NeON

Neutrino Elastic-scattering Observation with NaI

Exploring coherent neutrino-nucleus scattering

CENTER FOR UNDERGROUND PHYSICS ibs

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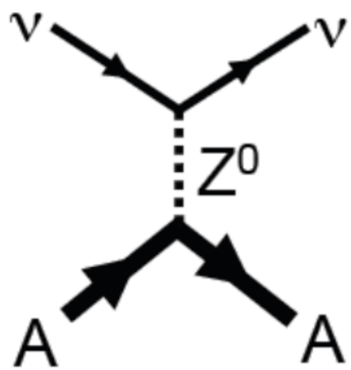
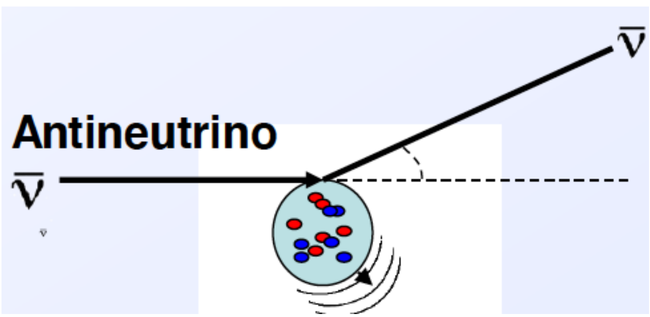
CEνNS

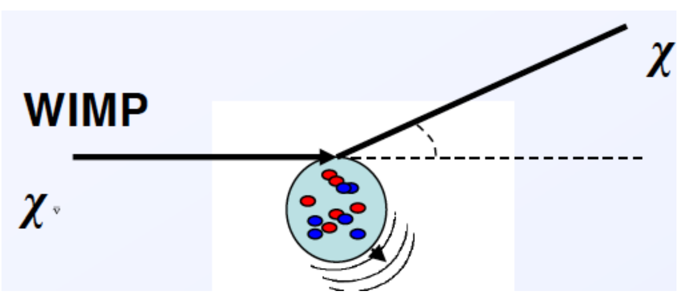


- CEνNS is a neutrino scatter off a nucleus where all target nucleons recoil in phase
- Coherence enhances the cross section depending on number of neutron

$$\sigma \approx \frac{G_F^2 N^2}{4\pi} E_\nu^2$$

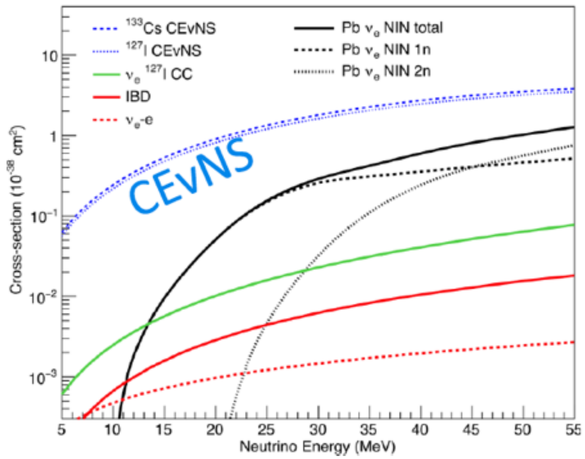
- Similar process as WIMP dark matter interaction
  - Irreducible background from solar neutrino for WIMP search
  - Calibrate WIMP dark matter detector with neutrino

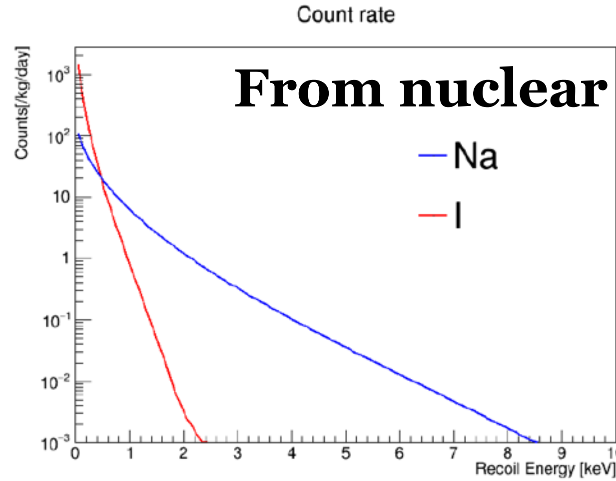




CEνNS

- **Cross section** is **large**, but tiny recoil energy

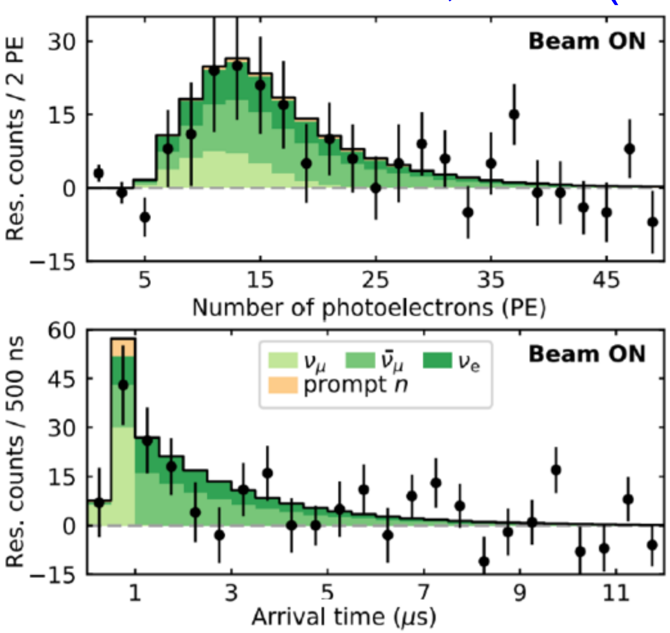




From nuclear reactor

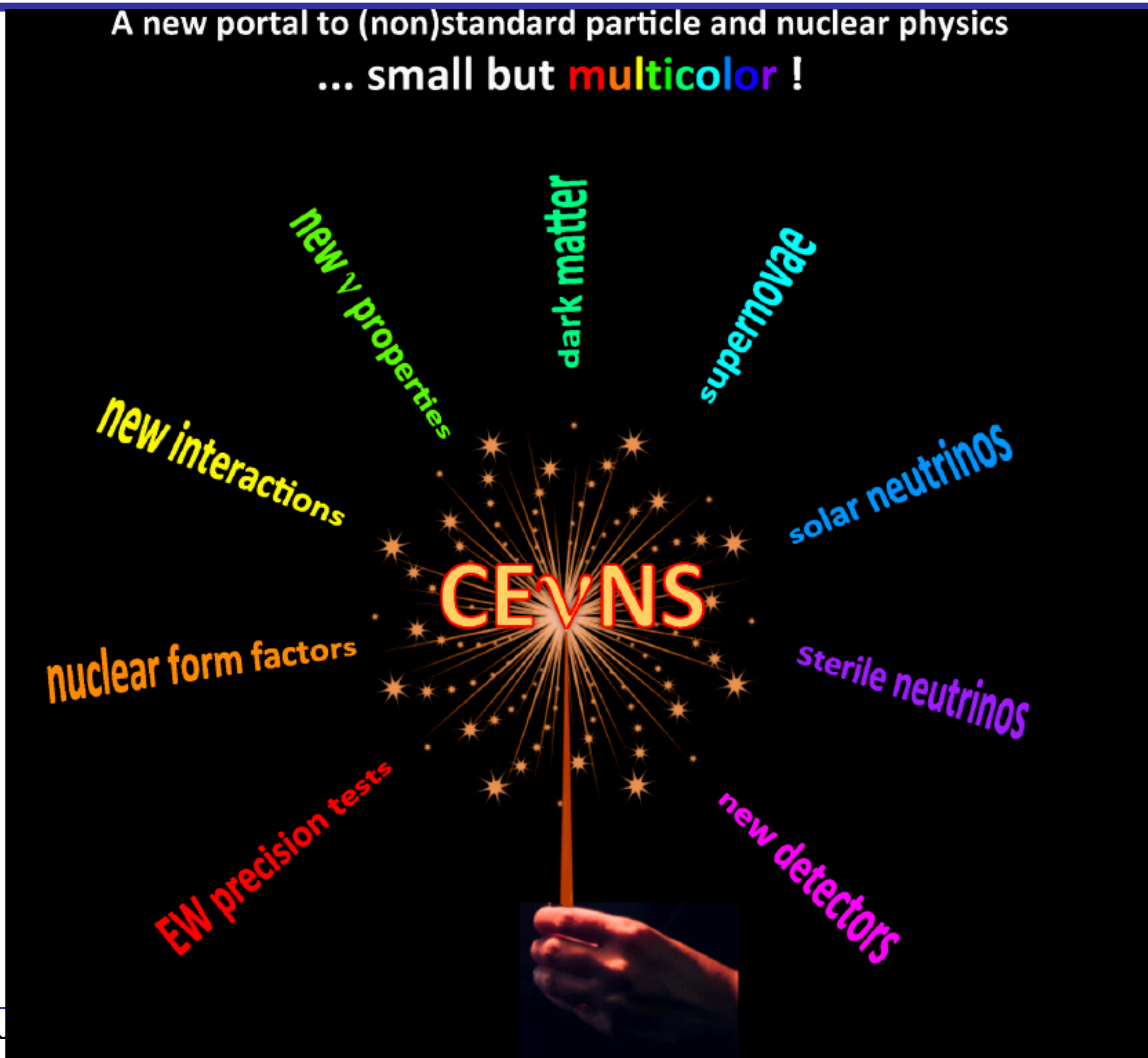
Science **357**, 1123 (2017)

