3±0.9
NEO-3	1.67	3 × 4	21.8±0.9
NEO-4	3.35	3 × 8	22.4±1.0
NEO-5	3.35	3 × 8	21.8±0.9
NEO-6	1.65	3 × 4	21.7±1.0
COSINE-100(C6)	12.5	4.8 × 11.8	14.6±1.5

Exploring coherent elastic neutrino-nucleus scattering using reactor electron antineutrinos in the NEON experiment

J.J. Choi,[1,2] E.J. Jeon,[2,3] J.Y. Kim,[4] K.W. Kim,[2] S.H. Kim,[2] S.K. Kim,[1] Y.D. Kim,[2,3] Y.J. Ko,[2] B.C. Koh,[5] C. Ha,[5] B.J. Park,[3,2] S.H. Lee,[3,2] I.S. Lee,[2] H. Lee,[3,2] H.S. Lee,[2,3] J. Lee,[2] and Y.M. Oh[2]

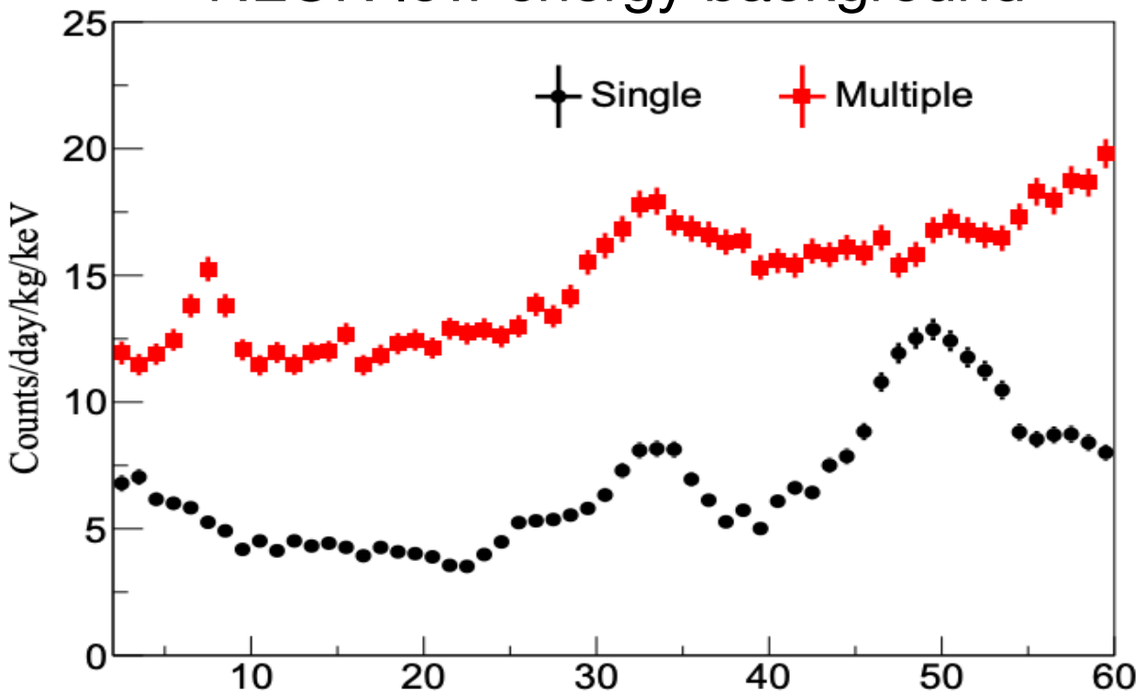
(NEON Collaboration)

[1] *Department of Physics and Astronomy, Seoul National University, Seoul 08826, Republic of Korea*
[2] *Center for Underground Physics, Institute for Basic Science (IBS), Daejeon 34126, Republic of Korea*
[3] *IBS School, University of Science and Technology (UST), Deajeon 34113, Republic of Korea*
[4] *Department of Physics, Sejong University, Seoul 05006, Republic of Korea*
[5] *Department of Physics, Chung-Ang University, Seoul 06973, Republic of Korea*

(Dated: August 5, 2022)

NEON engineering run

NEON low energy background

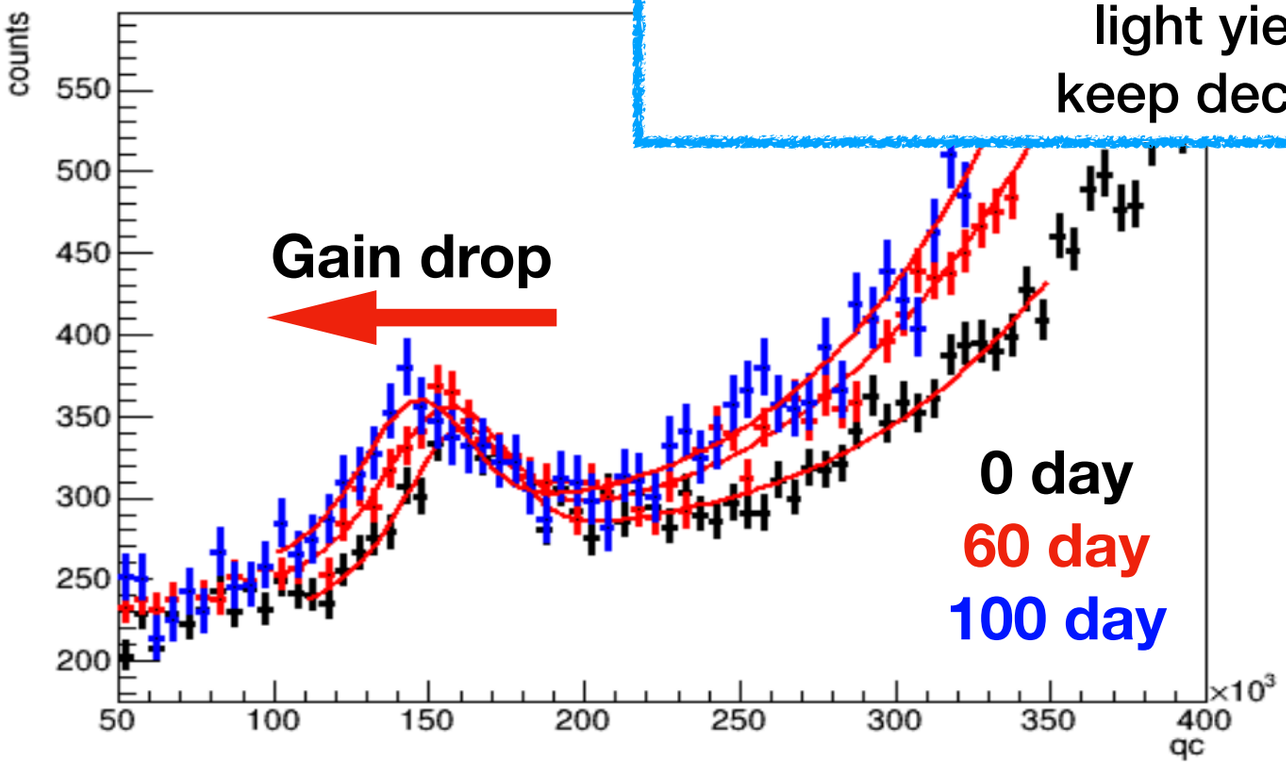


Eur. Phys. J. C **83**, 226 (2023)

NEON detector mass and LY

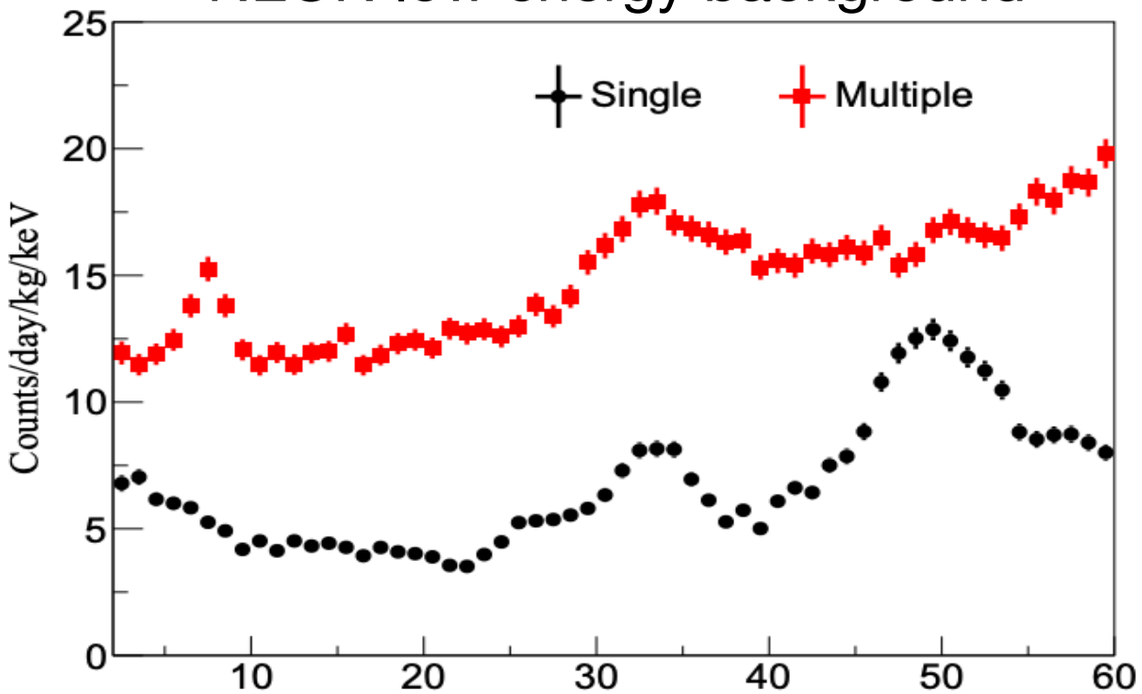
Crystal	Mass (kg)	Size (inch, D × L)	Light yield (NPE/keV)
NEO-1	1.62	3 × 4	20.5±0.9
NEO-2	1.67	3 × 4	19.3±0.9
NEO-3	1.67	3 × 4	21.8±0.9
NEO-4	3.35	3 × 8	22.4±1.0
NEO-5	3.35	3 × 8	21.8±0.9
NEO-6	1.65	3 × 4	21.7±1.0
COSINE-100(C6)	12.5	4.8 × 11.8	14.6±1.5

Because of a air leaks, light yield was keep decreased..



NEON engineering run

NEON low energy background

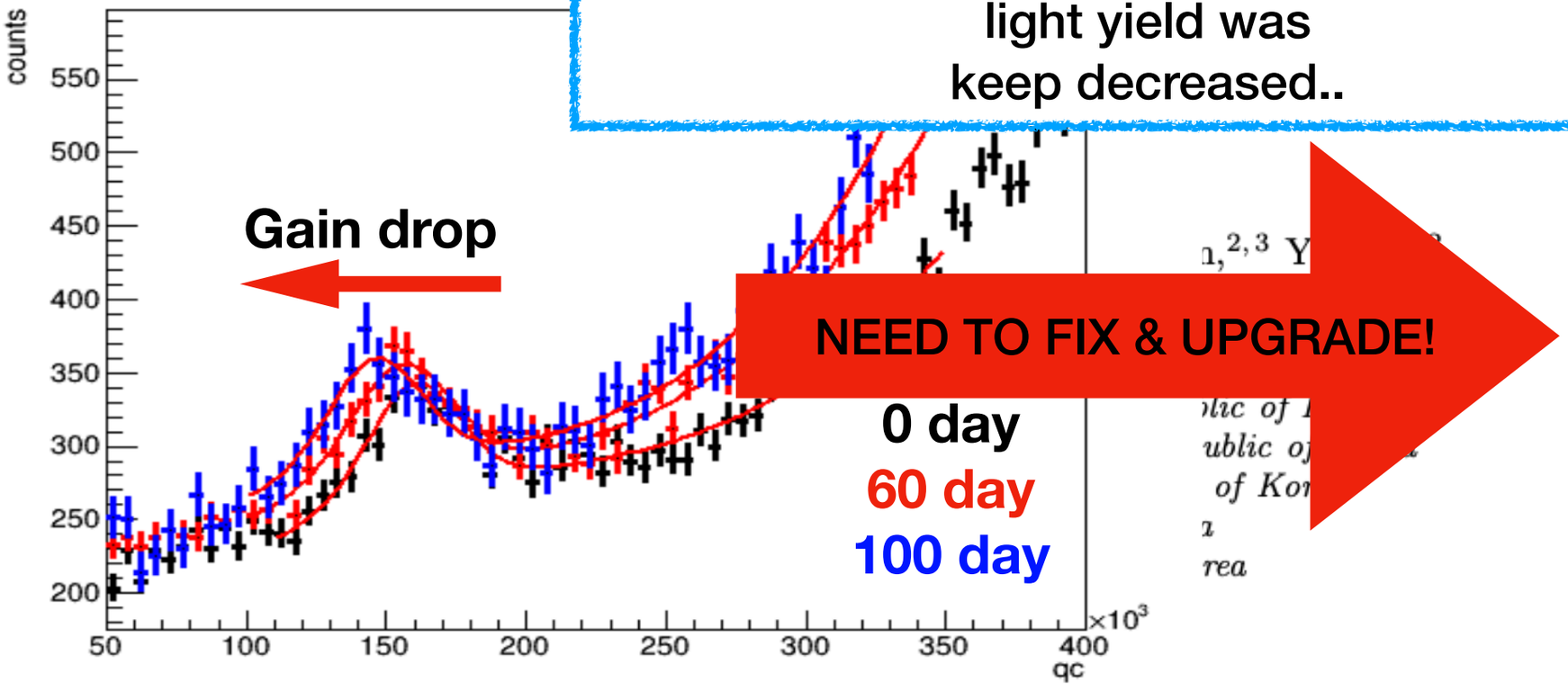


NEON detector mass and LY

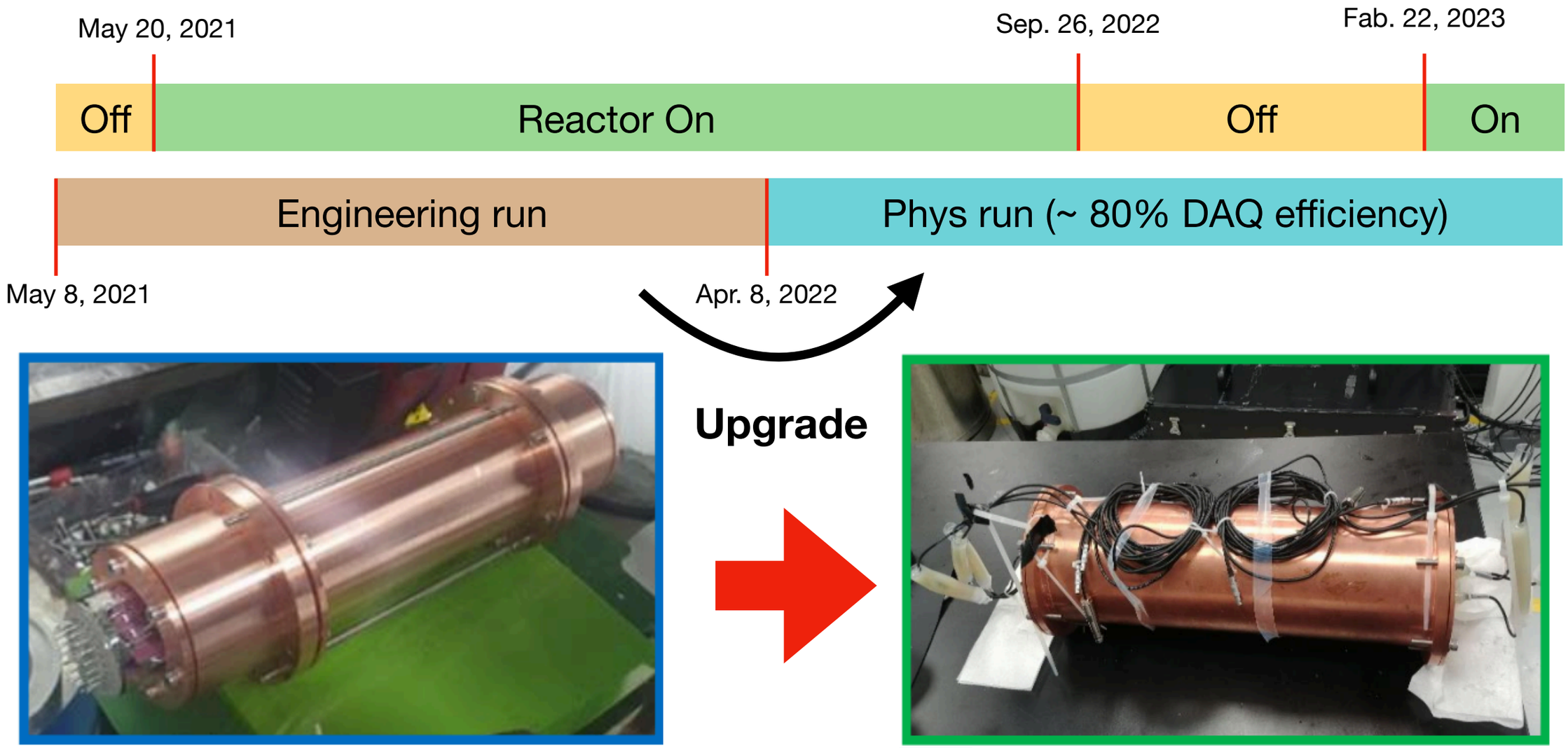
Crystal	Mass (kg)	Size (inch, D × L)	Light yield (NPE/keV)
NEO-1	1.62	3 × 4	20.5±0.9
NEO-2	1.67	3 × 4	19.3±0.9
NEO-3	1.67	3 × 4	21.8±0.9
NEO-4	3.35	3 × 8	22.4±1.0
NEO-5	3.35	3 × 8	21.8±0.9
NEO-6	1.65	3 × 4	21.7±1.0
COSINE-100(C6)	12.5	4.8 × 11.8	14.6±1.5

Eur. Phys. J. C **83**, 226 (2023)

Because of a air leaks, light yield was keep decreased..