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



- CEνNS was observed by COHERENT at 2017
  - CsI(Na) : 14.6 kg
  - Light yield ~ 13 photoelectrons/keV$_{ER}$
    - ~1.17 photoelectrons/keV$_{NR}$
  - ν_μ, $\bar{\nu}_\mu$, ν_e from spallation neutron source

Physics potential for CEνNS

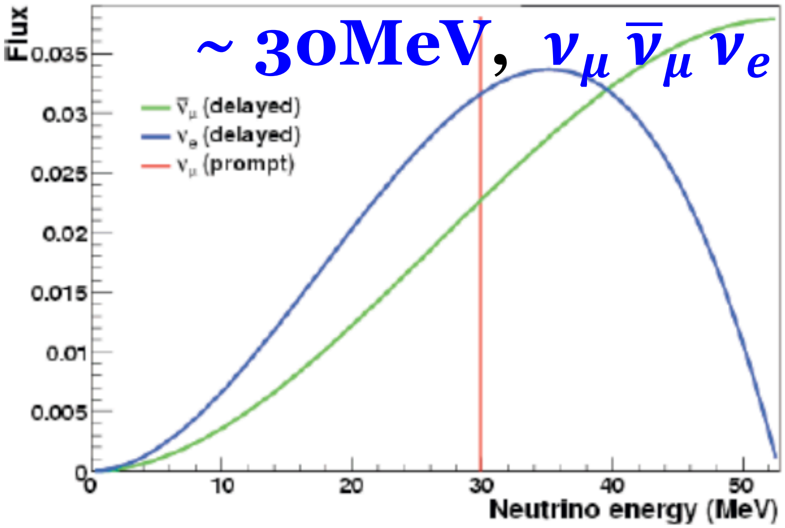


From E. Lisi

Neutrino 2018

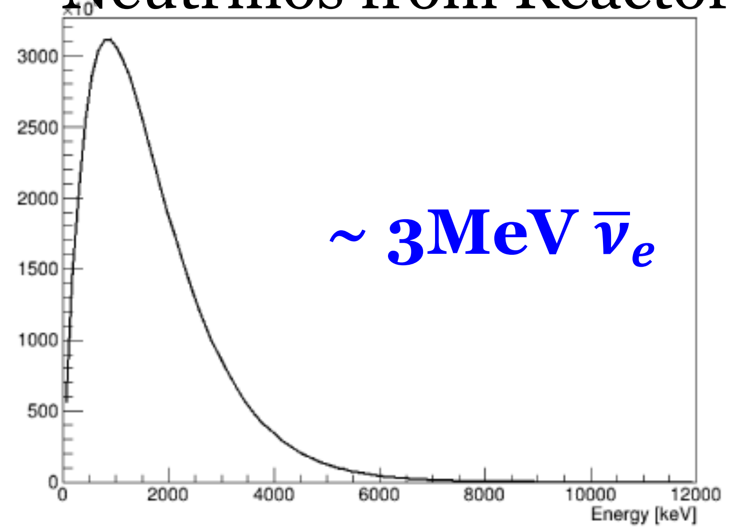
Reactor neutrinos for CEνNS

Neutrinos from SNS



Few times 10^7/s/cm² at 20 m

Neutrinos from Reactor



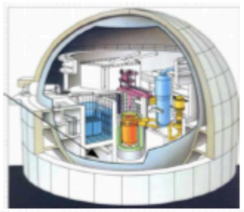
about 10^{13}/s/cm² at 25 m

- Much large neutrino flux
- Much lower energy deposition
- If we have a proper detector…
  - ❖ Precision measurement for neutrino properties
  - ❖ Reactor monitoring & nuclear non-proliferation

Reactor neutrinos for CEνNS

- Advanced detector technologies for low-threshold measurement

- CONUS(HPGe)
  - First hint from reactor neutrinos



Rate comparison (all detectors):

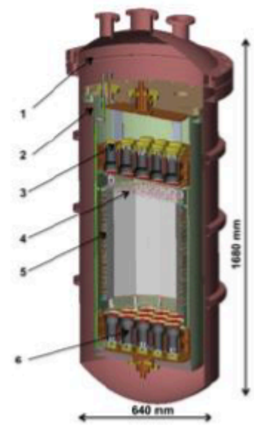
	counts	counts/(d·kg) (*)
reactor OFF (114 kg*d)	582	
reactor ON (112 kg*d)	653	
ON-OFF (exposure corr.)	84	0.94
Significance	2.4 σ	2.3 σ

Some systematics still under study

(*) Including stat. uncertainty and above efficiencies

W. Maneschg, Nu2018

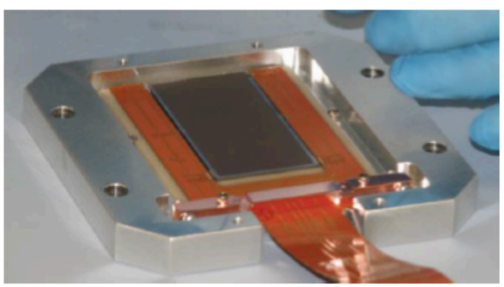
- RED-100(LXe)



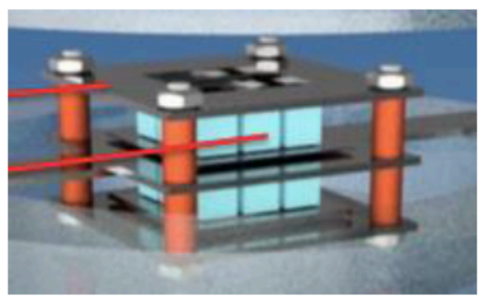
- MINER(Ge)

- vGeN(HPGe)

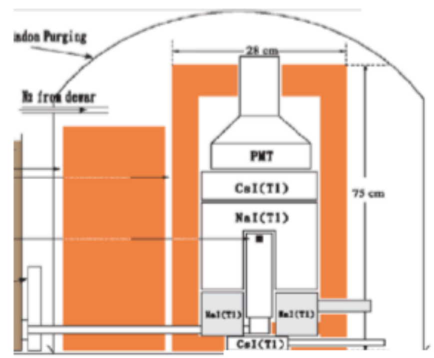
- CONNIE(Si CCD)



- Nu-cleus($CaWO_4$+Al_2O_3)



- TEXONO(PCGe)



arXiv:1608.00306

- Many groups do experiment on reactor neutrino-nucleus scattering

NEON Collaboration

~ 15 people who are all active members of COSINE-100 or NEOS

Aim to observe CEνNS from reactor $\bar{\nu}_e$ using NaI(Tl) detector

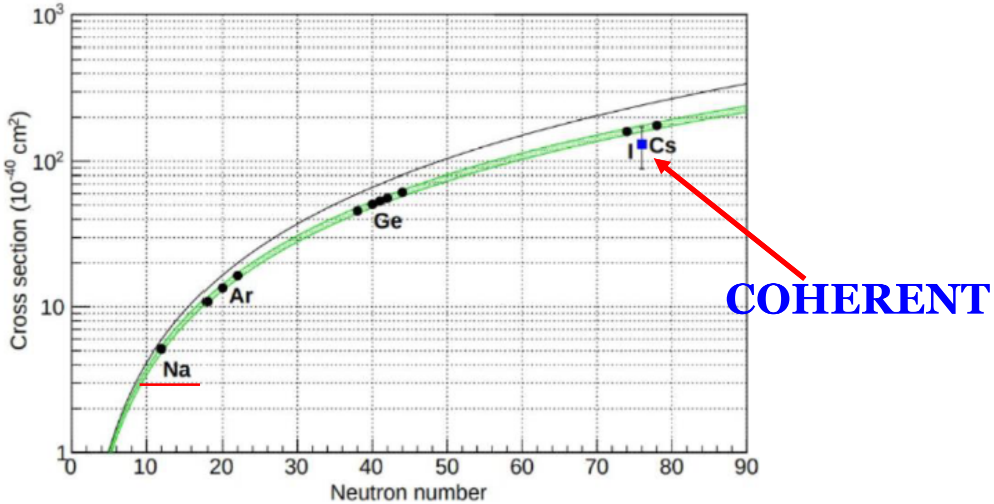
Can take an advantage of COSINE-100 and NEOS experiences

NaI(Tl) for CEνNS

- High measured light yield (15 NPE/keV in COSINE-100)
- Larger recoil energy from Na (N^2 dependence testable)
- Easy to make large size detector O(10 kg)
- Low background detector available (3 counts/kg/day/keV=3dru)
- Easy to scale up with affordable costs O(100 kg)

- Can we reach to low enough energy threshold? 0.2 keV_{ER}?

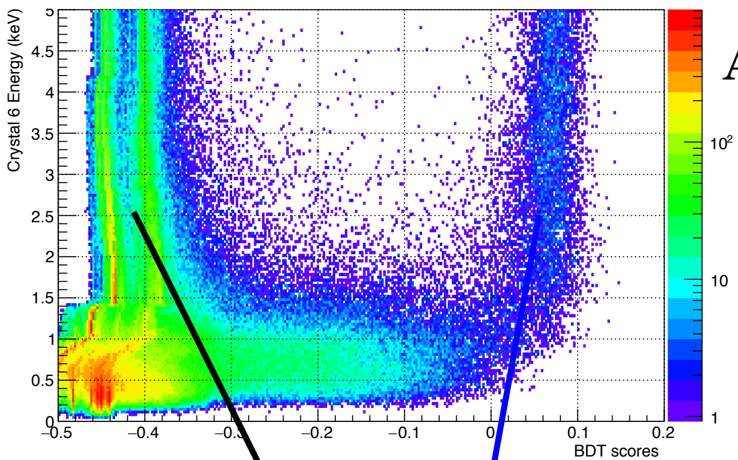
COSINE-100 detector

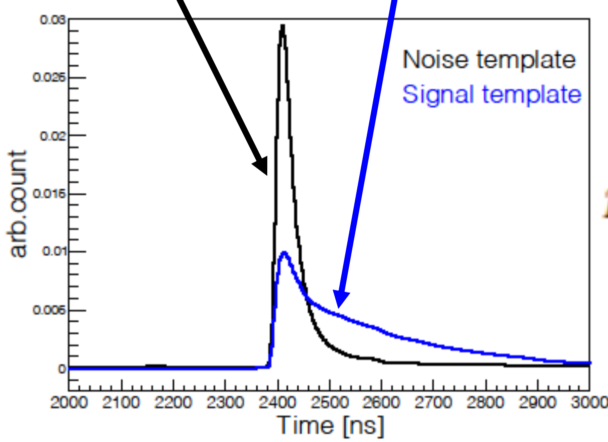


NaI(Tl) in COSINE-100 experiments

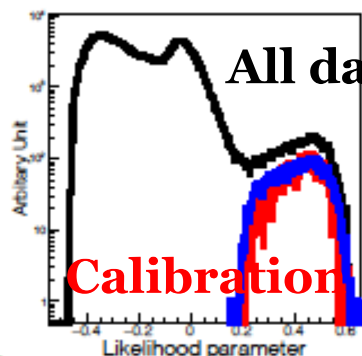
- 1 keV (15 NPE) energy threshold with multivariable analysis

Previous BDT score



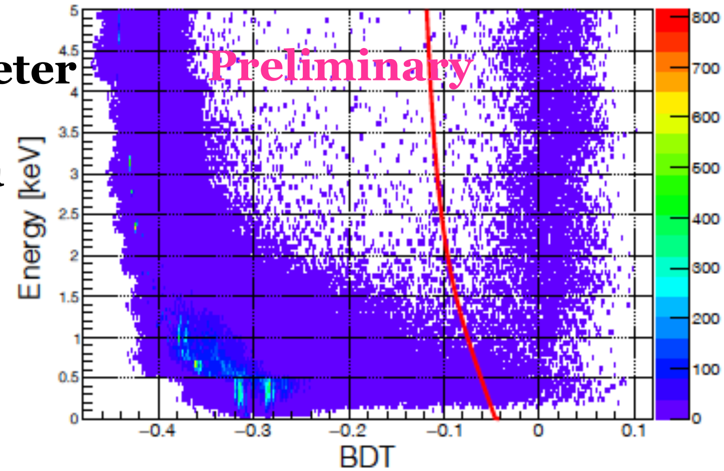


Add likelihood parameter

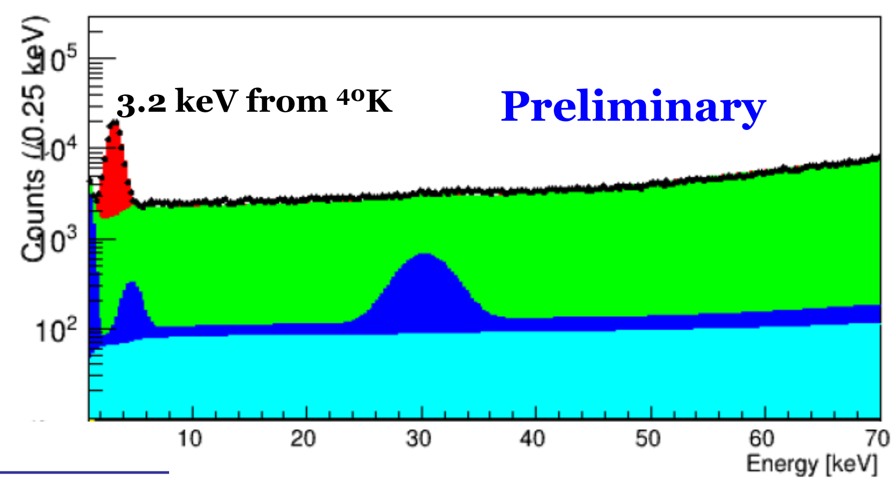


$$p_l = \frac{\ln \mathcal{L}_n - \ln \mathcal{L}_s}{\ln \mathcal{L}_n + \ln \mathcal{L}_s}$$