NEON upgrade



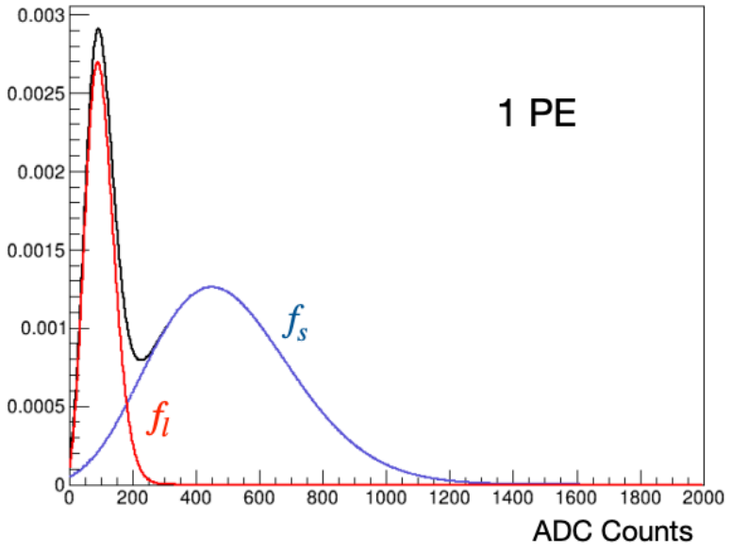
NEON upgrade

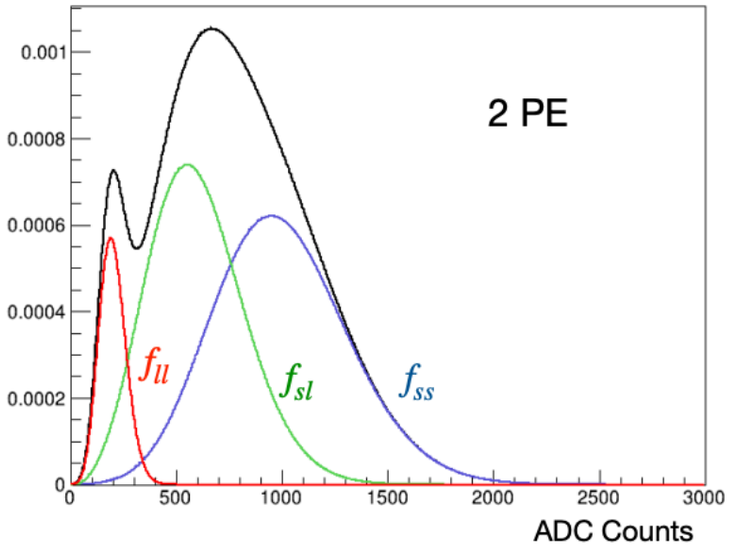
- **Encapsulation design was changed**
- **Air leak in detectors was fixed**
- **Total target mass : 13.5 kg -> 16.7 kg**

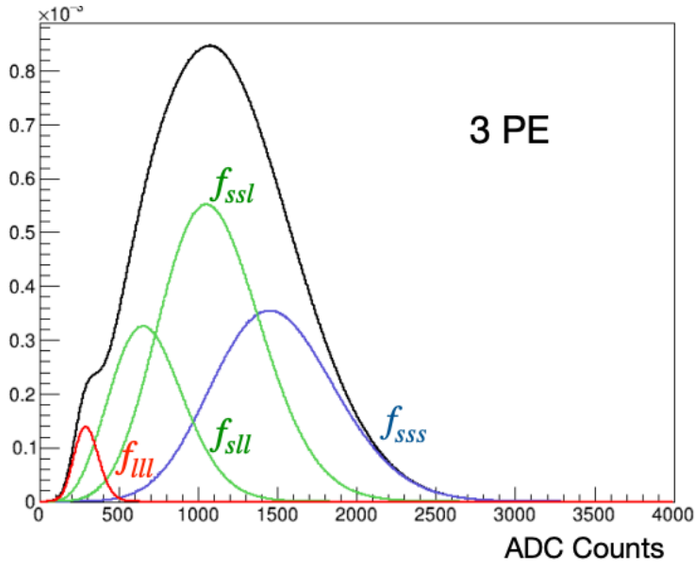
Crystal	Mass (kg)
NEO1	1.62
NEO2	1.67
NEO3	**1.67**
NEO4	**3.35**
NEO5	**3.32**
NEO6	**1.65**
NEO7	**3.35**
NEO8	**3.34**

Light yield calculation with low gain

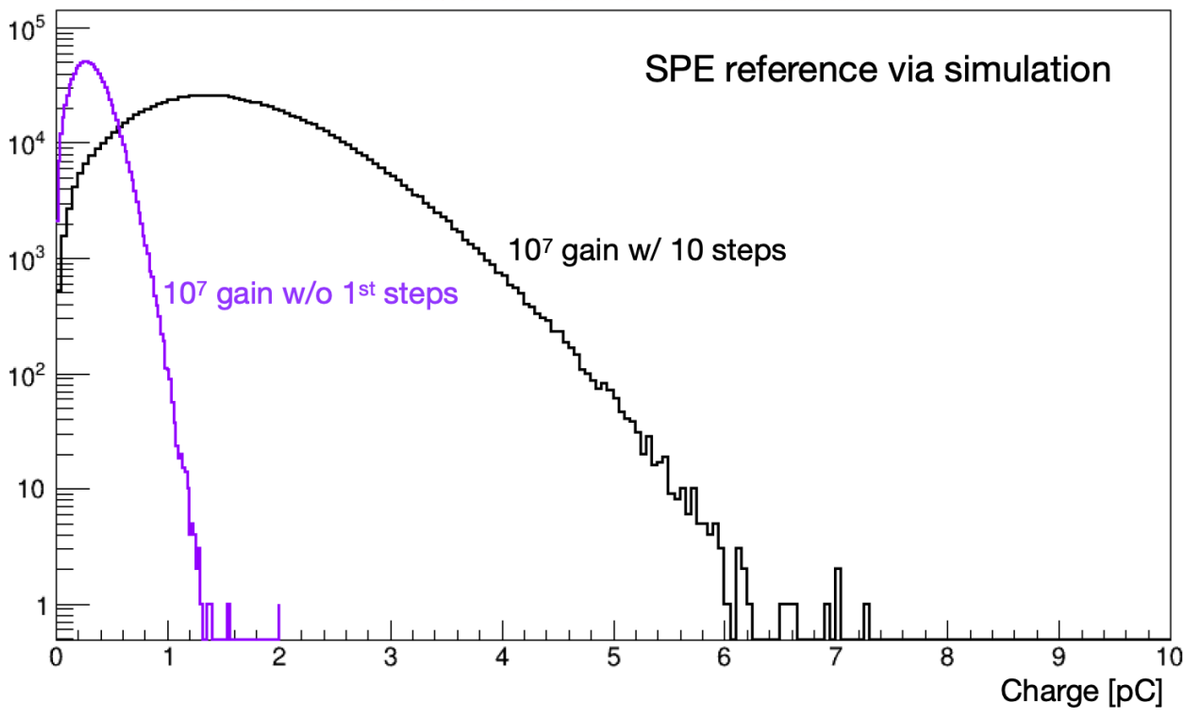
SPE Model

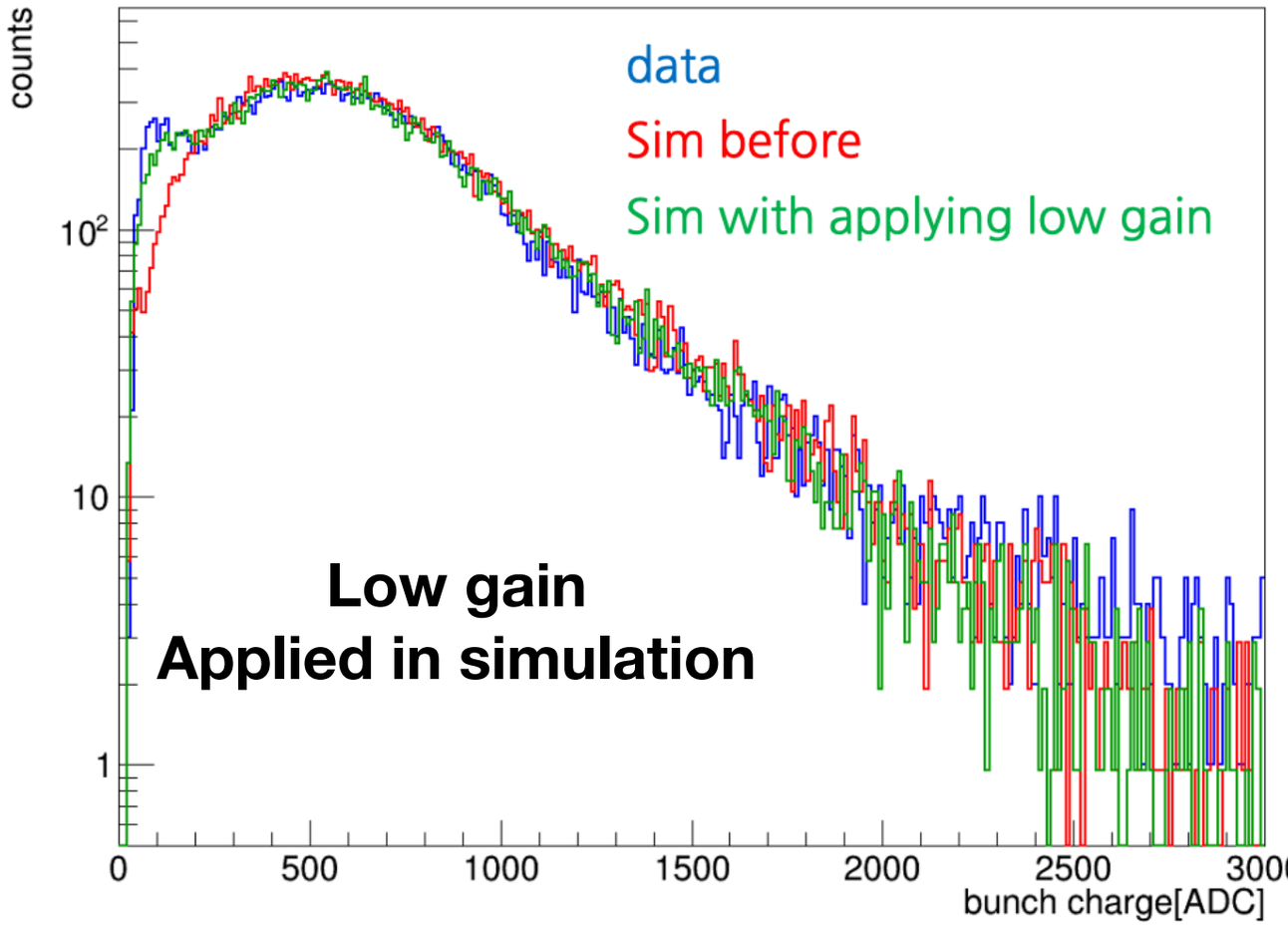






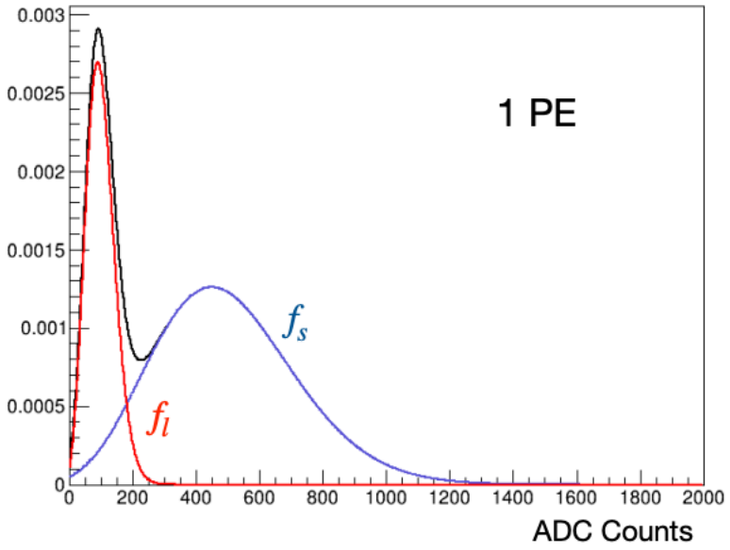
10 steps for amplification
→ 9 steps for **low gain**