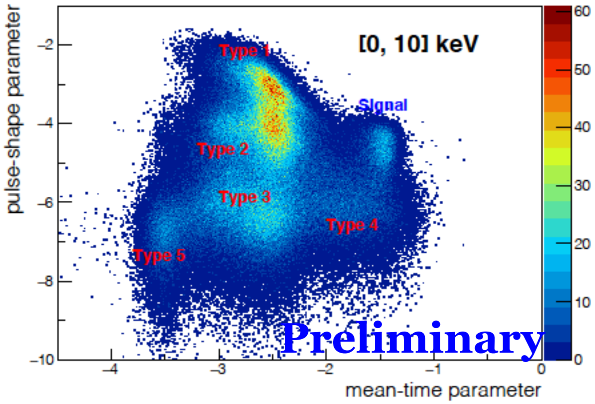
Updated BDT score

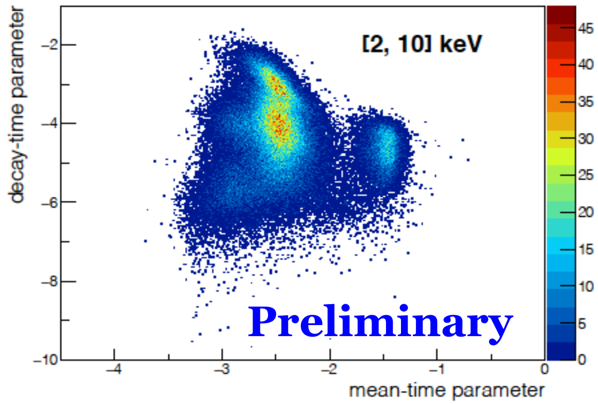


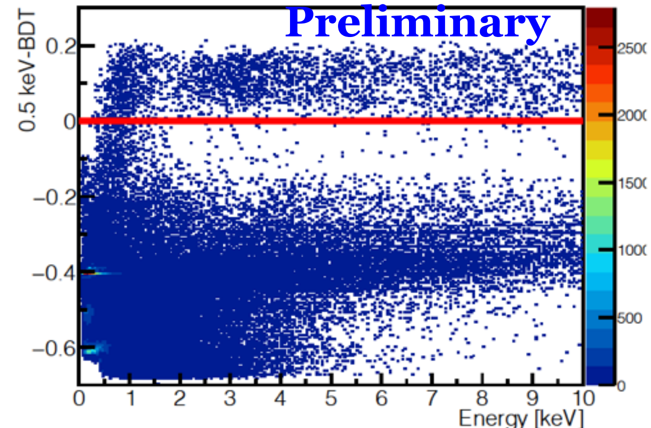
Y.D Kim's talk

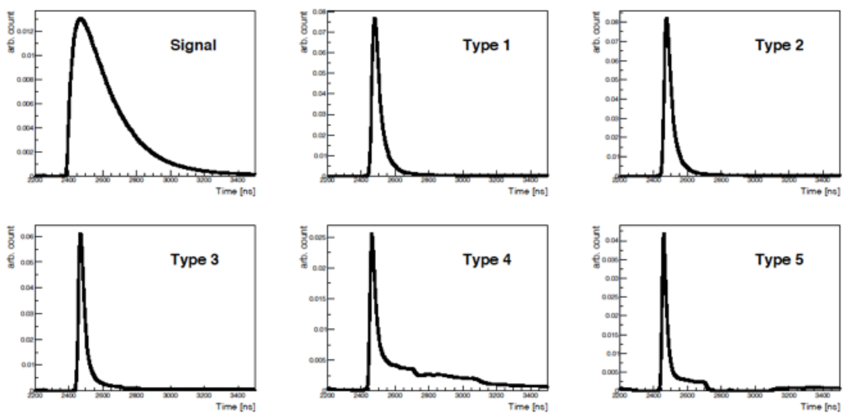


Lowering energy threshold with COSINE-100



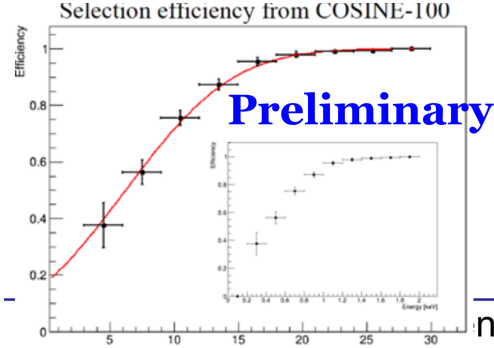




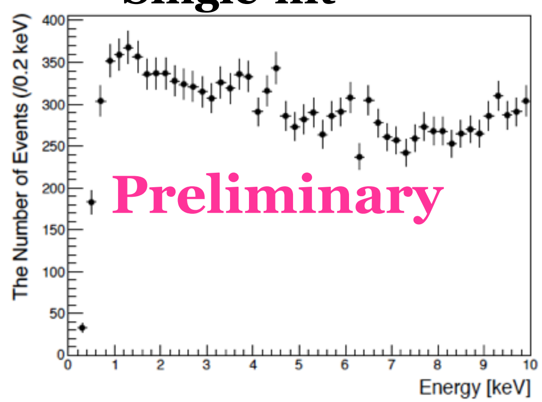


Categorize different noise type with likelihood parameters

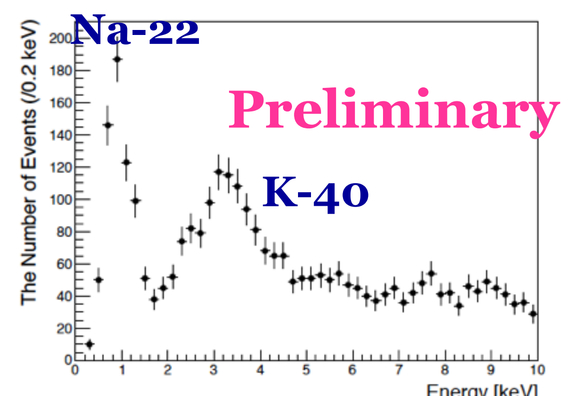
Selection efficiency from COSINE-100



Single-hit



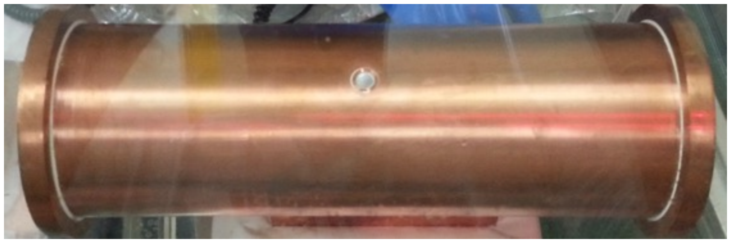
Multiple-hit

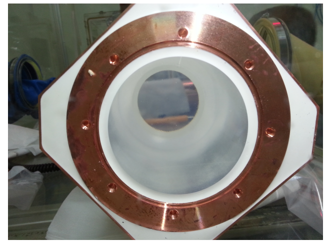


~0.4 keV (6 NPE) threshold

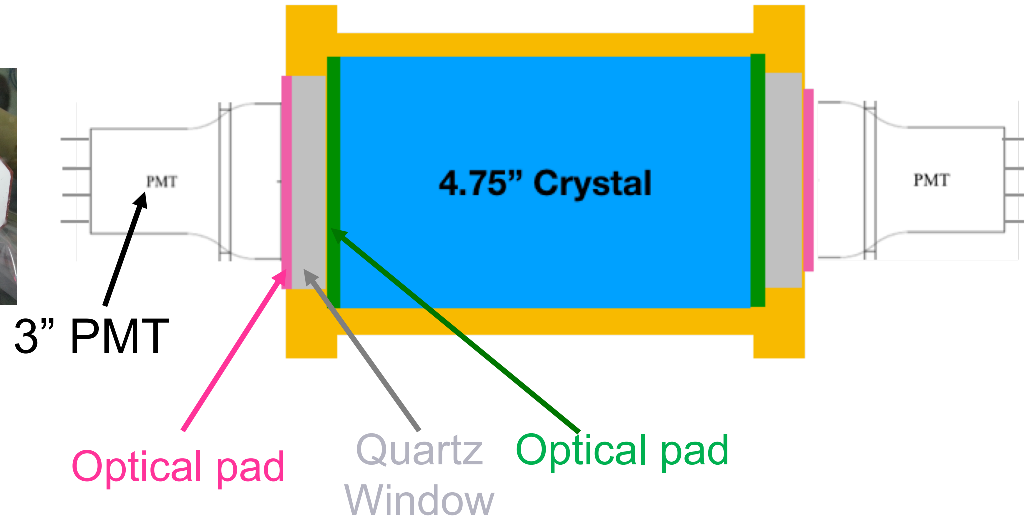
COSINE-100 detector

4.75” (D)× 11.75”(H), 12.5 kg





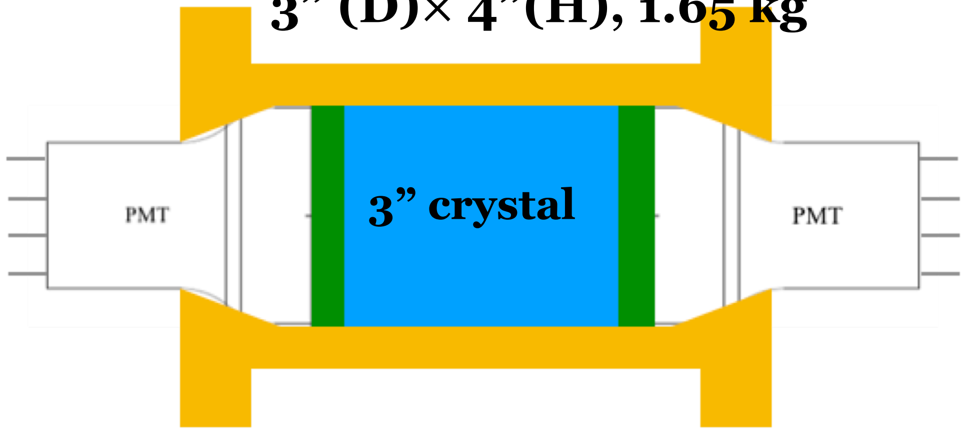
Encapsulated with quartz and copper

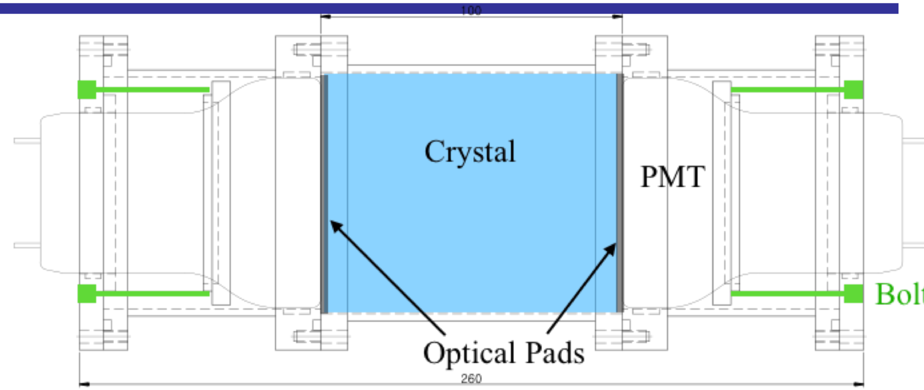


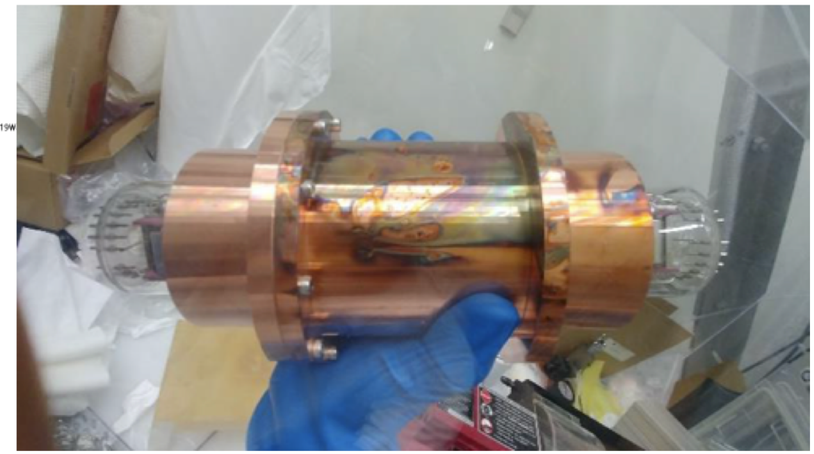
- COSINE-100 detector is not optimized for high light yield
  - 3” PMT for 4.75” Diameter crystal
  - Three layers of optical interface between PMT and crystal
- Machining, polishing, and detector assembly for NaI is prepared for COSINE-200

NEON detector

3” (D)× 4”(H), 1.65 kg







Commercial crystals

- 3” diameter crystal
- **Direct attach** between crystal and PMT
  - ❖ No quartz window
- Three detectors were built

NEON detector @ underground

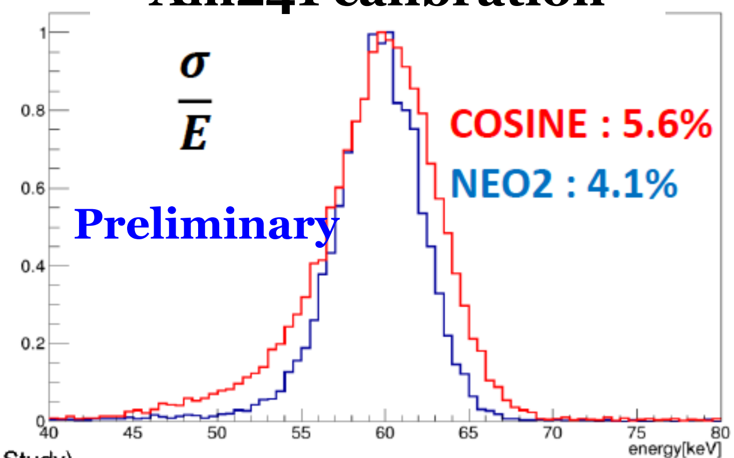
- NEON detector has been measured at Yangyang underground laboratory

~25 NPE/keV !!

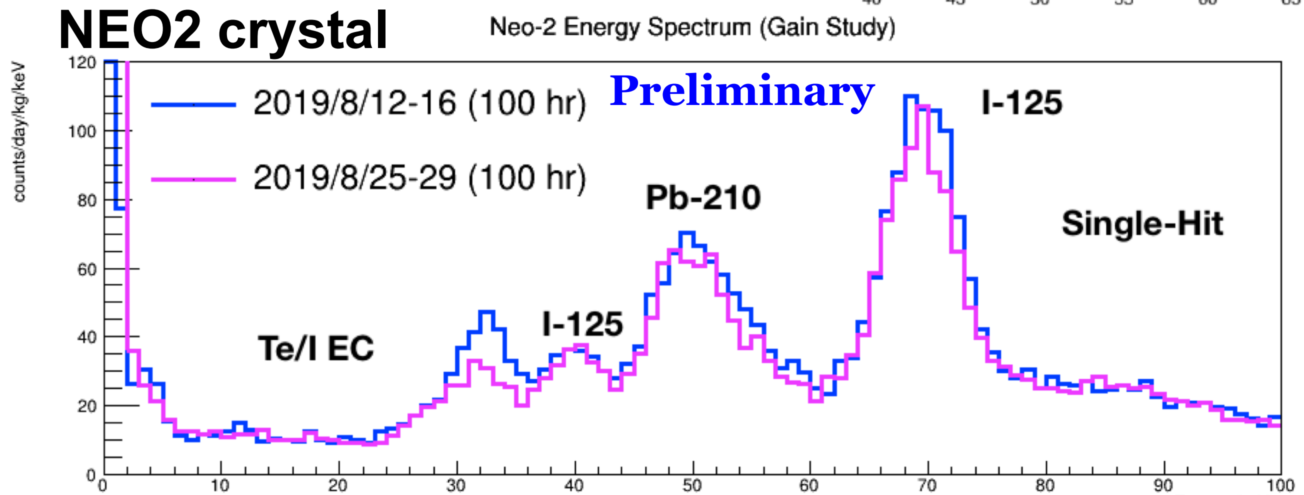
6 NPE ~ 0.24 keV

4NPE ~ 0.16 keV

Am241 calibration



NEO2 crystal

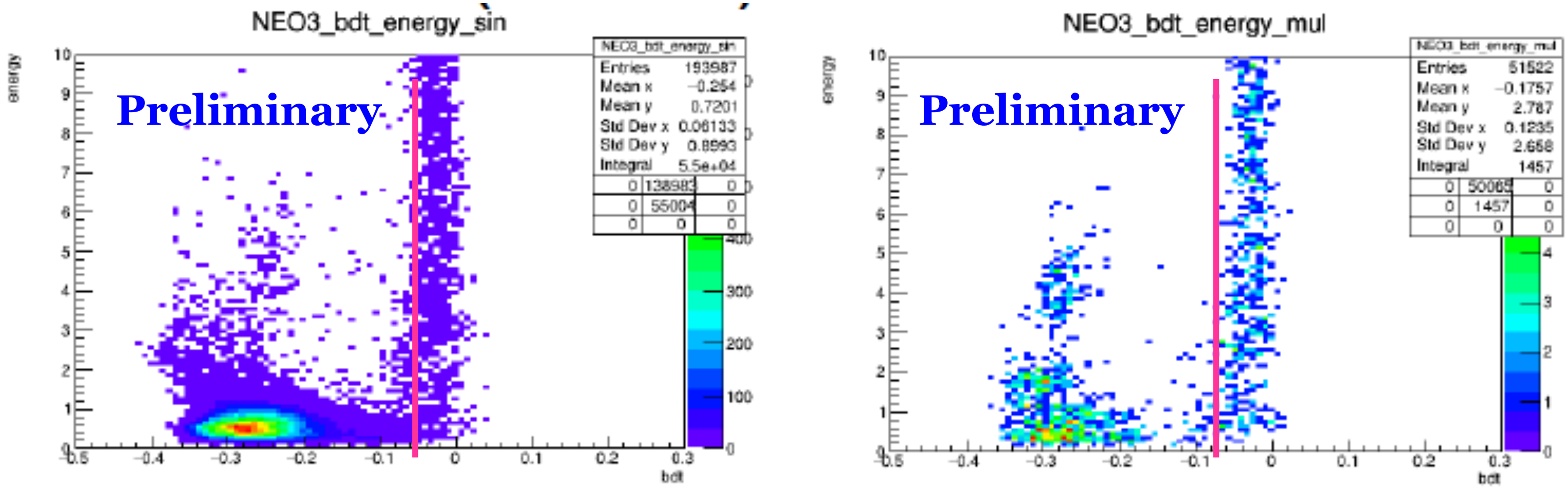


Stable gain (proof of our encapsulation)

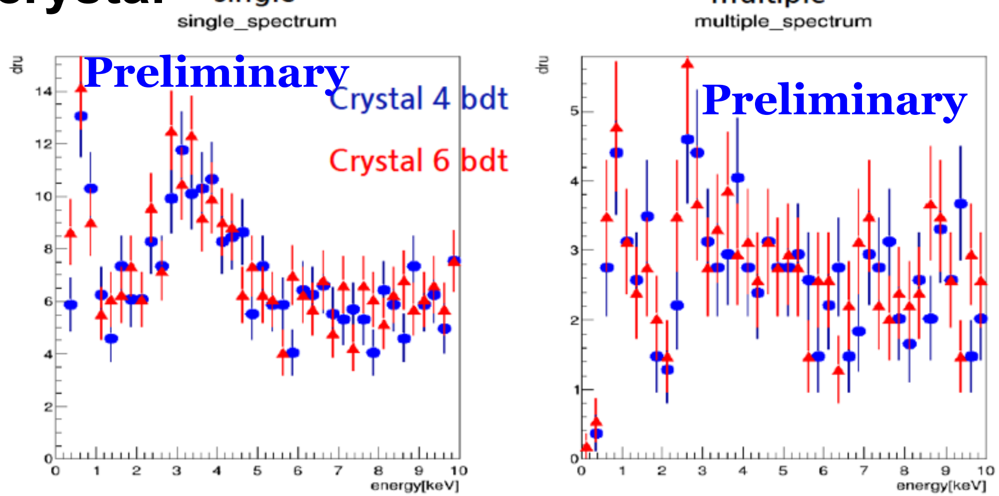
Background @ 10keV is 10 counts/keV/kg/day

Understanding low-energy events

- BDT trained with COSINE-100 data are used



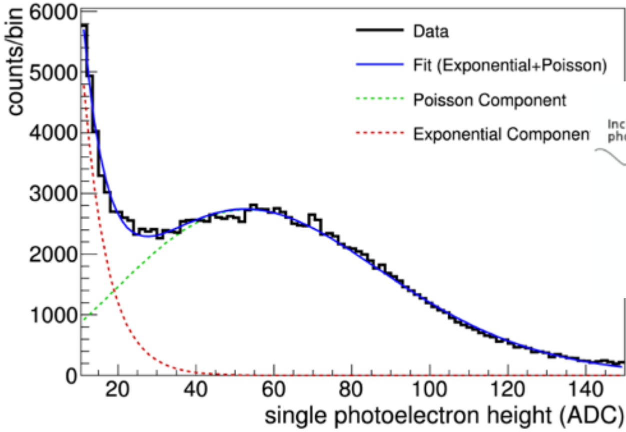
NEO3 crystal single multiple

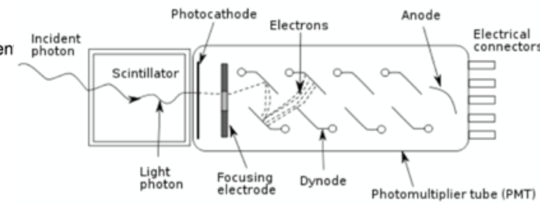


- Pure signal samples are necessary for multivariable training

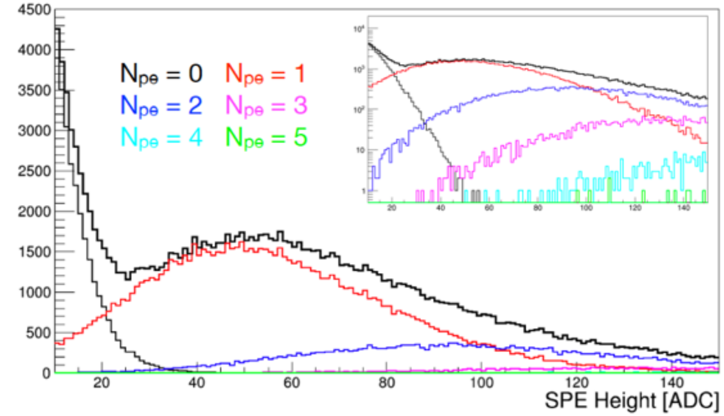
Simulation for low energy events

Single photoelectron data





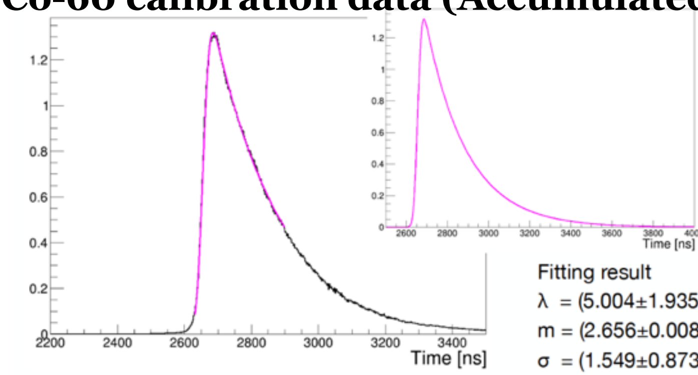
Single photoelectron simulation



- The number of dynode (# of steps) = 10
- Expected Gain = $5^{10} \sim 9.77\times10^{6}$
- Pedestal RMS = 0.1 pC