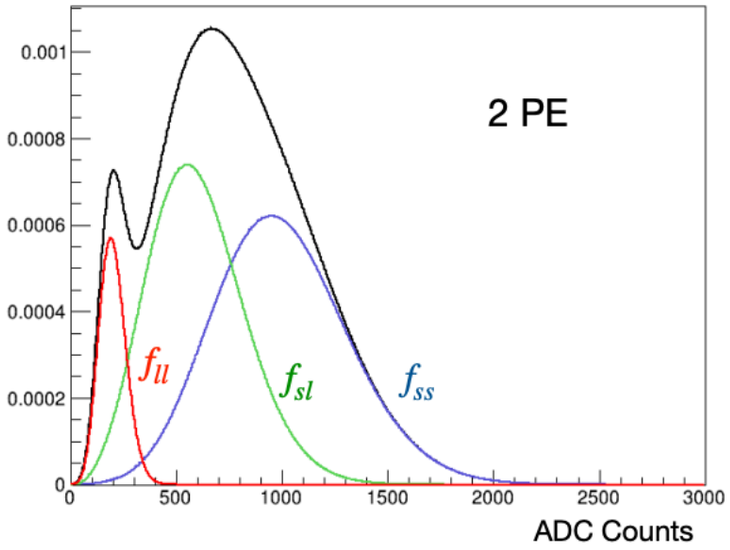


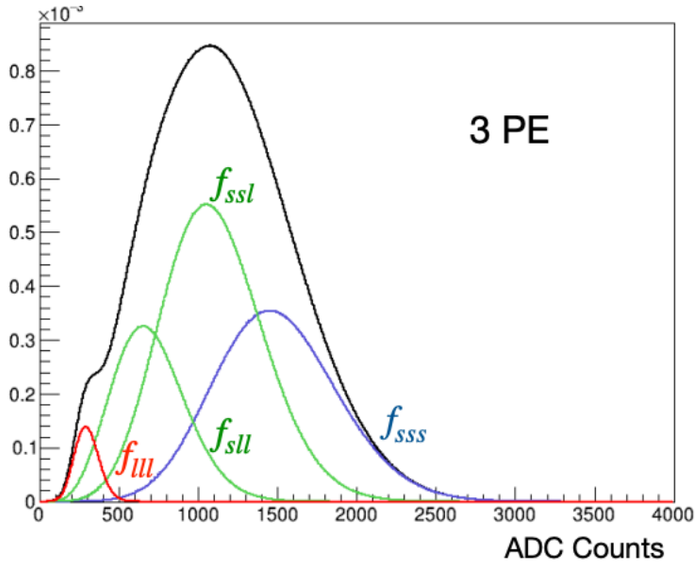


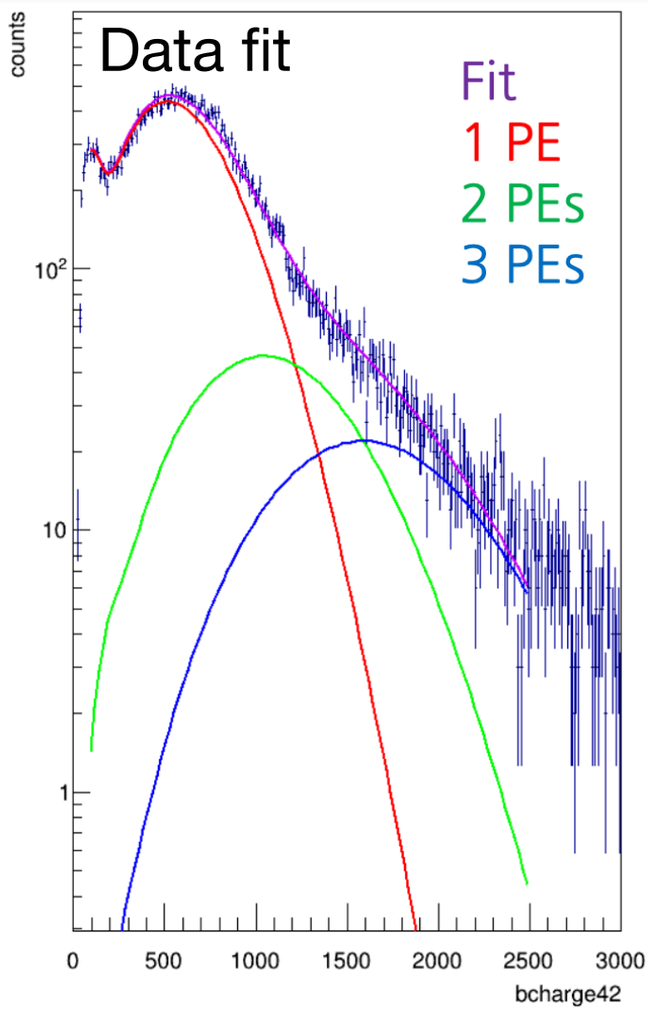
Light yield calculation with low gain

SPE Model





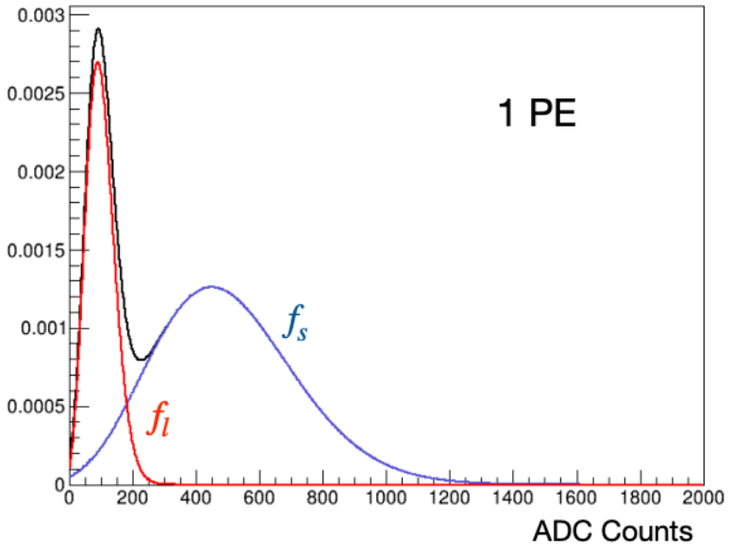


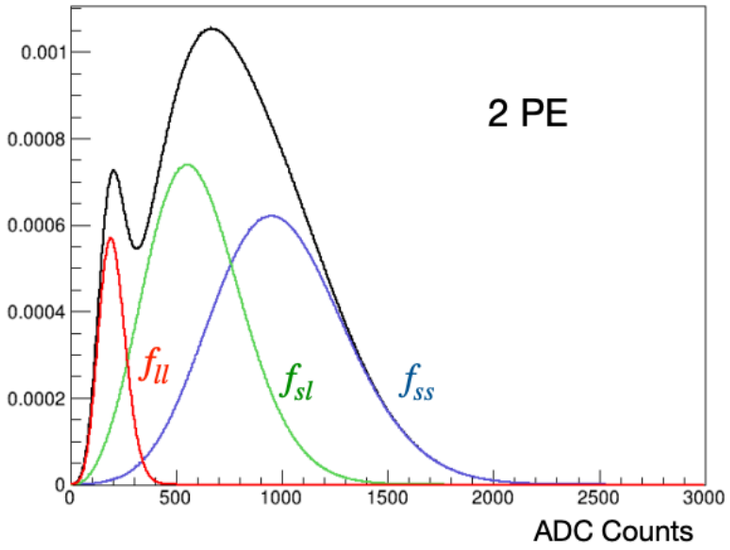


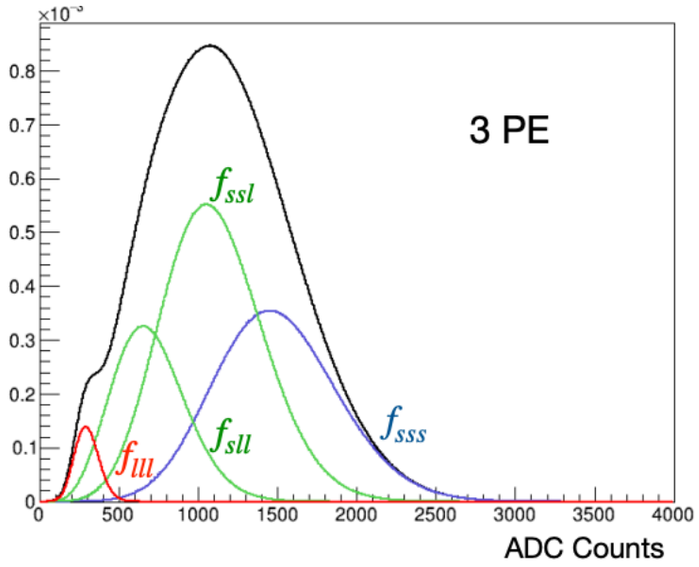
Detector Number	Mass (kg)	LY (w/o low gain) (NPE/keV)	LY (w/ low gain) (NPE/keV)
D1	1.67	23.89 ± 0.82	26.81 ± 1.32
D2	3.32	24.48 ± 0.74	27.65 ± 1.15
D3	1.67	20.20 ± 0.42	21.77 ± 0.69
D4	3.32	22.87 ± 0.40	24.34 ± 0.70
D5	3.34	21.99 ± 0.47	23.41 ± 0.88
D6	3.34	26.73 ± 0.79	29.12 ± 1.30

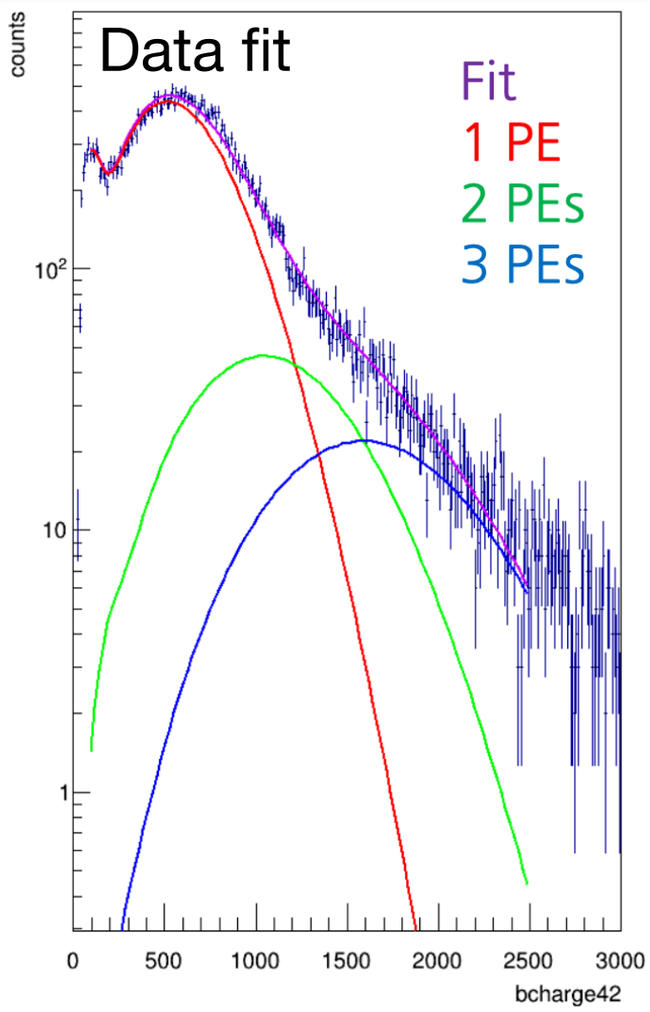
Light yield calculation with low gain

SPE Model





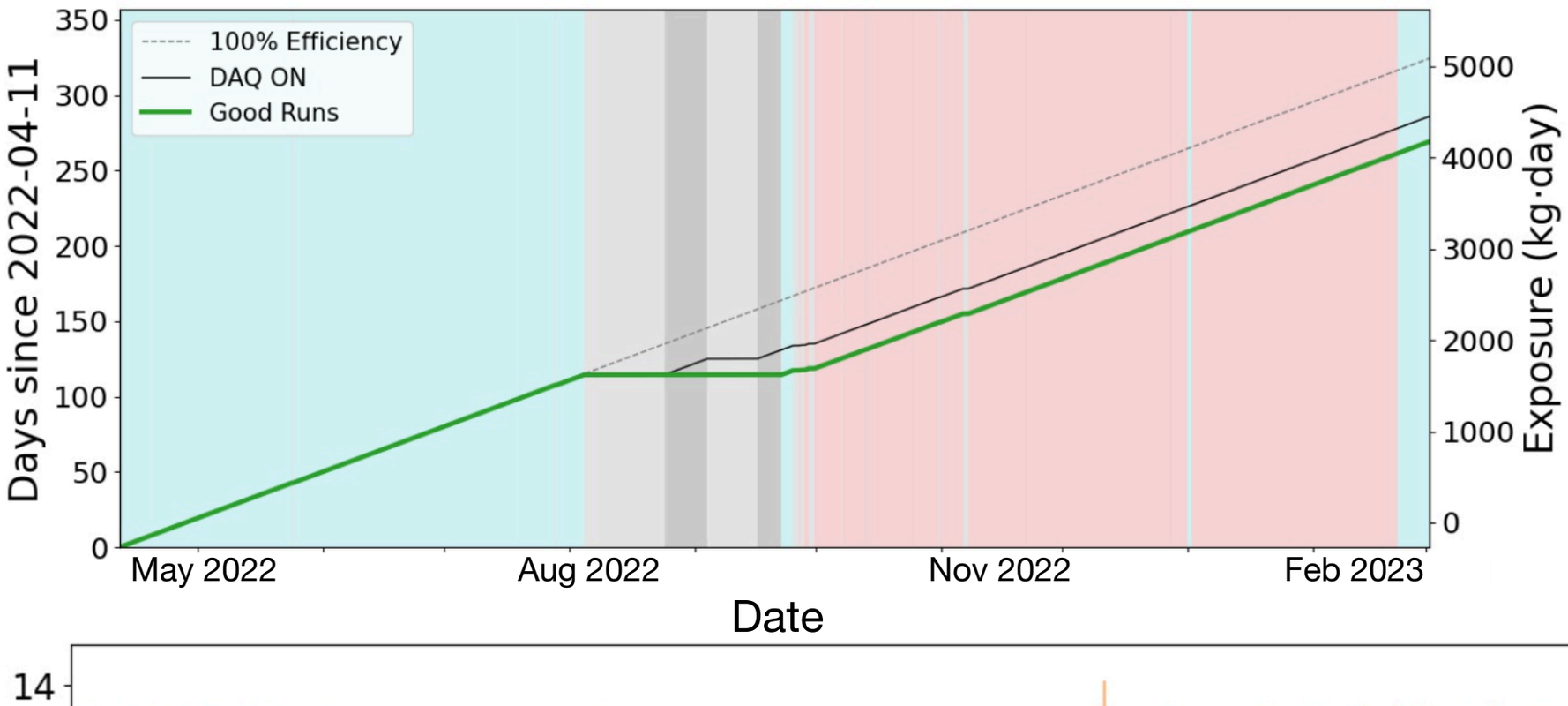


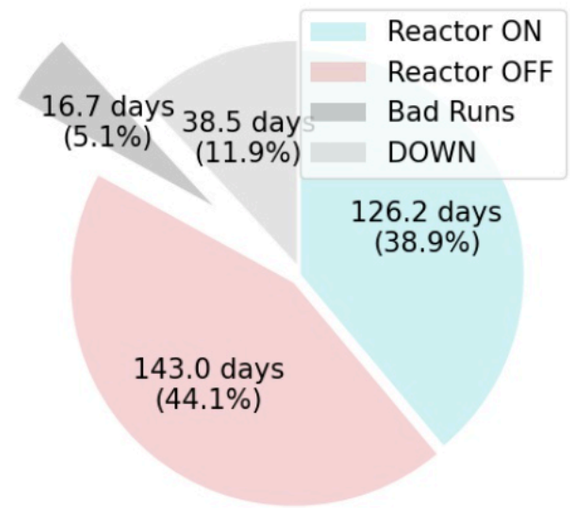


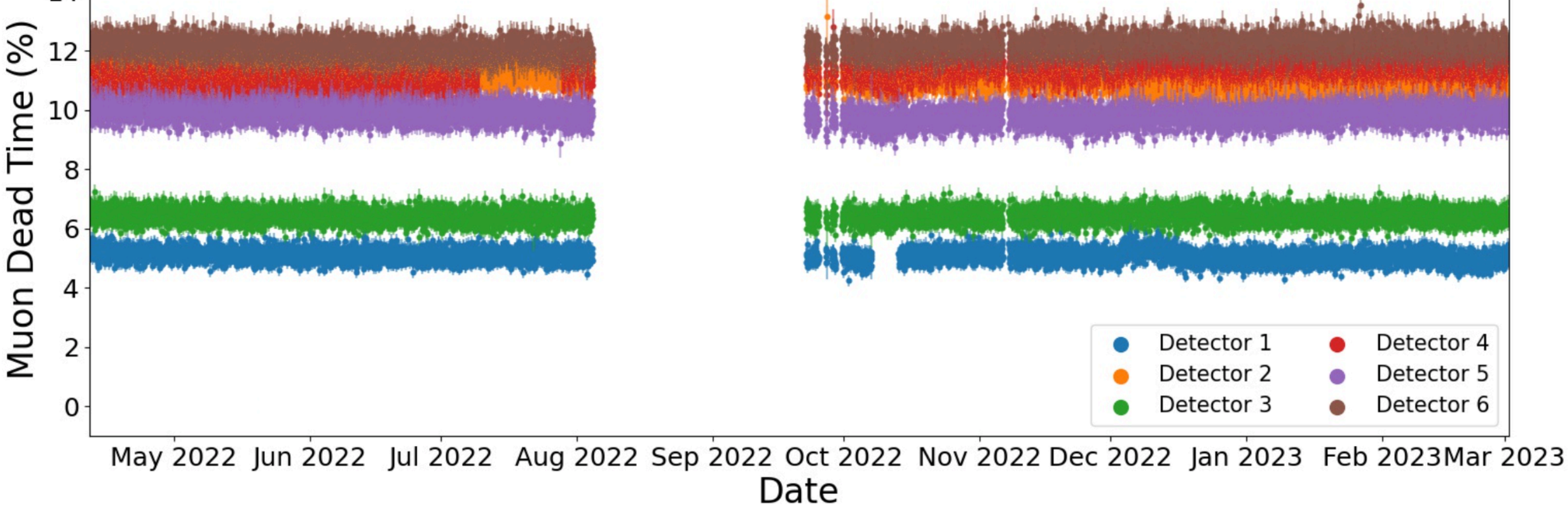
Detector Number	Mass (kg)	LY (w/o low gain) (NPE/keV)	LY (w/ low gain) (NPE/keV)
D1	1.67	23.89 ± 0.82	26.81 ± 1.32
D2	3.32	24.48 ± 0.74	27.65 ± 1.15
D3	1.67	2[illegible]	[illegible]
D4	3.32	22.[illegible]0.40	24.34 ± 0.70
D5	3.34	21.99 ± 0.47	23.41 ± 0.88
D6	3.34	26.73 ± 0.79	29.12 ± 1.30