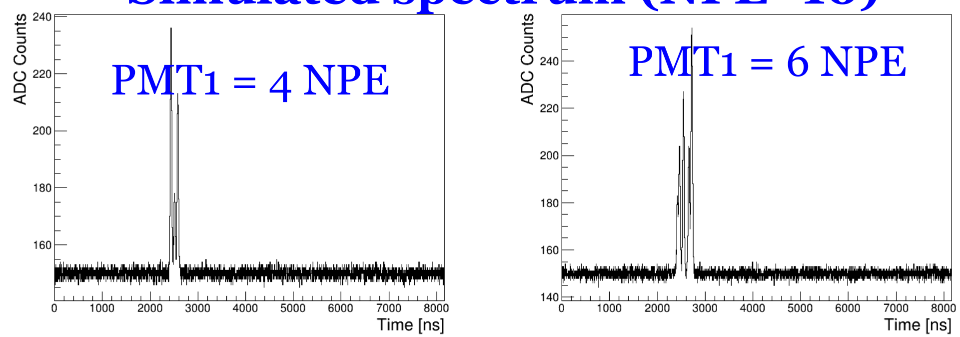
Modeling for scintillation decay time

Co-60 calibration data (Accumulated spectrum)



Fitting result
λ = $(5.004\pm1.935)\times10^{-3}$
m = $(2.656\pm0.008)\times10^{3}$
σ = $(1.549\pm0.873)\times10^{1}$

Simulated spectrum (NPE=10)

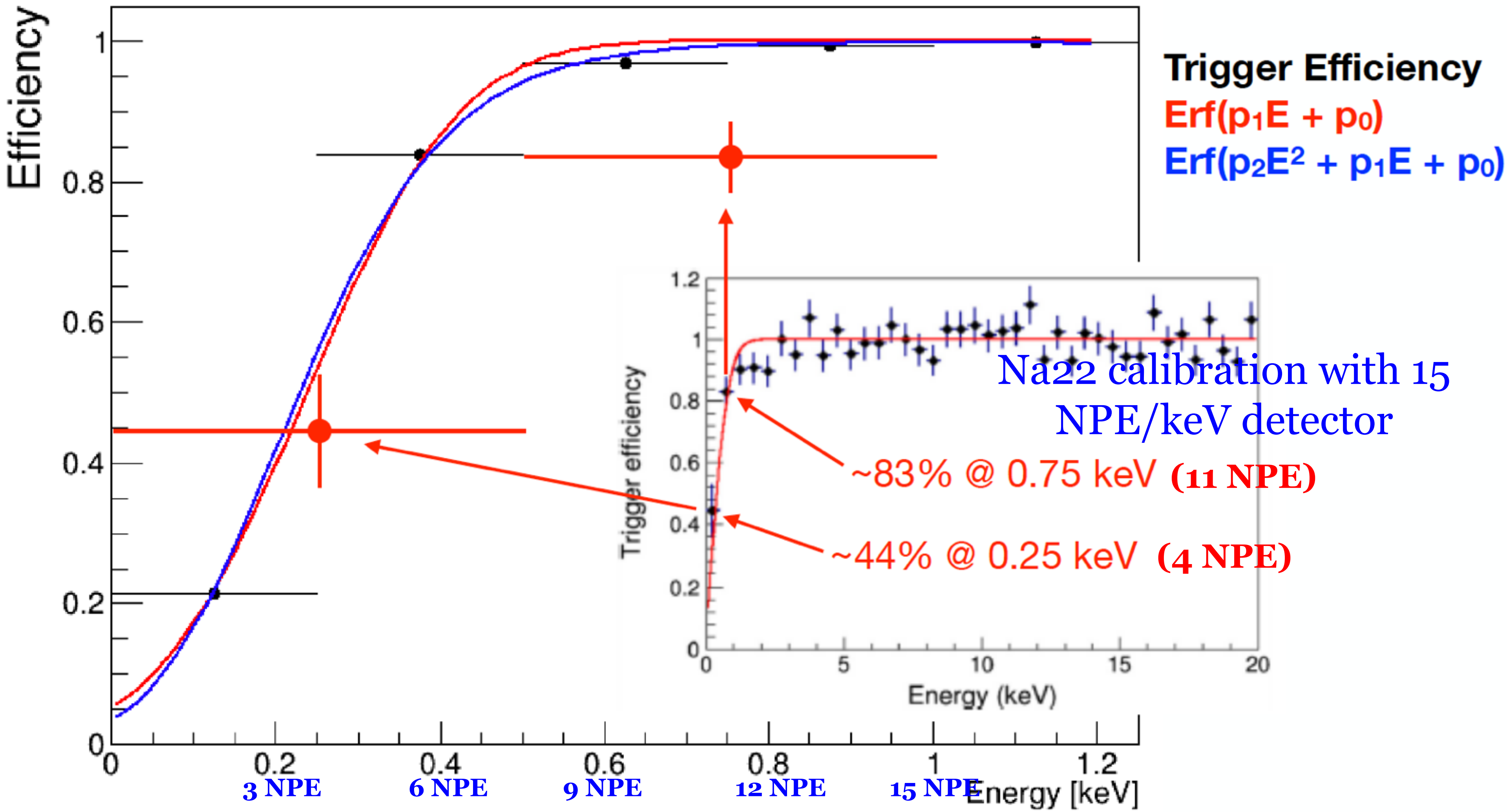


Trigger : one PE/PMT within 200ns

- PMT by PMT optimization are necessary

Simulation for low energy events

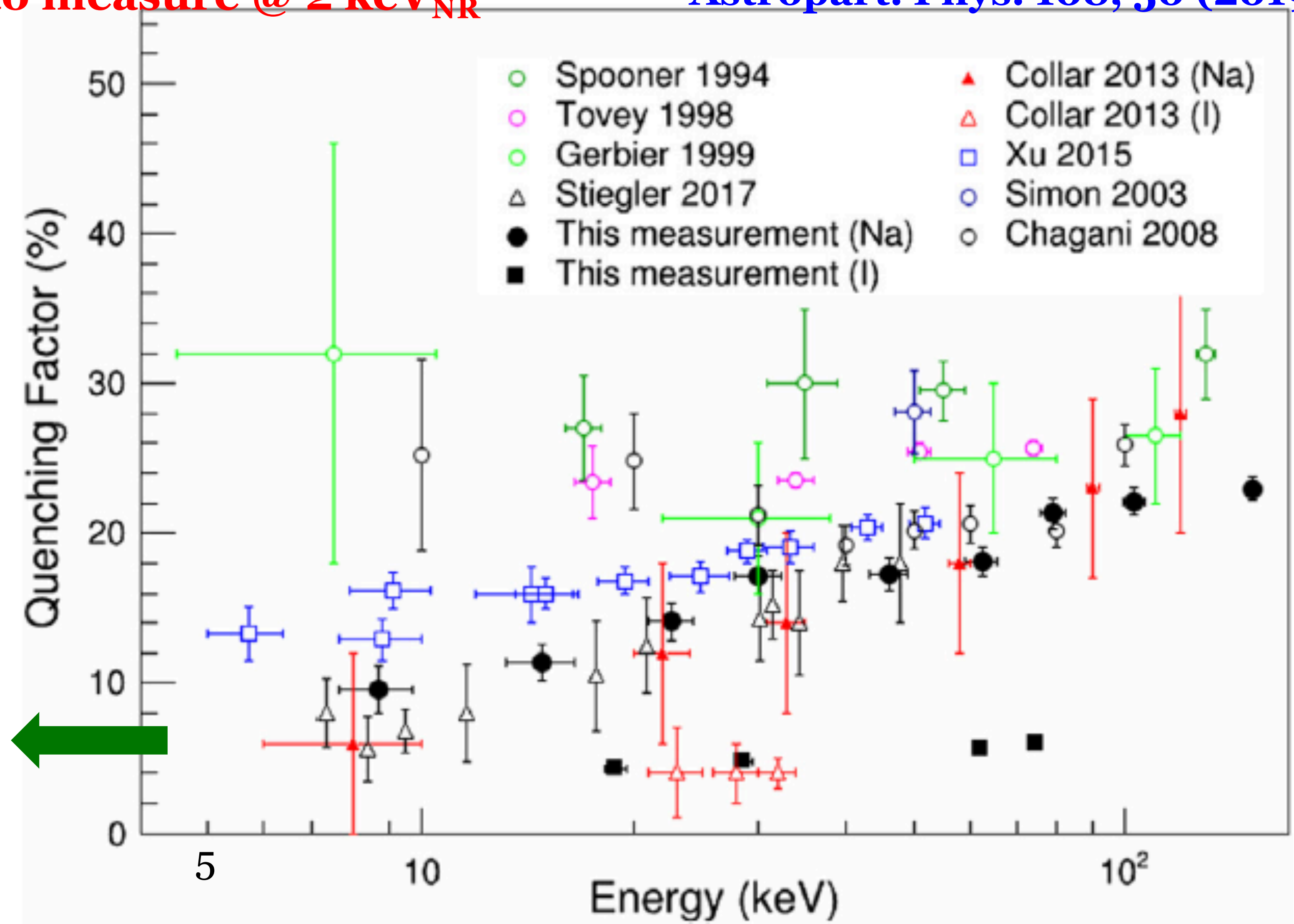
Trigger Efficiency for 15 NPE/keV



Quenching factor

Need to measure @ 2 keV_{NR}

Astropart. Phys. 108, 50 (2019)