~ 24 NPE/keV

Physics run

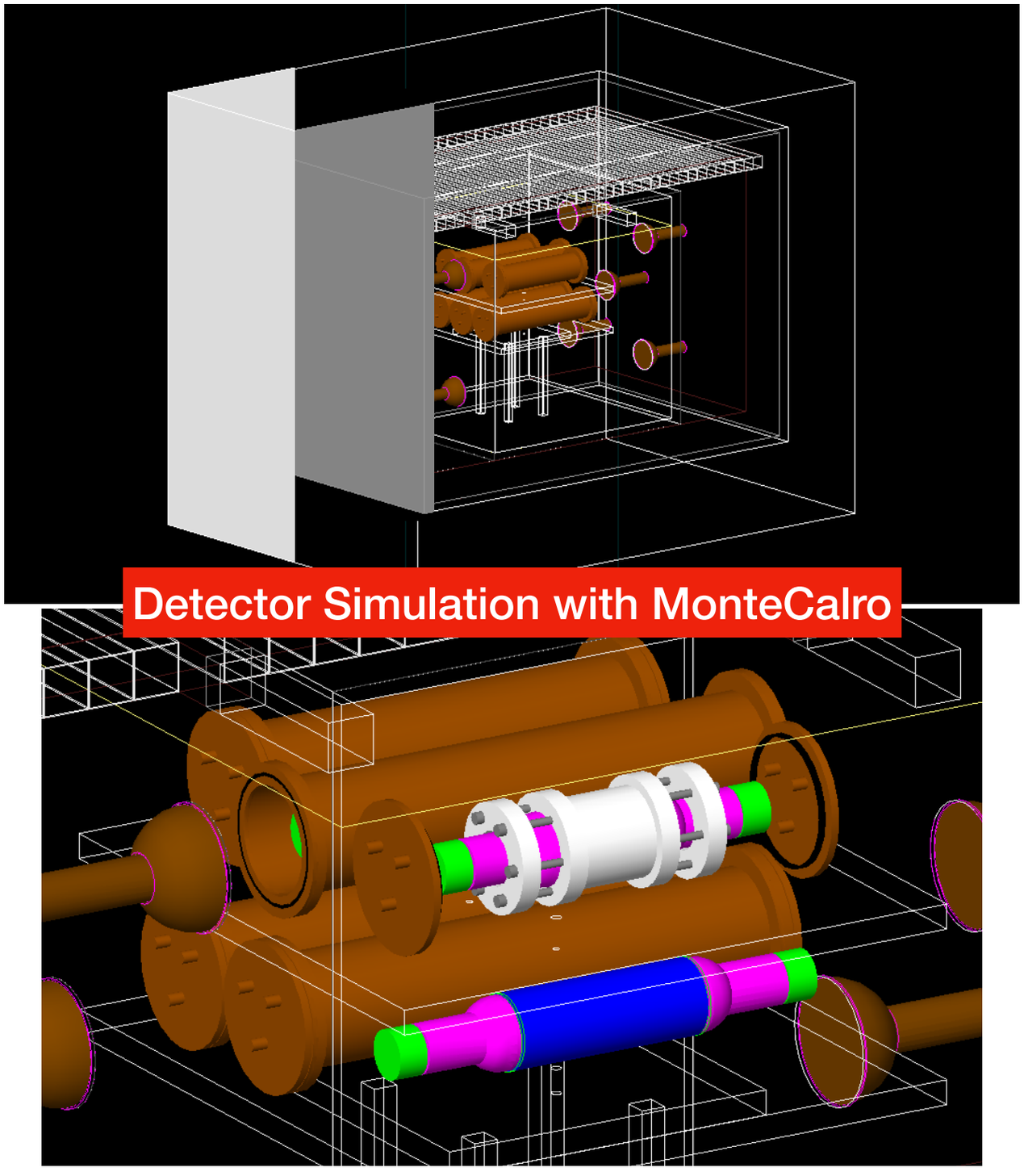

100% Efficiency
DAQ ON
Good Runs
Days since 2022-04-11
Exposure (kg·day)
May 2022
Aug 2022
Nov 2022
Feb 2023
Date

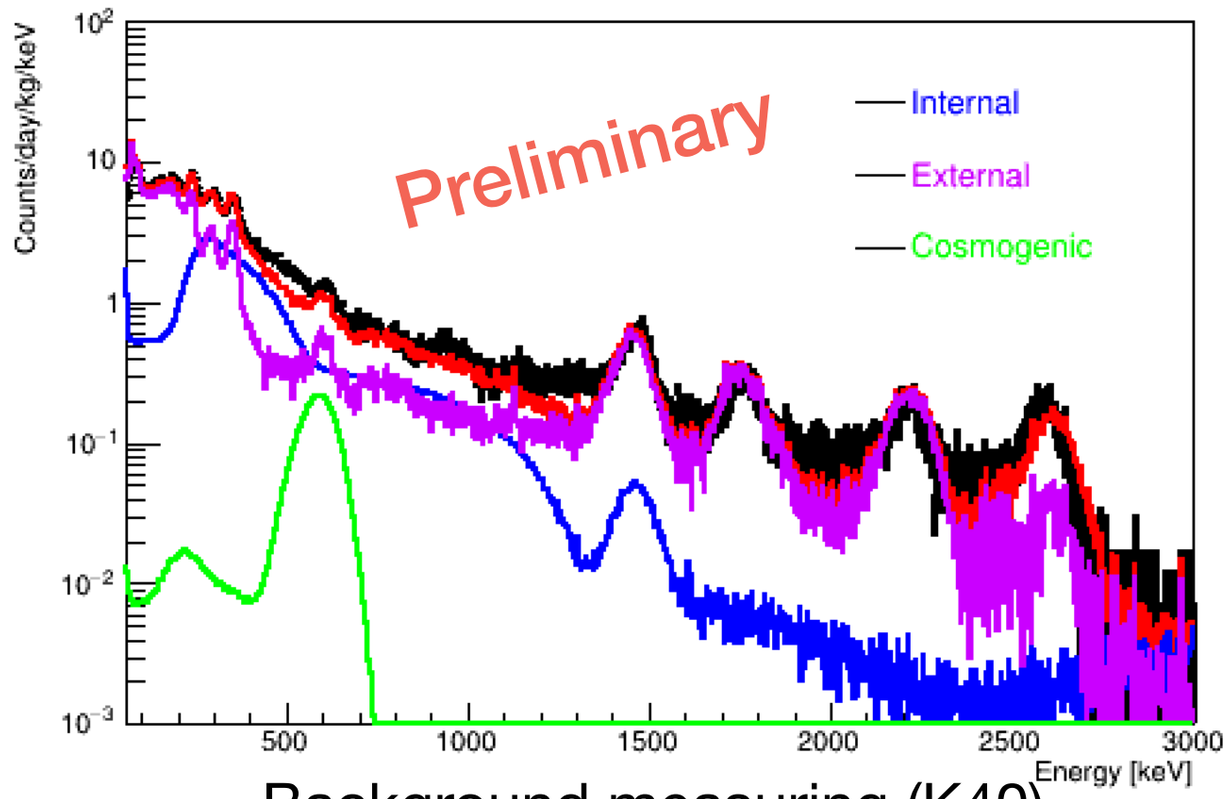

Reactor ON
Reactor OFF
Bad Runs
DOWN
16.7 days
(5.1%)
38.5 days
(11.9%)
126.2 days
(38.9%)
143.0 days
(44.1%)


Muon Dead Time (%)
Detector 1
Detector 2
Detector 3
Detector 4
Detector 5
Detector 6
May 2022
Jun 2022
Jul 2022
Aug 2022
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Feb 2023
Mar 2023
Date

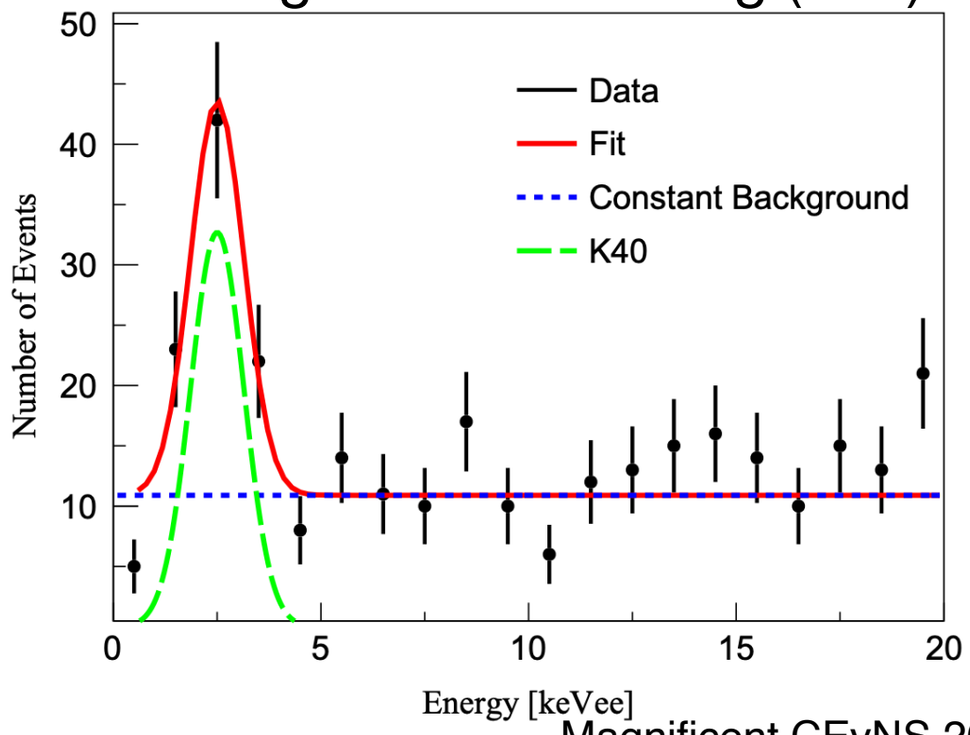
Background understanding

NEON Background measure and background modeling



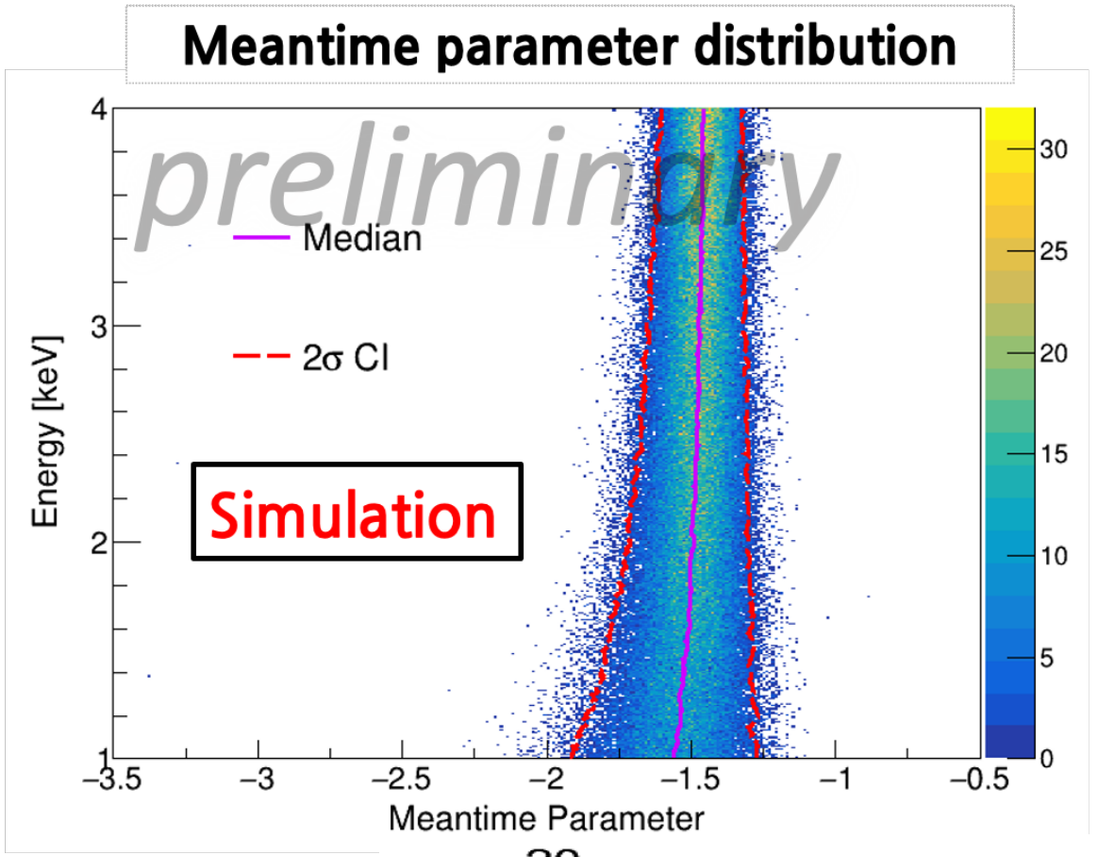


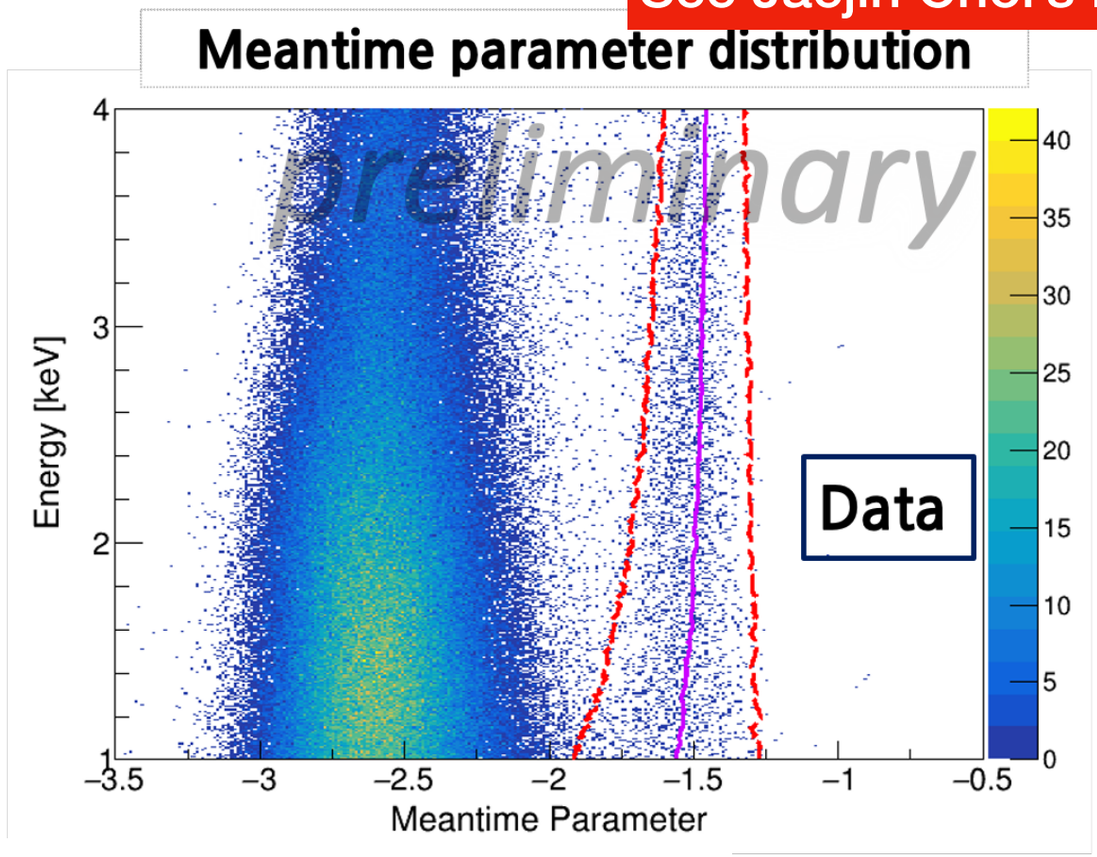
Background measuring (K40)

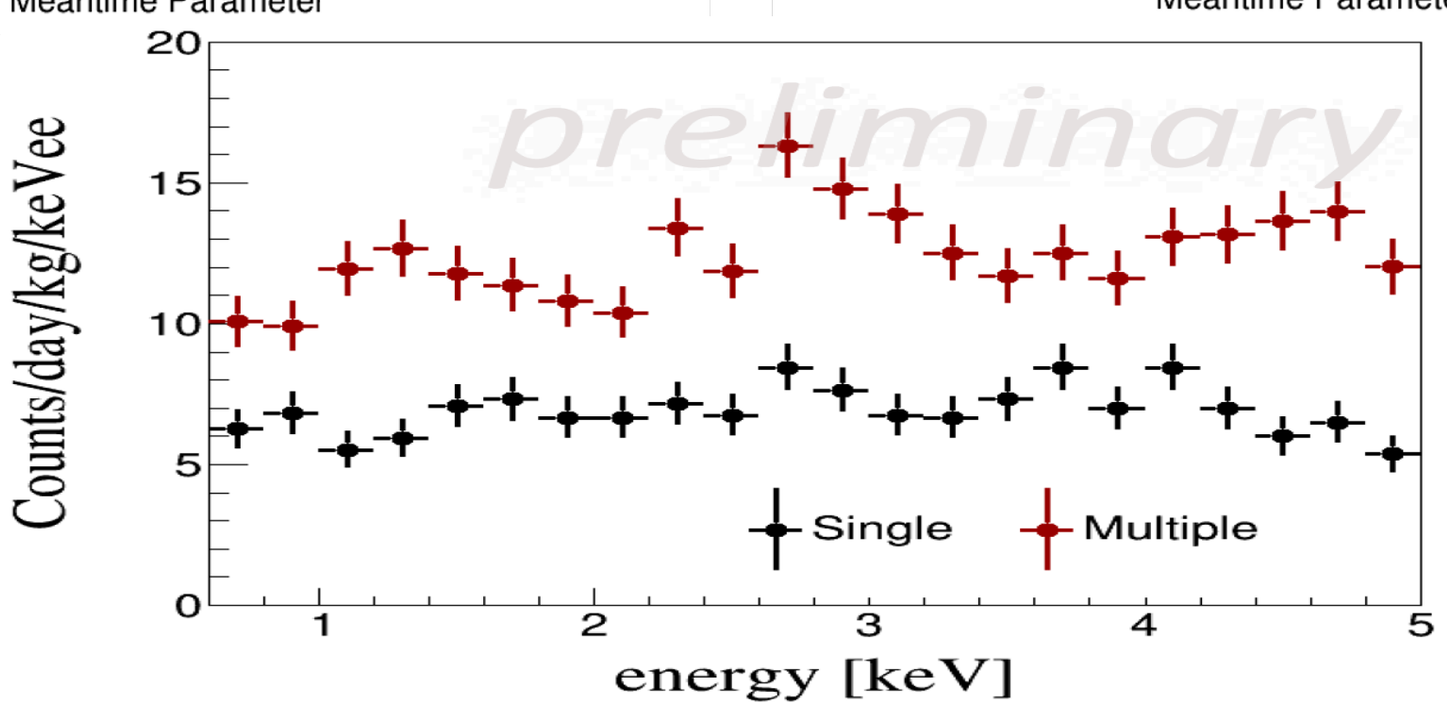


Events selection

See Jaejin Choi's Poster



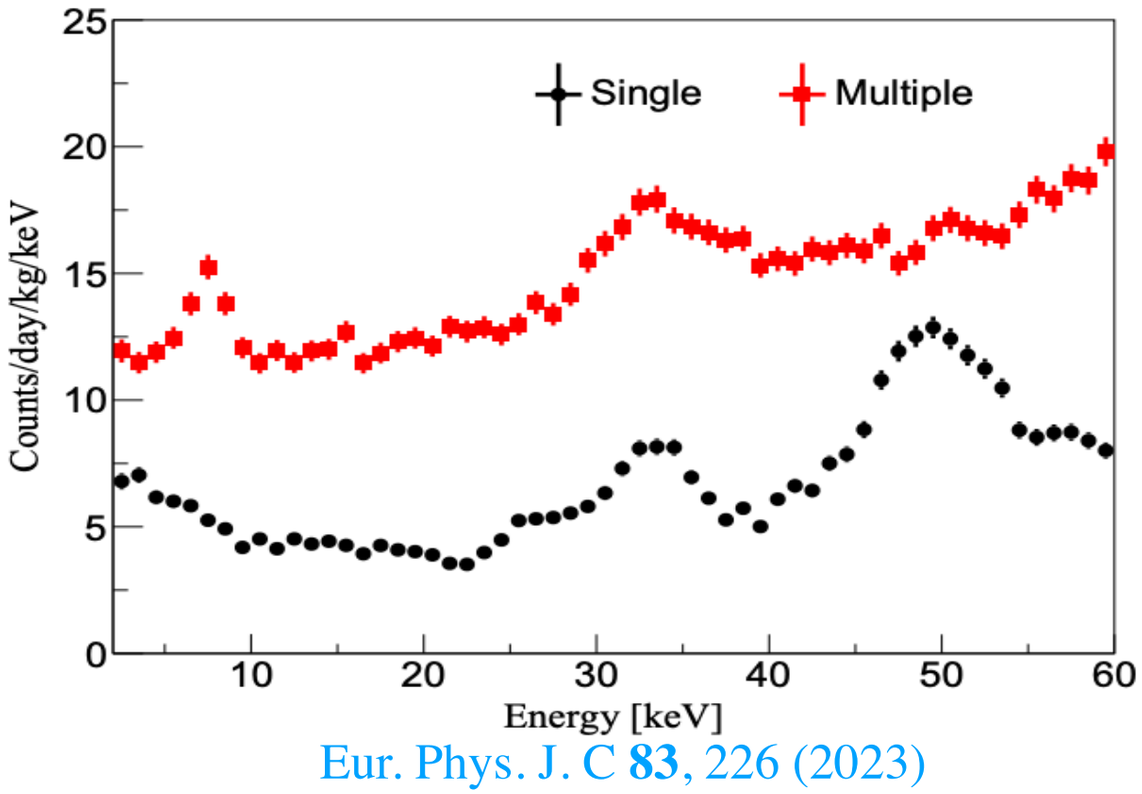




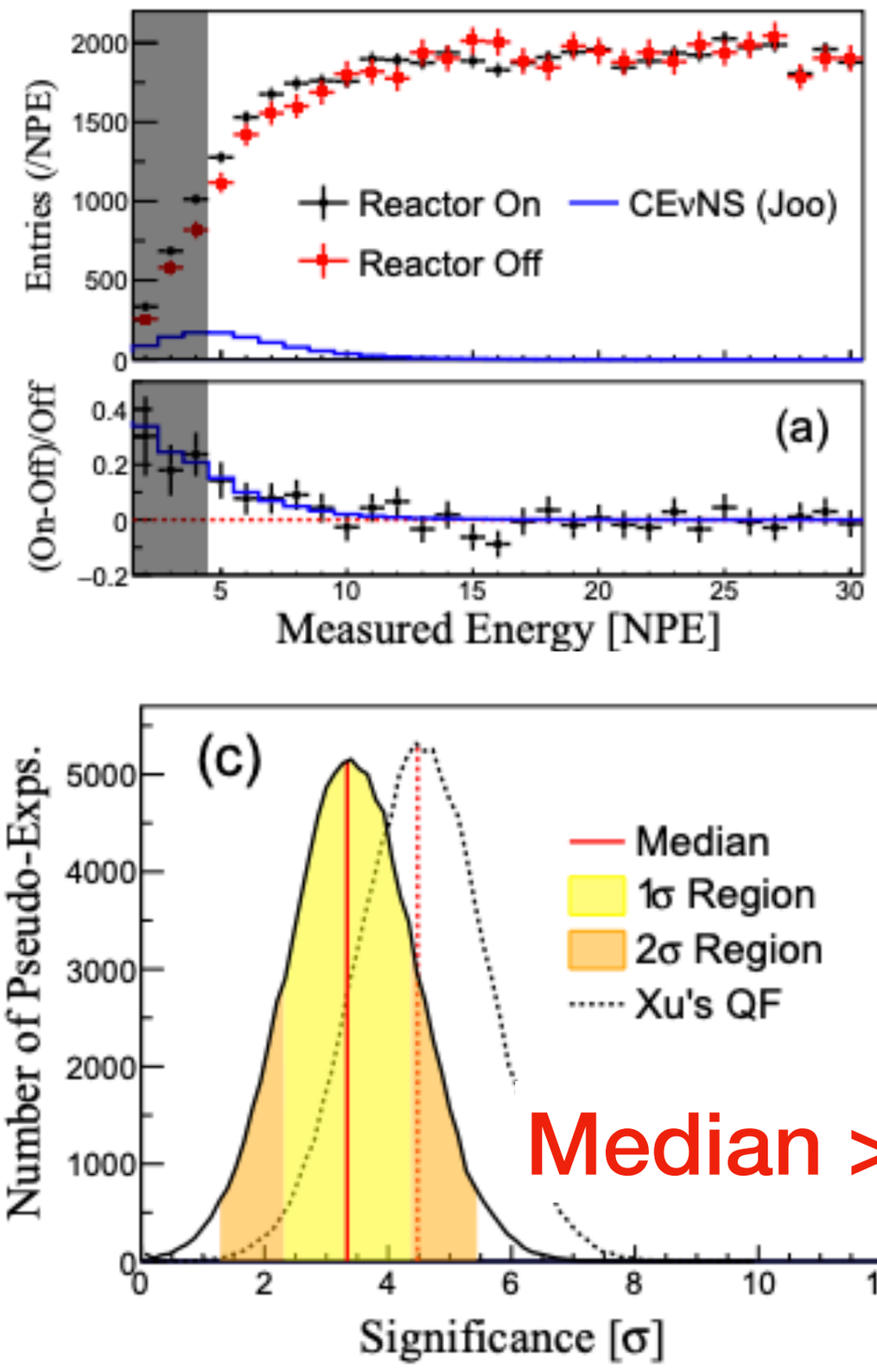
Now we are challenging 5NPE!!

~ 6 counts/kg/keV/day about 1 keV

Detector sensitivity based on engineering run



Eur. Phys. J. C **83**, 226 (2023)

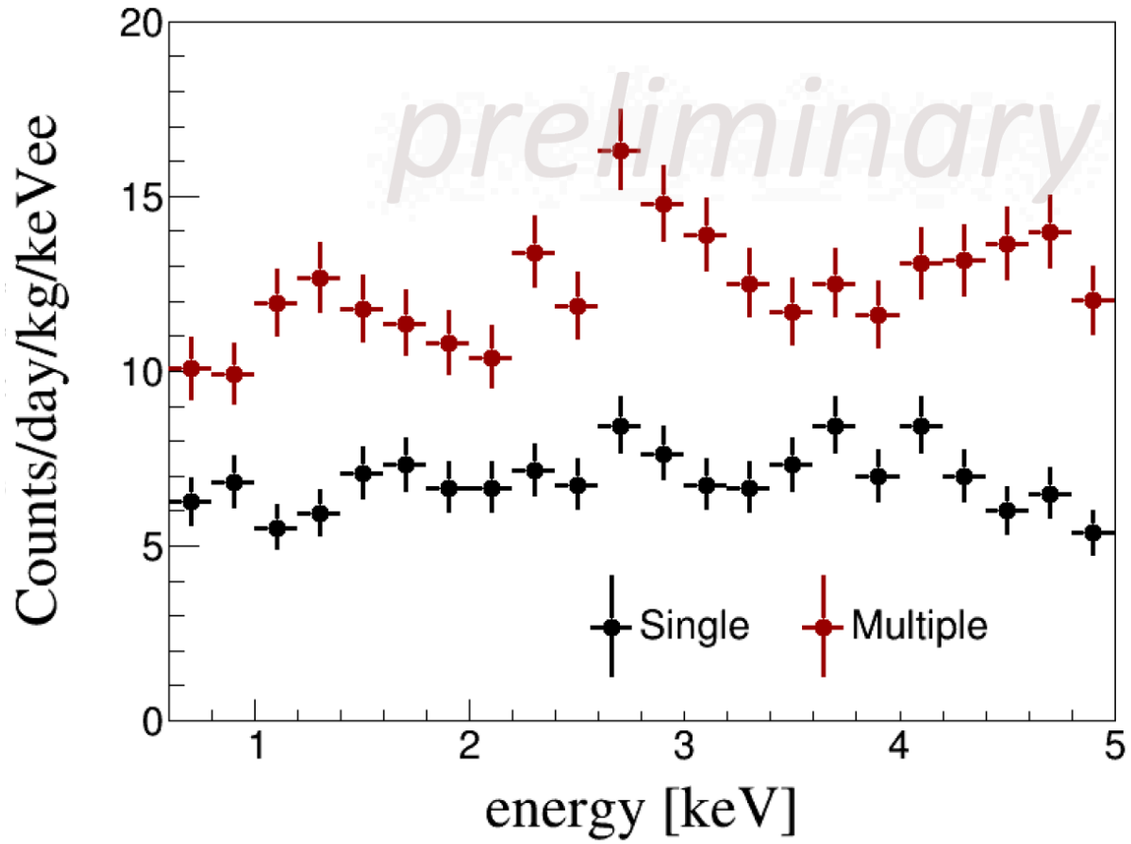


Detector performance :

- **7 counts/day/kg/keV (DRU) flat bkg**
- **22 NPEs/keV light yield**
- **0.2 keV threshold (5 NPE)**
- **13.5 kg detector mass**
- **1 year reactor on data**
- **100 days reactor off data**

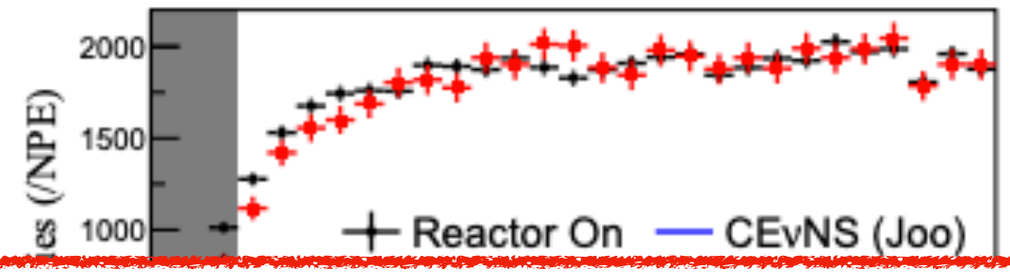
Median > 3σ

Detector sensitivity based on engineering run



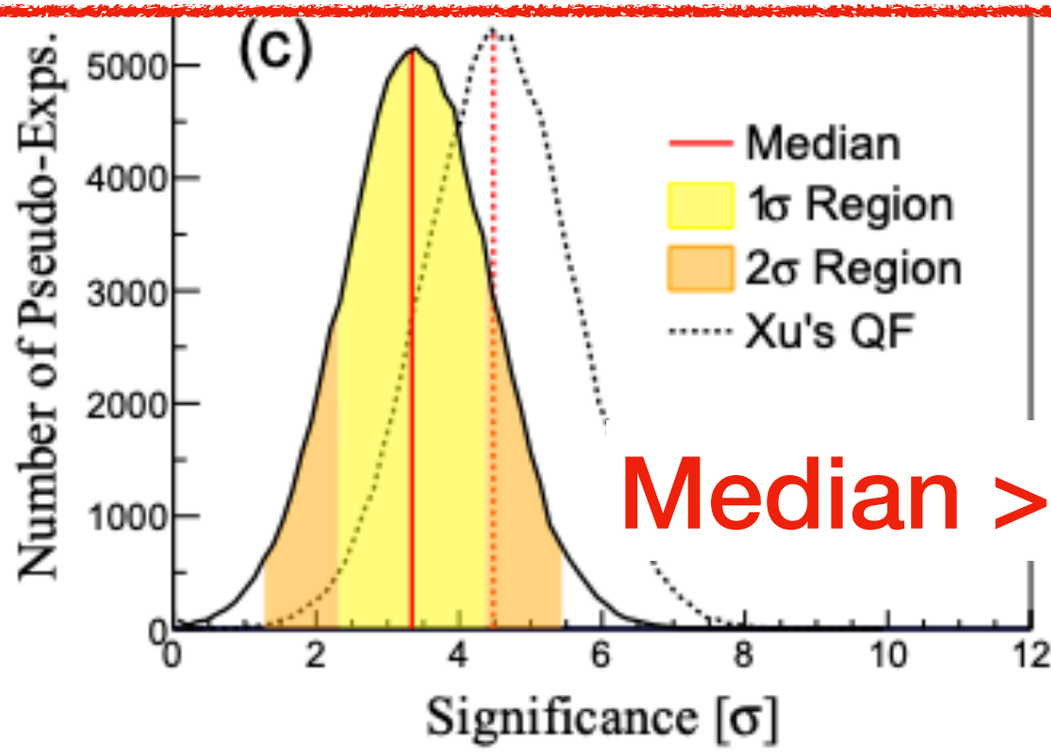
Assumed detector performance :

- ~~7 counts/day/kg/keV (DRU) flat bkg~~
- ~~22 NPEs/keV light yield~~
- 0.2 keV threshold (5 NPE)
- ~~13.5 kg detector mass~~
- 1 year reactor on data
- ~~100 days reactor off data~~



Detector performance :

- 6 counts/day/kg/keV (DRU) flat bkg
- 24 NPEs/keV light yield
- 0.2 keV threshold (5 NPE) <- On going!!
- 16.7 kg detector mass
- 1 year reactor on data <- Just wait!!
- 140 days reactor off data



Conclusion

- NEON is an experiment to observe CEvNS from reactor antineutrino with NaI(Tl) crystals.

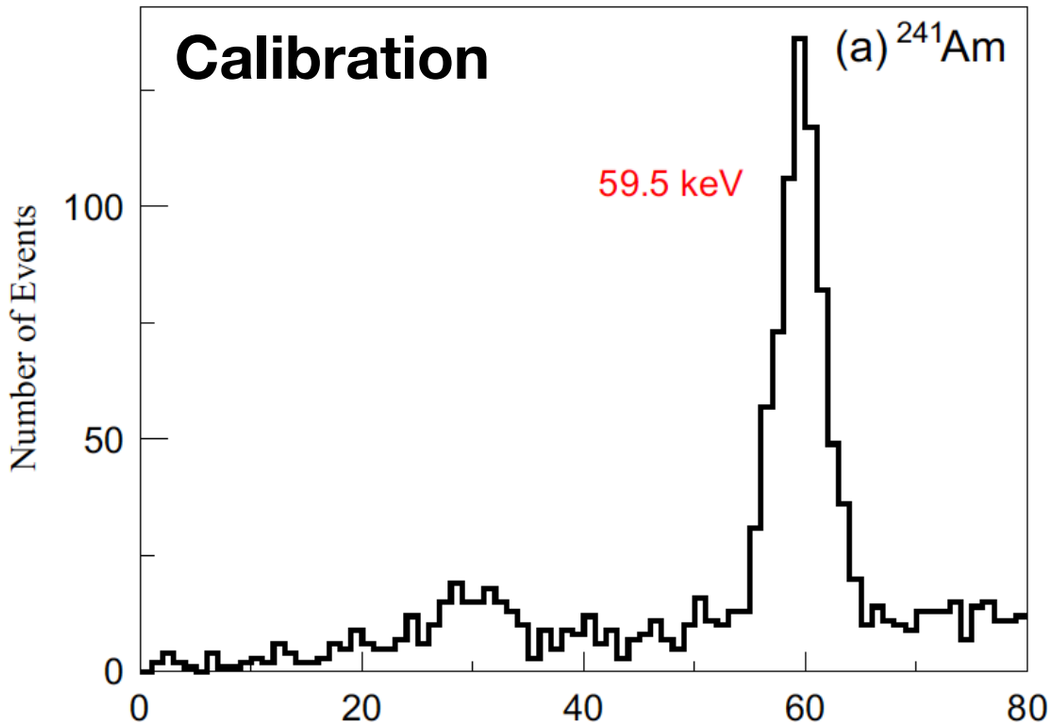
- NEON started physics operation from April 2022 at Hanbit nuclear reactor, South Korea.