Quenching factor

~18.2 NPE/keV

Scattering angle (deg)	Sim. Na recoil energy (keV_{nr})	Observed recoil energy (keV_{ee})	Quenching factor
18.2	2.9 ± 0.7	<0.65	<0.22
24.9	5.7 ± 0.7	0.76 ± 0.4	0.133 ± 0.018
31.1	8.8 ± 1.2	1.13 ± 0.5	0.129 ± 0.014
32.2	9.1 ± 1.2	1.46 ± 0.5	0.162 ± 0.012
41.1	14.3 ± 2.4	2.21 ± 0.9	0.159 ± 0.019
41.3	15.0 ± 1.4	2.36 ± 0.8	0.160 ± 0.010
47.9	19.4 ± 1.6	3.21 ± 1.0	0.168 ± 0.009
54.4	24.9 ± 2.4	4.10 ± 1.5	0.171 ± 0.010
59.1	29.0 ± 1.9	5.36 ± 1.9	0.188 ± 0.008
64.6	33.3 ± 2.8	6.19 ± 2.1	0.191 ± 0.011
74.2	43.0 ± 2.2	8.53 ± 2.7	0.204 ± 0.008
84.0	51.8 ± 2.6	10.59 ± 4.5	0.207 ± 0.010

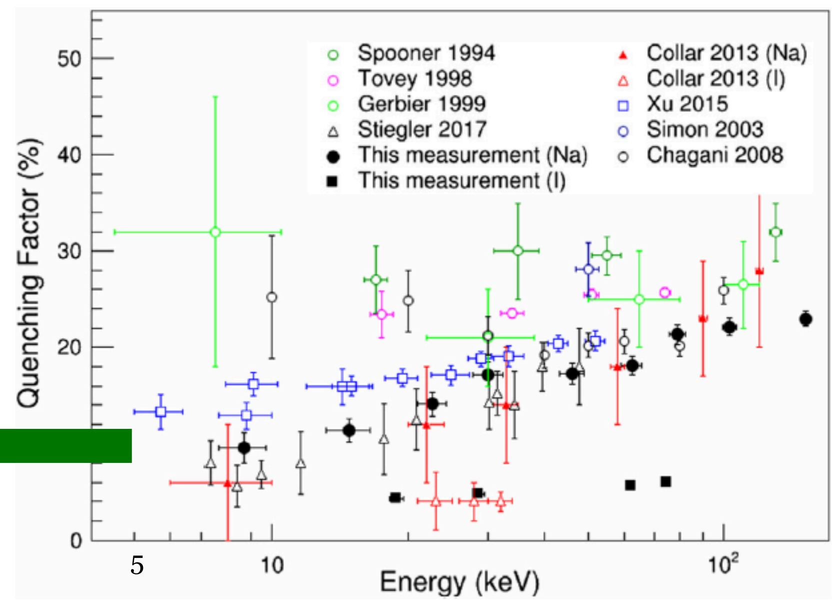
PRC 92, 015807 (2015)

~14 NPE/keV

Nuclei	Scattering angle (degree)	E_{ee} (keV)	E_{nr} (keV)	Quenching factor (%)
Na	13.2	< 0.5	5.8 ± 1.0	
	16.4	0.83 ± 0.07	8.7 ± 1.3	9.6 ± 1.6
	21.3	1.68 ± 0.04	14.8 ± 1.6	11.3 ± 1.2
	26.6	3.20 ± 0.05	22.7 ± 2.0	14.1 ± 1.3
	31.0	5.17 ± 0.07	30.1 ± 2.2	17.2 ± 1.3
	38.2	7.97 ± 0.09	46.1 ± 2.8	17.3 ± 1.1
	45.0	11.4 ± 0.1	62.6 ± 3.2	18.1 ± 0.9
	51.3	16.8 ± 0.2	78.9 ± 3.6	21.3 ± 1.0
	59.0	22.7 ± 0.2	102.7 ± 4.1	22.1 ± 0.9
	74.7	34.7 ± 0.3	151.6 ± 5.0	22.9 ± 0.8

Astropart. Phys. 108, 50 (2019)