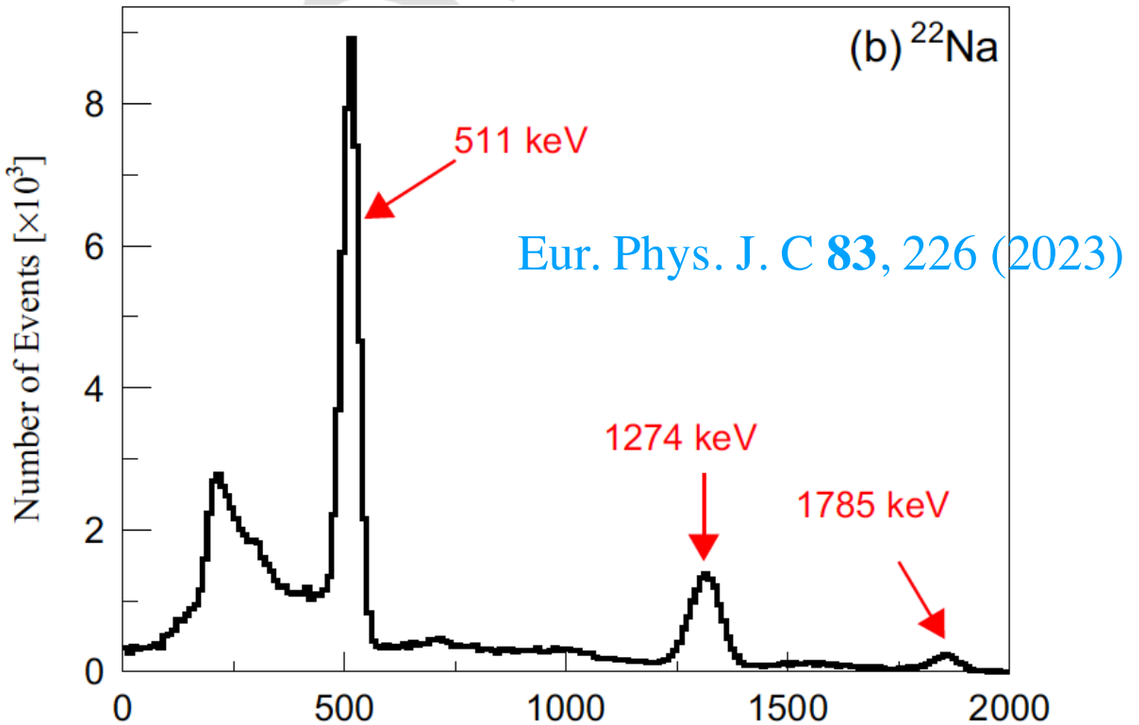
- We are working on low-threshold analysis and improving our understanding of detector background.

Stay tune!!

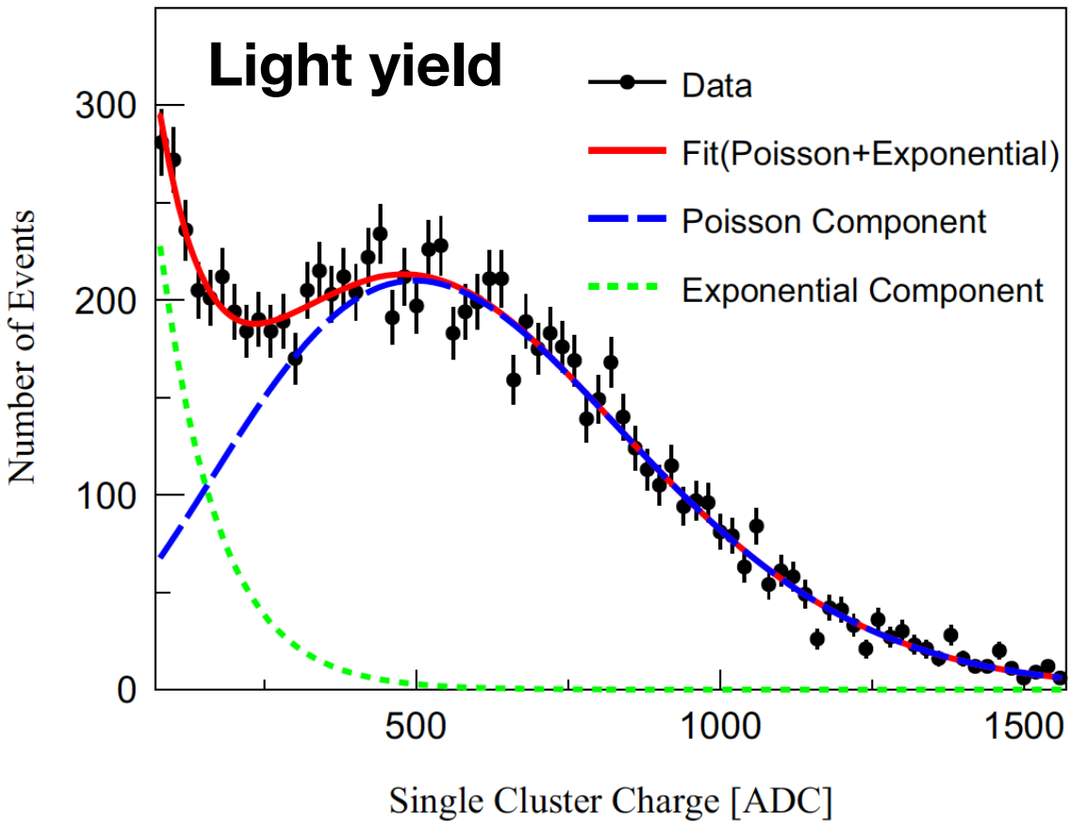
Thank you !

NEON engineering run



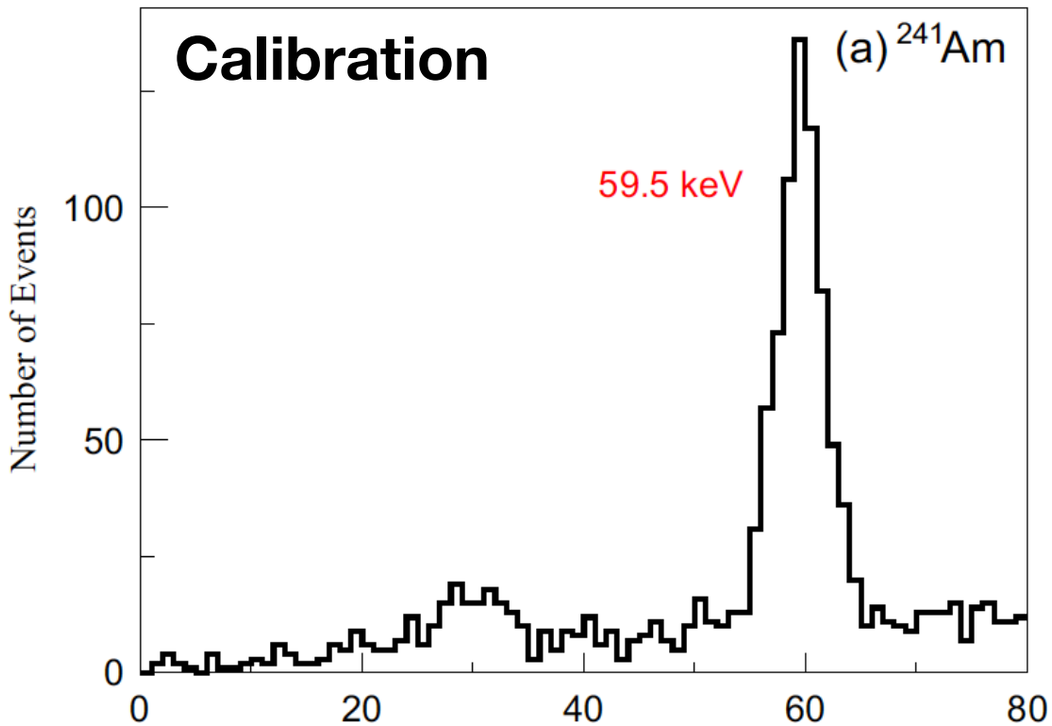


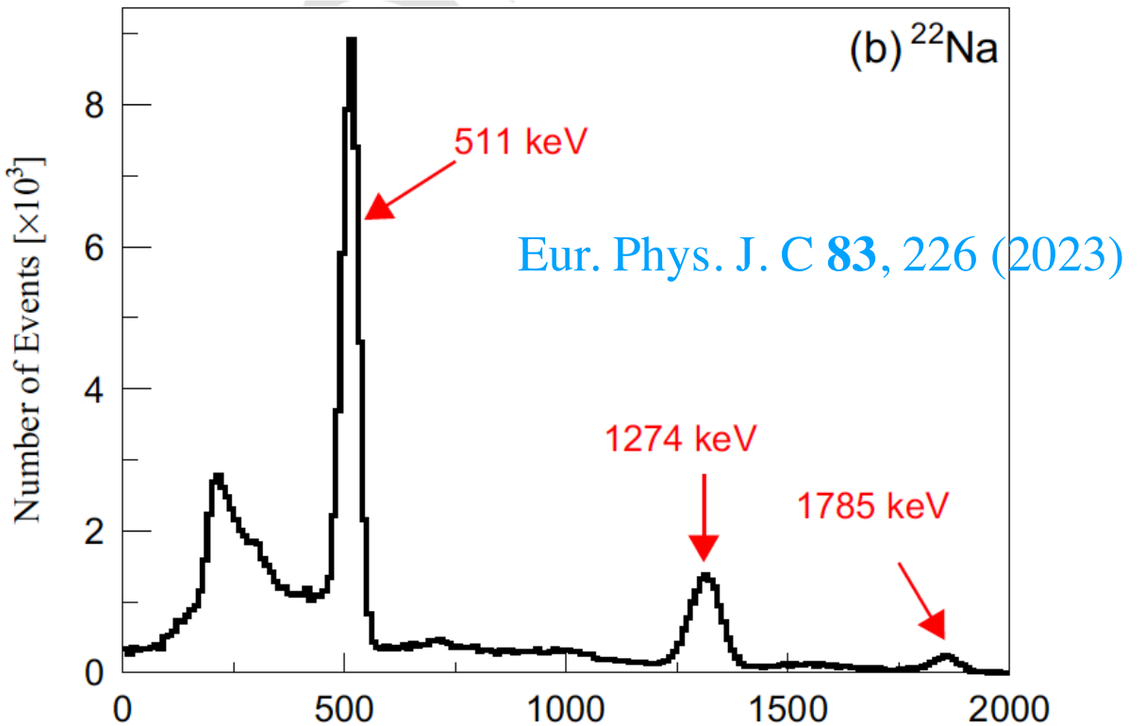
Eur. Phys. J. C **83**, 226 (2023)



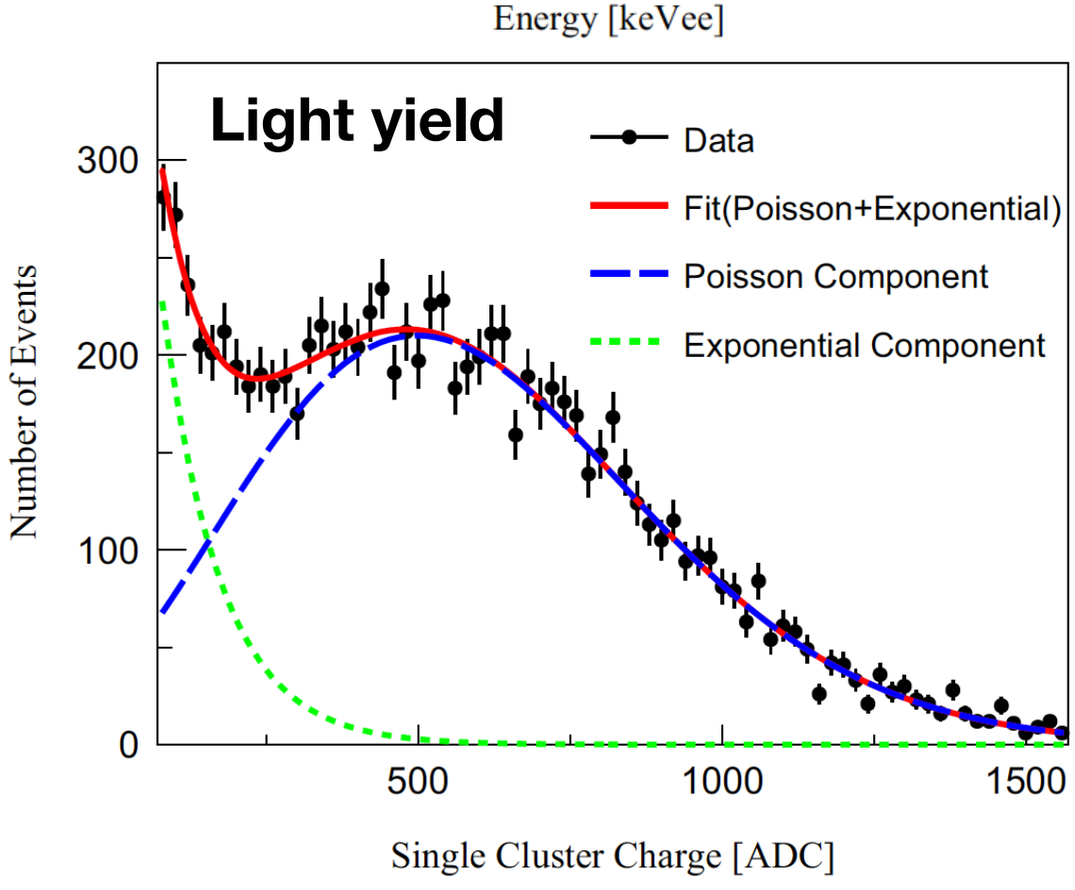
~ 22 NPE/keV Light yield

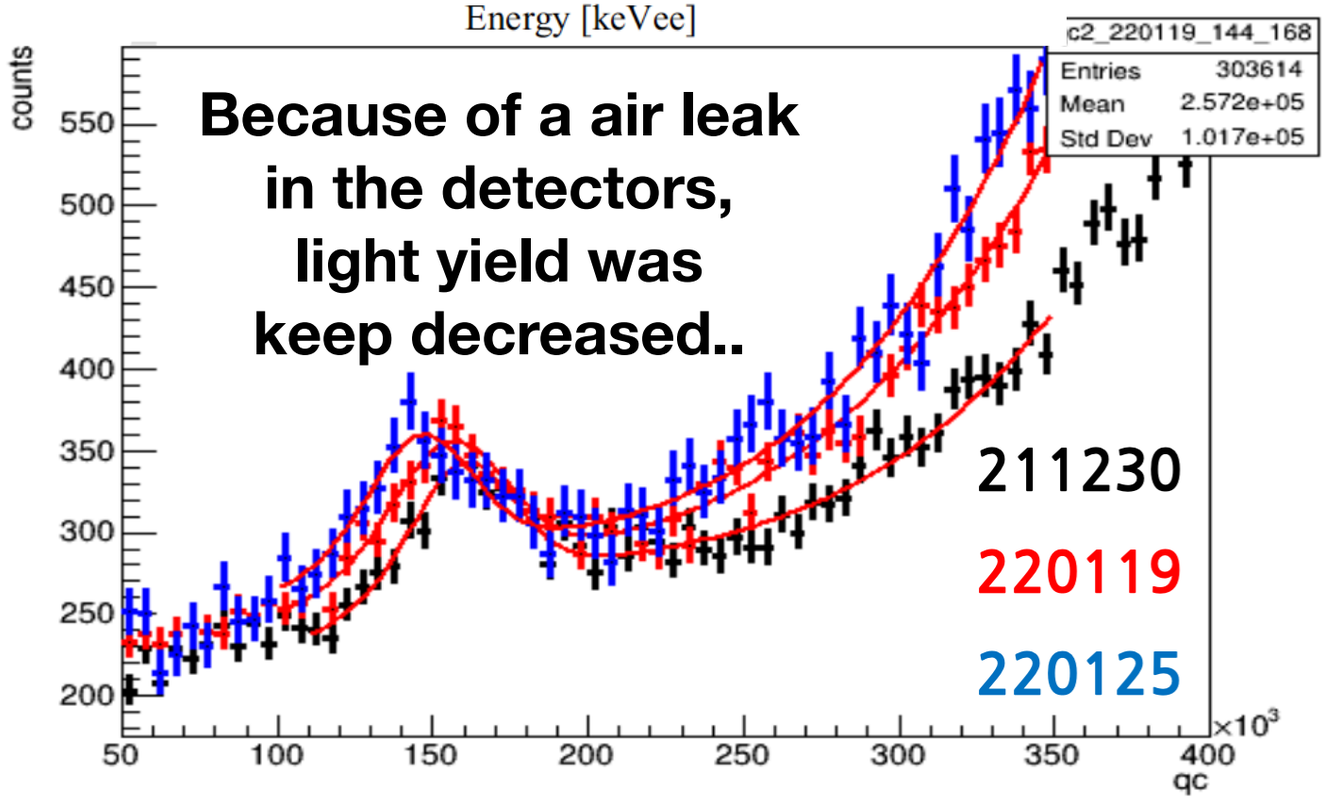
NEON engineering run



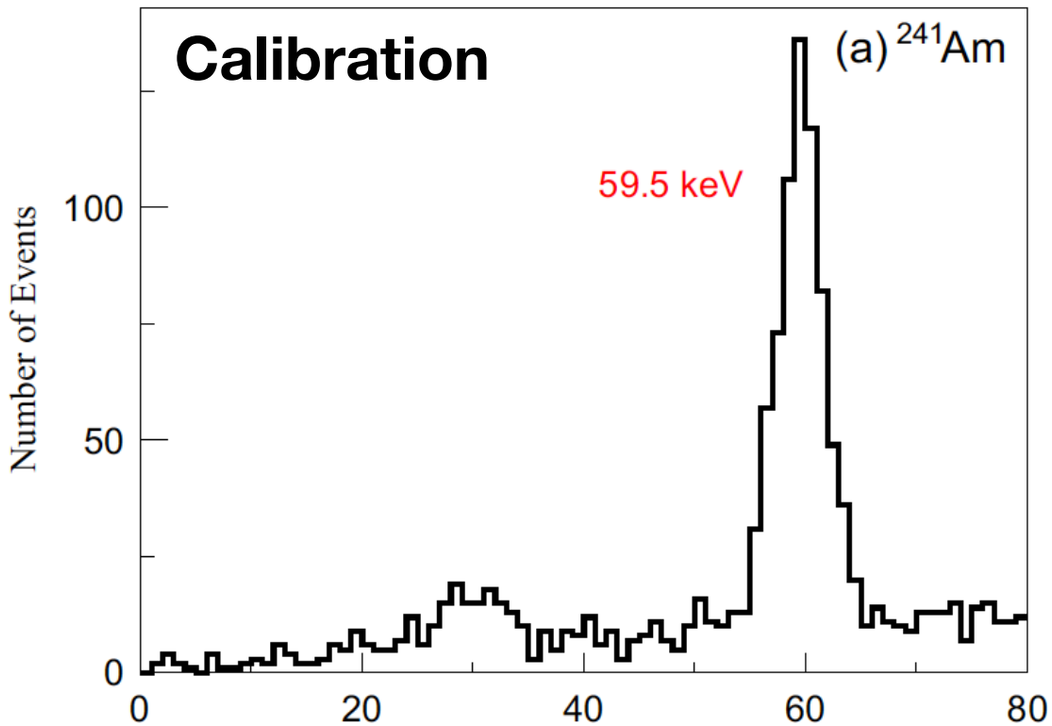


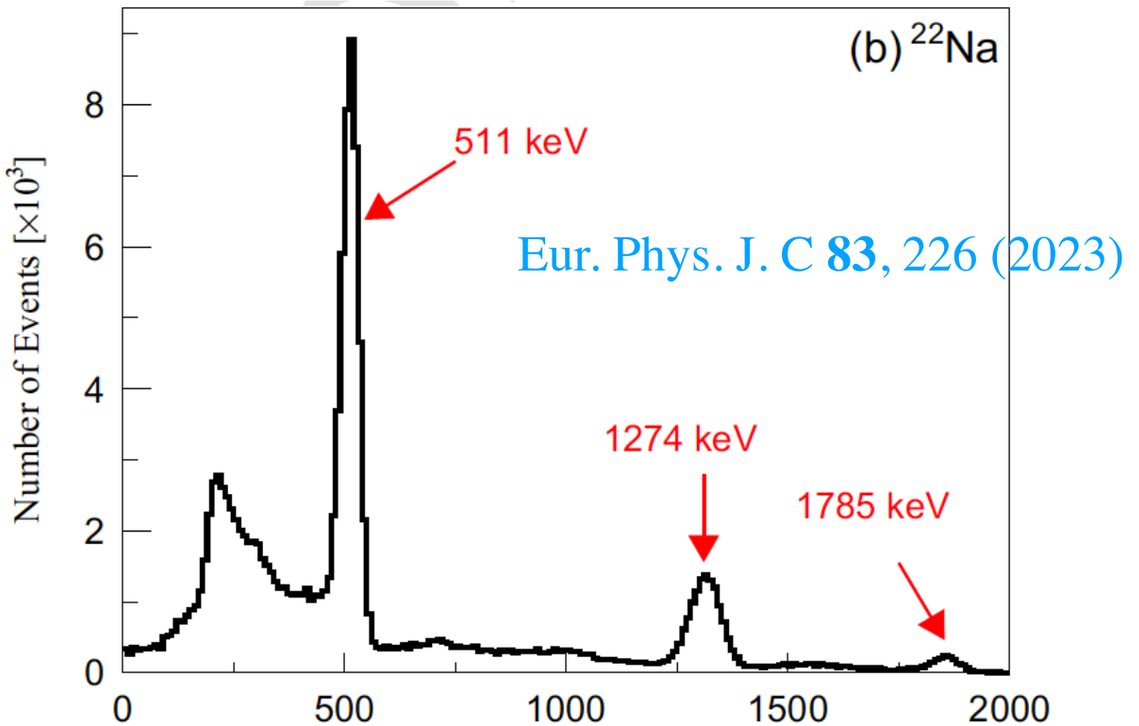
Eur. Phys. J. C **83**, 226 (2023)



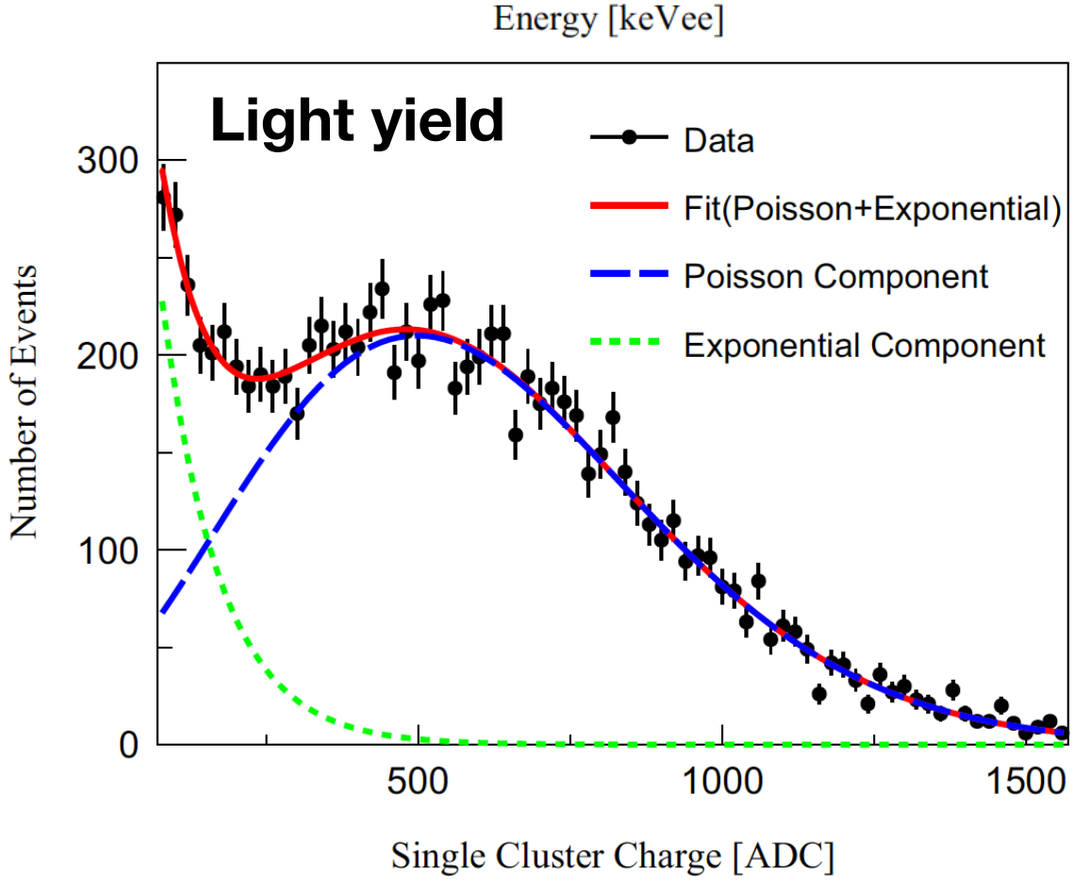


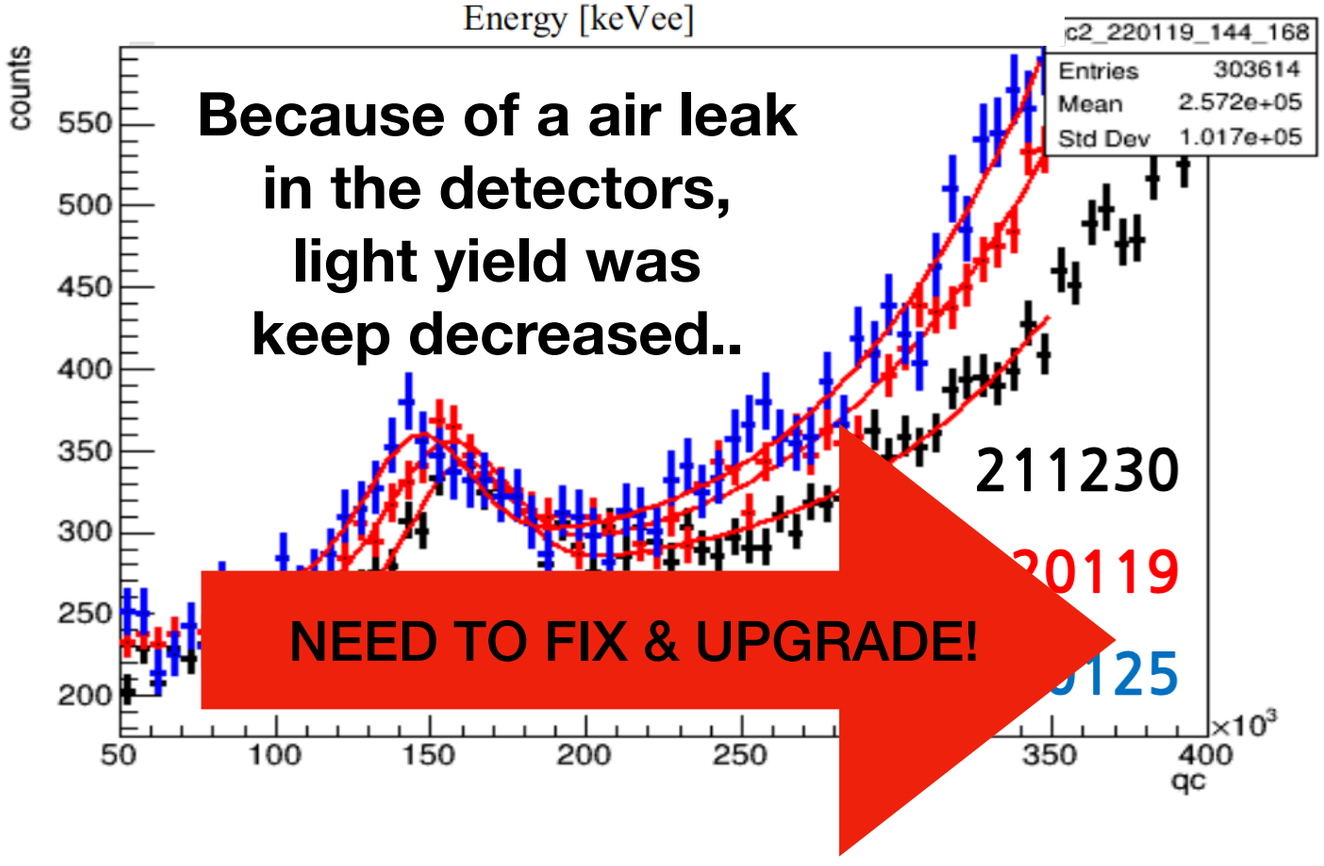
NEON engineering run





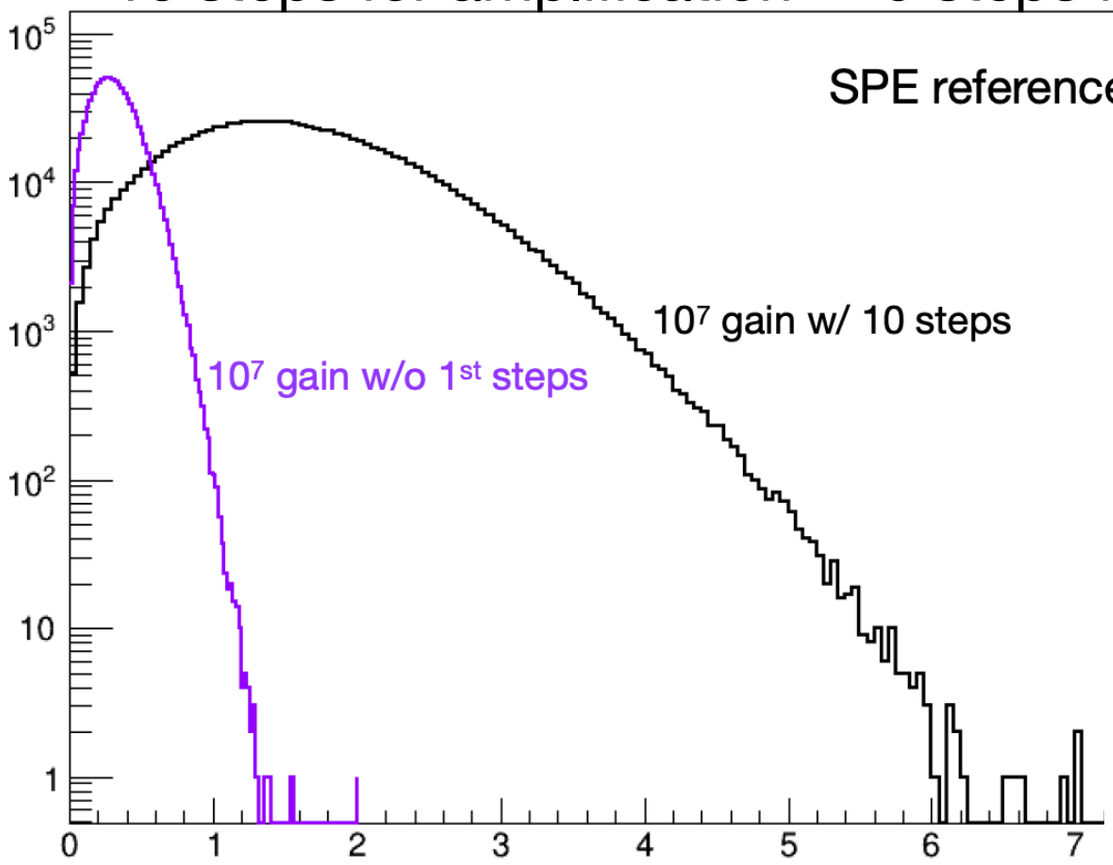
Eur. Phys. J. C **83**, 226 (2023)

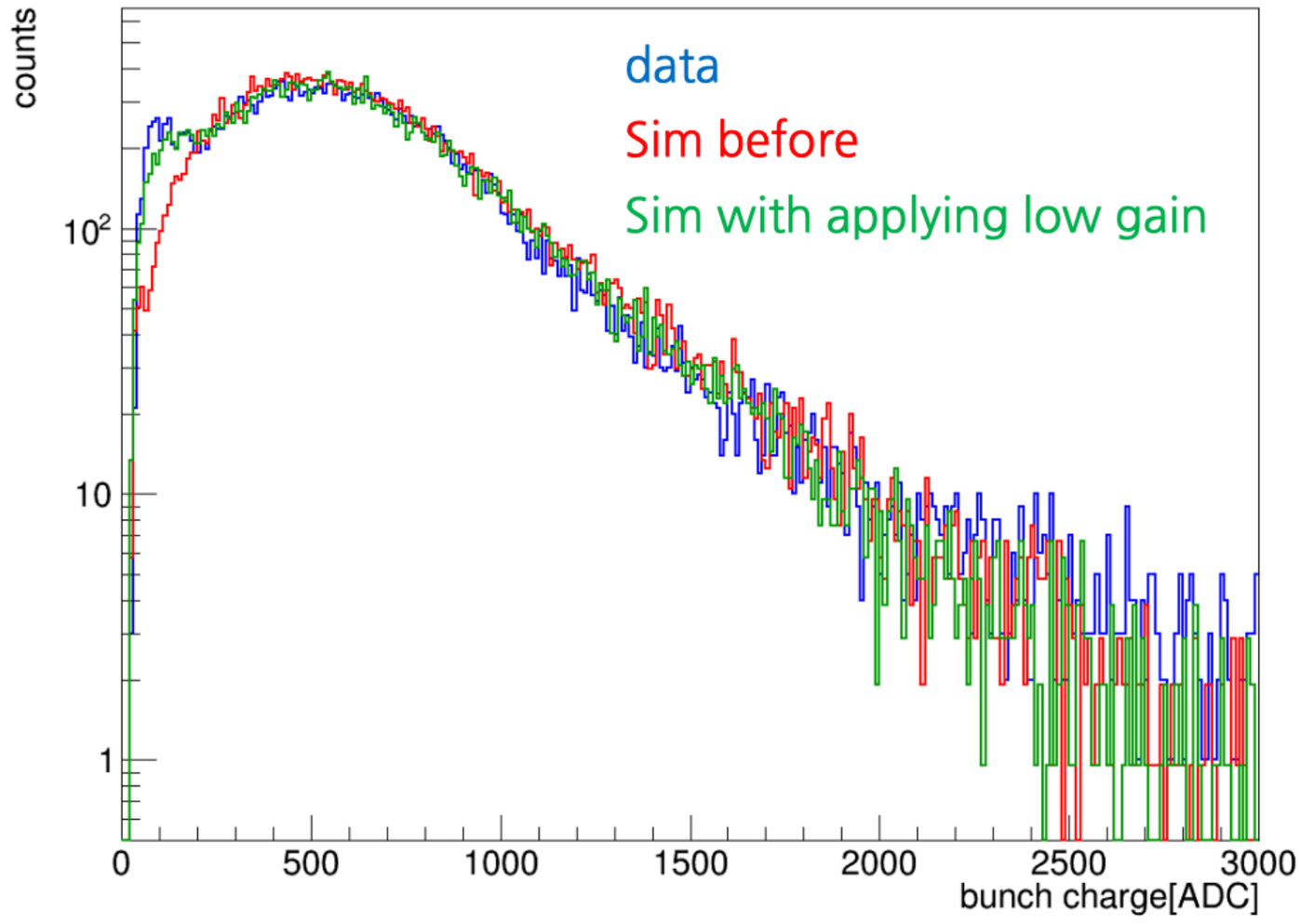




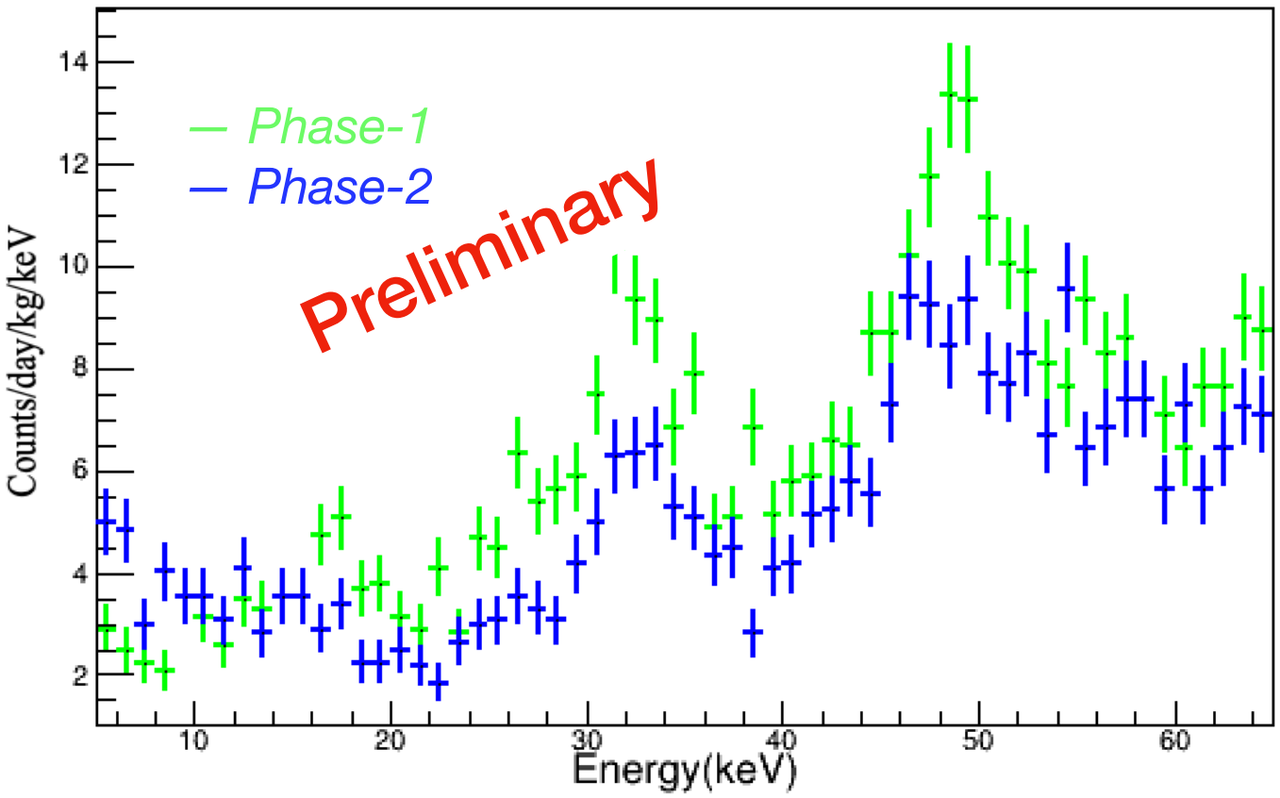
low gain studies

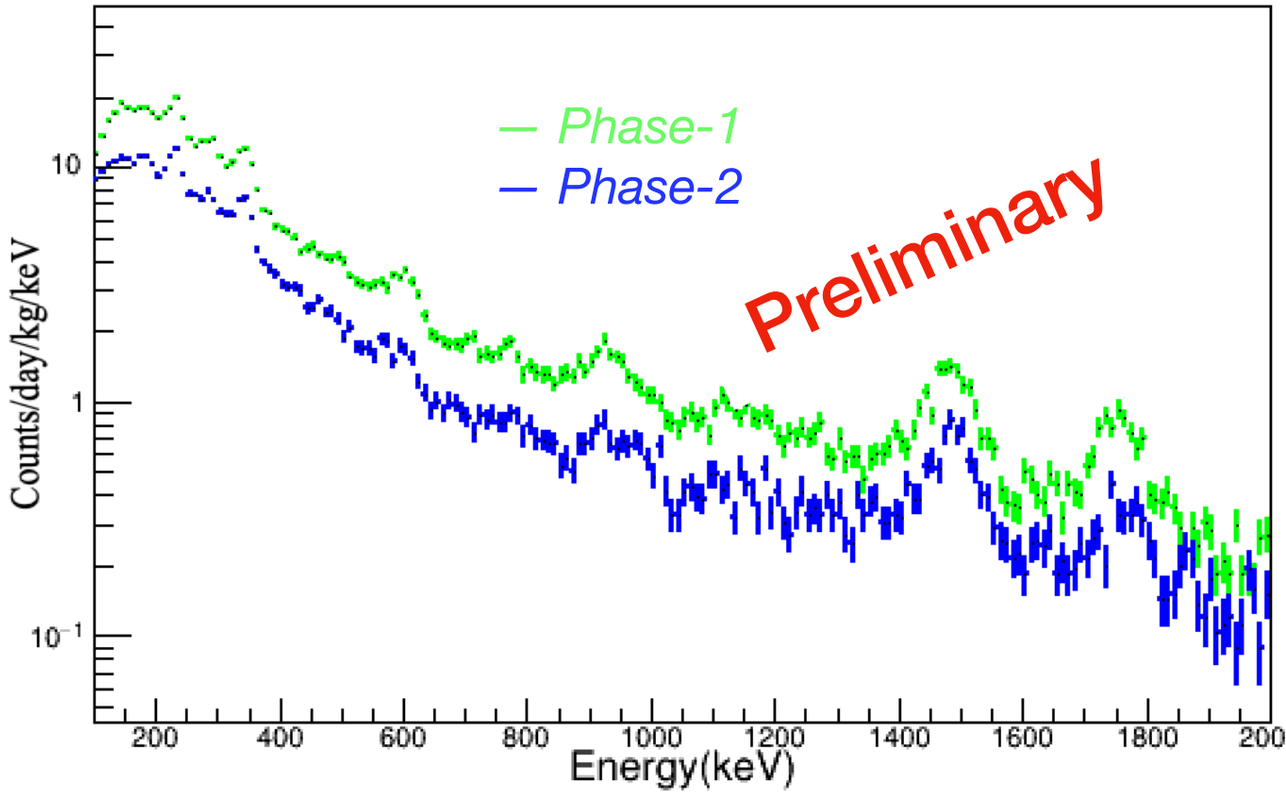
10 steps for amplification → 9 steps for **low gain**





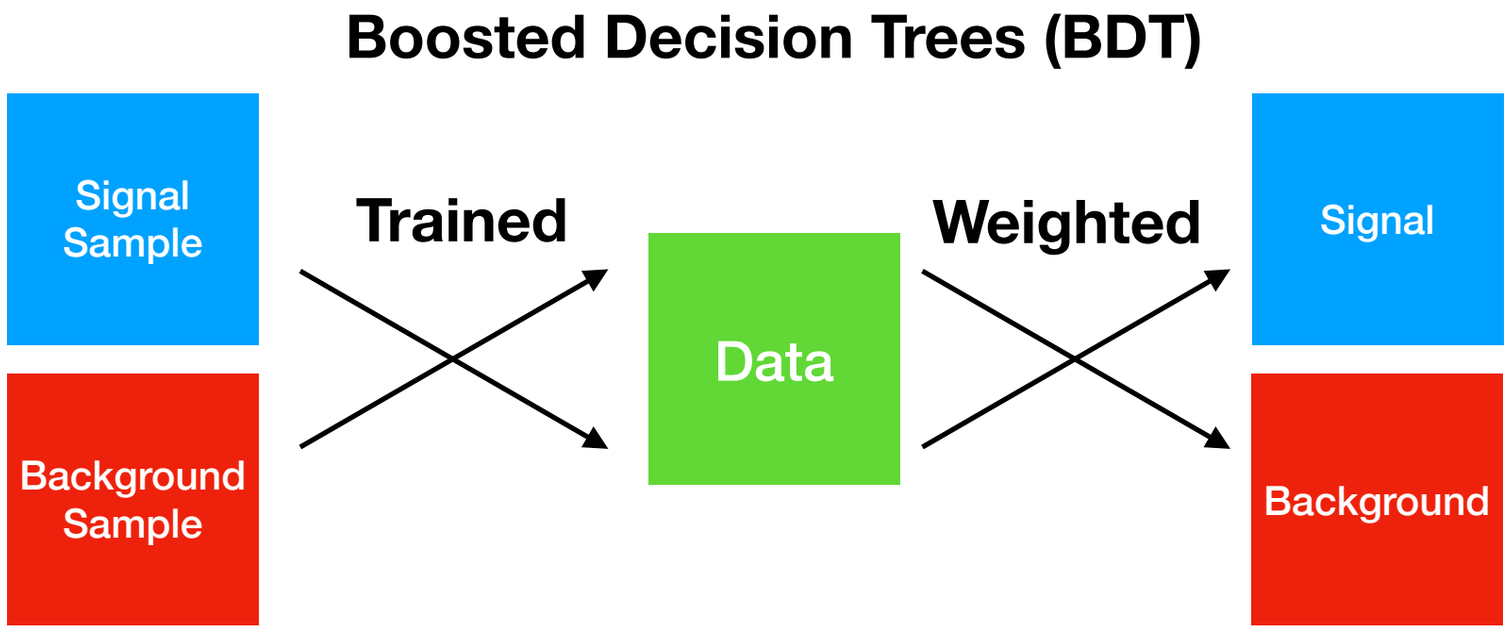
NEON Energy spectra





Reduced background after upgrade

NEON Events selection



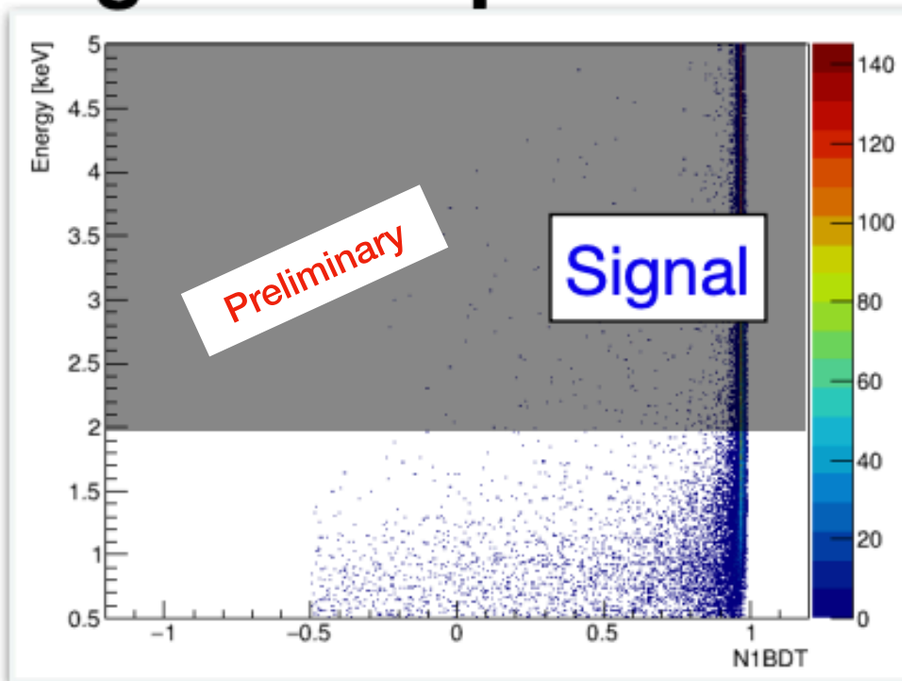
In Boosted Decision Trees, the selection is done on a majority vote on the result of several decision trees, which are all derived from the same training sample by supplying different event weights during the training.

COSINE-100 Events selection

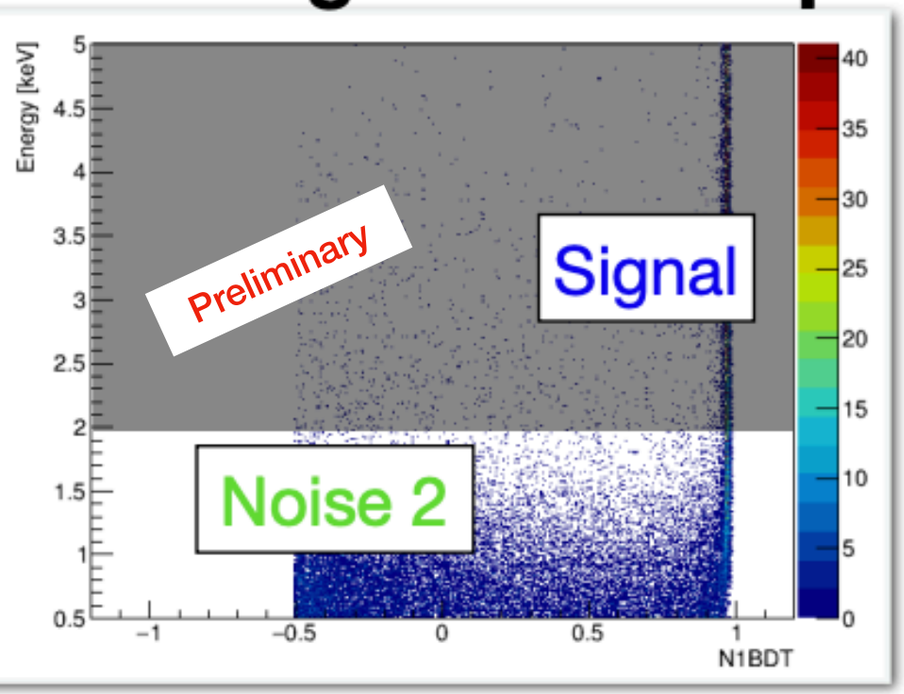
NPE 7.5 threshold

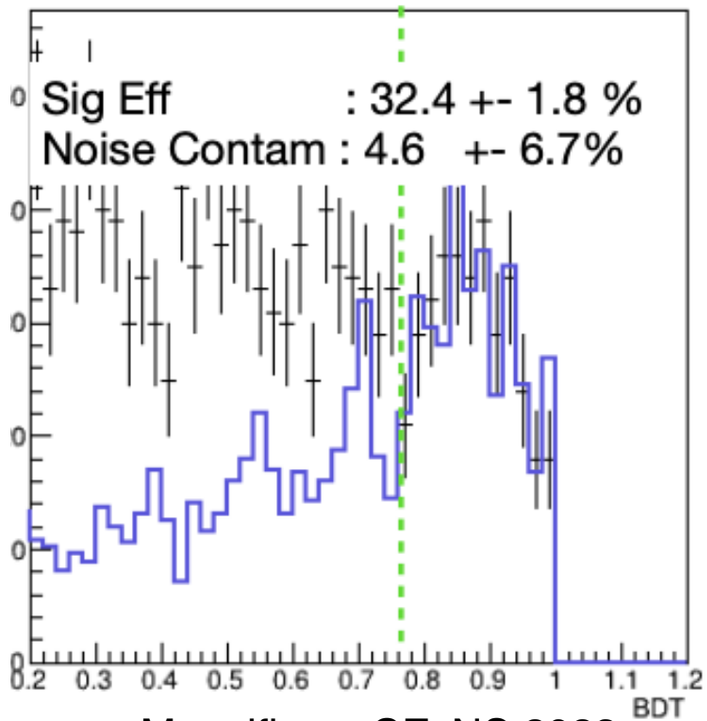
NPE 7.50 ~ 11.25

Signal Sample



Background Sample





NEON Detector Sensitivity