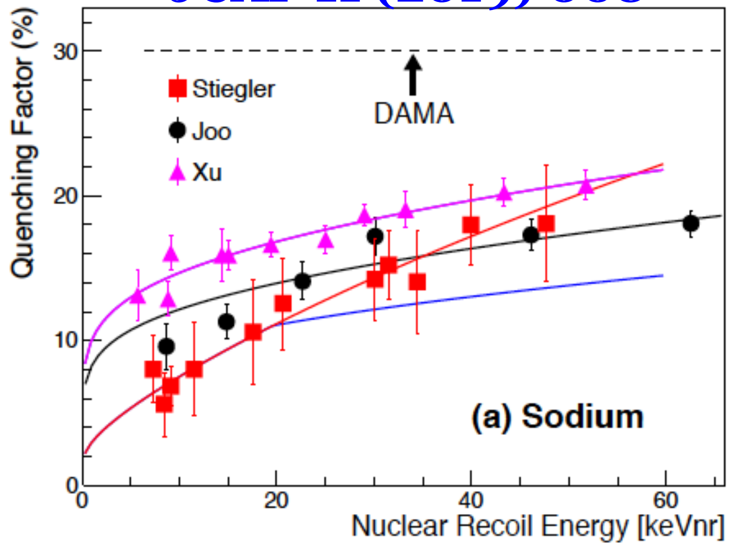
Need to measure @ 2 keV_{nr}



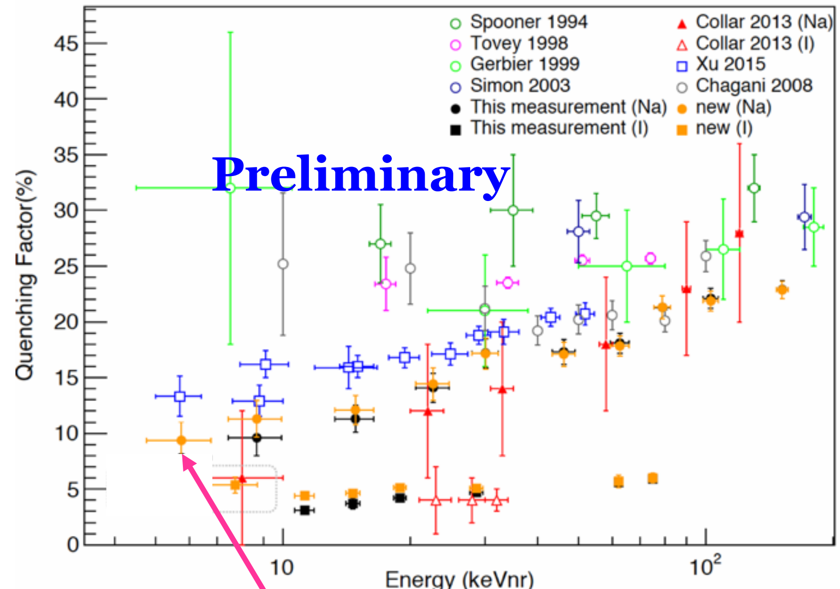
Quenching factor

Fit with modified Lindhard model

JCAP 11 (2019) 008



Update Event Selection + trigger & selection efficiencies

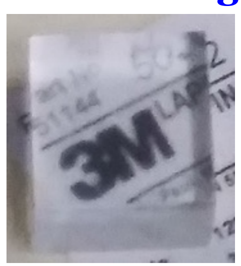


Recover 5.8 keV_{nr}

- We need high light yield detector for low energy calibration

Detector under preparation

Polishing



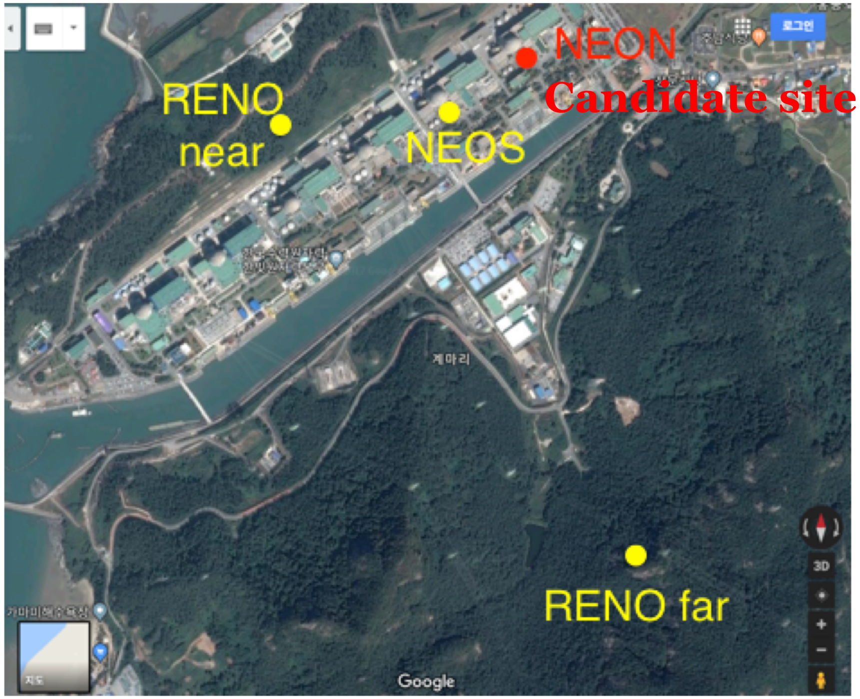
+

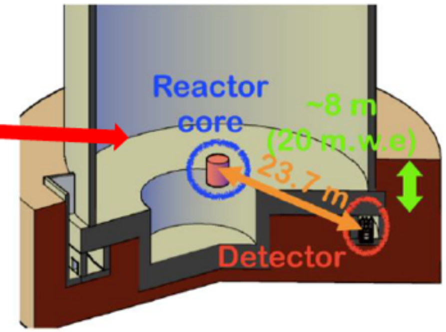
Encapsulation

=

High LY Detector

Hanbit nuclear power plant

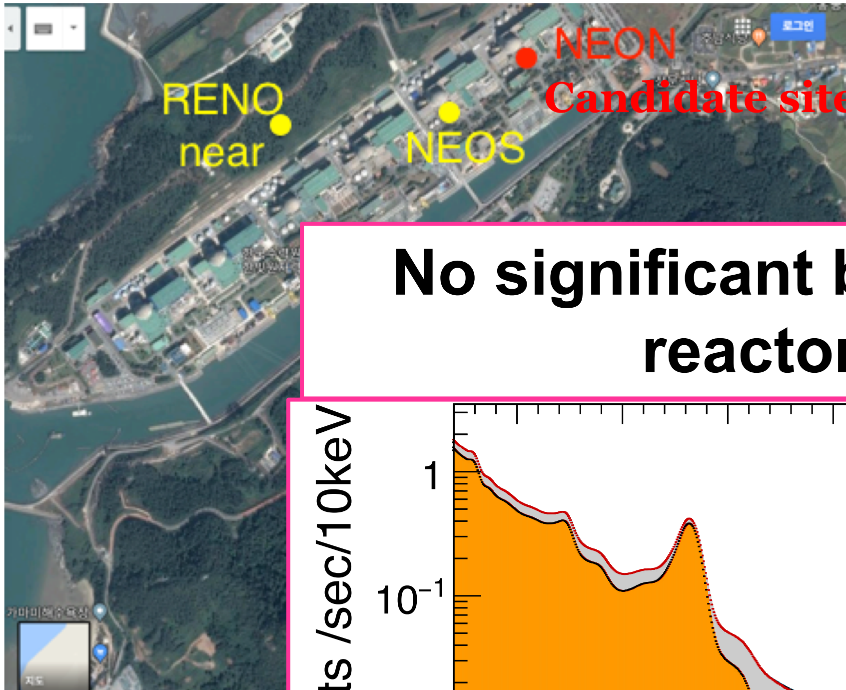


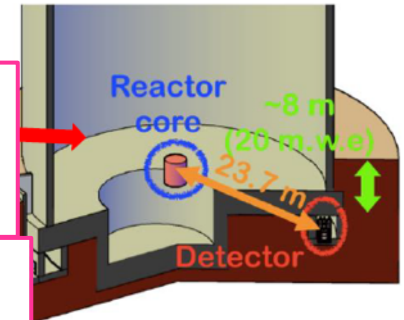


Tendon Gallery of Hanbit Nuclear Power Plant (Yeonggwang)

- Good relation with company (positive for new project)
- 2.8 GW thermal power
- Tendon gallery is ~24 m far from reactor core
  - ❖ Environmental conditions were well understood with NEOS experiment

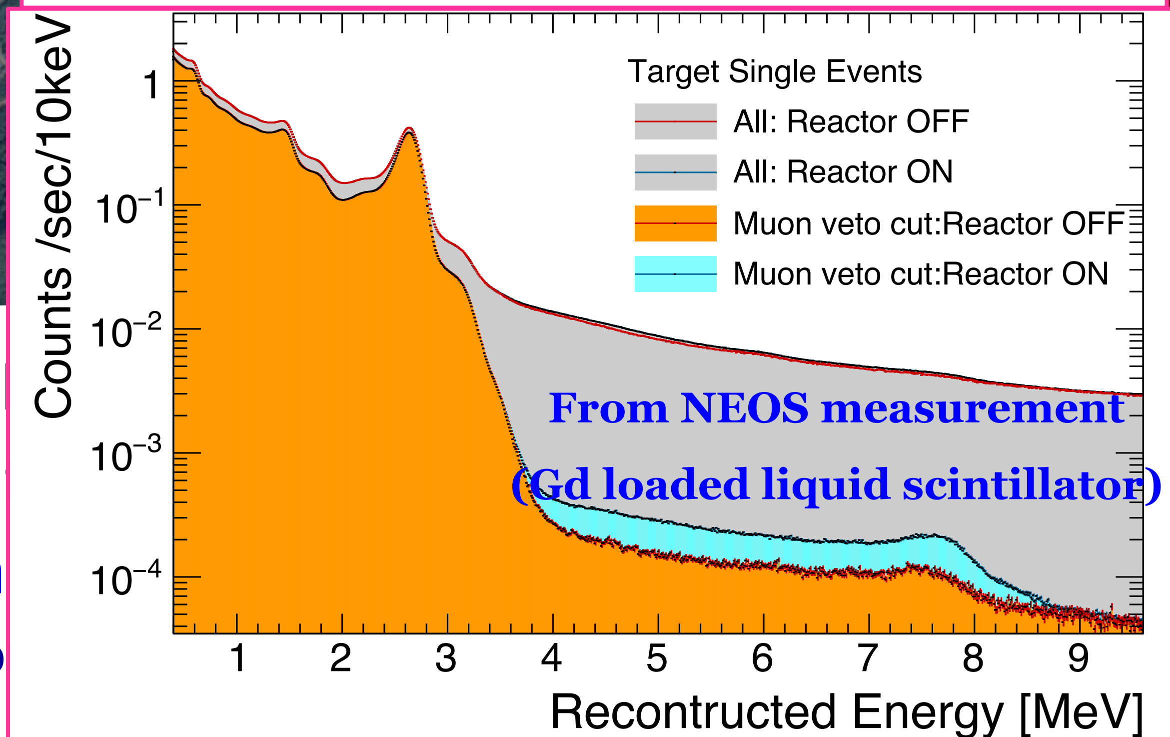
Hanbit nuclear power plant





Power Plant (Yeonggwang)

No significant background from reactor-on data

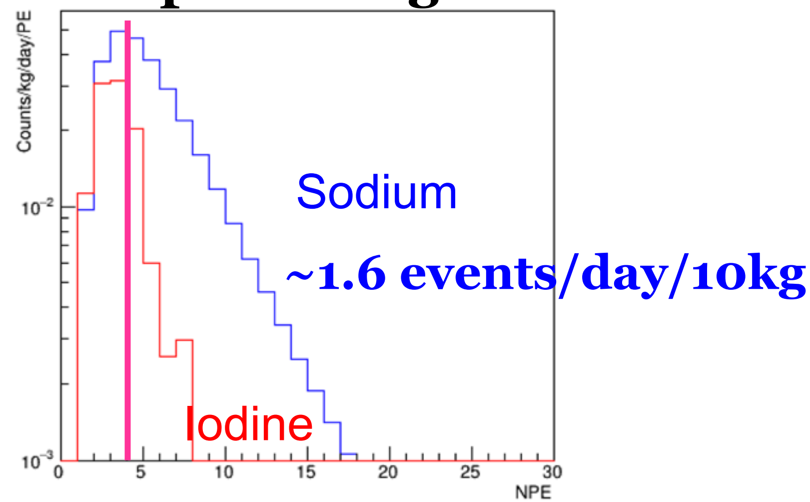


- Good re ... ect)
- 2.8 GW
- Tendom
  - ❖ Enviro ... OS experiment

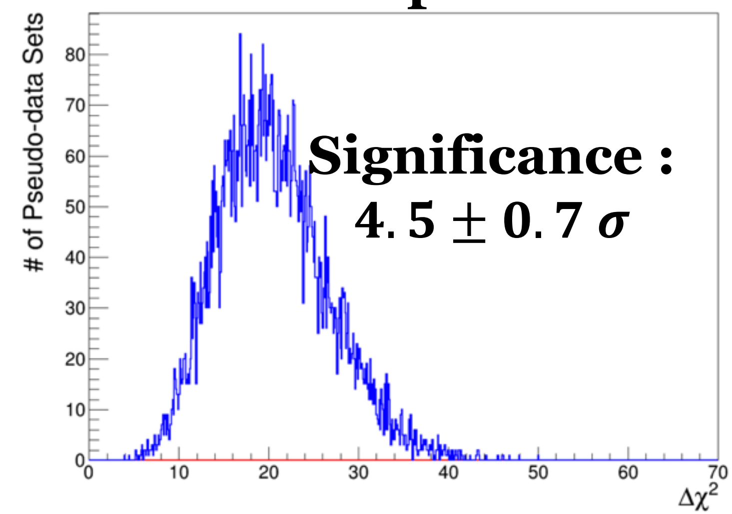
Sensitivity

- Flat background ~10 dru
- Detector mass = 10 kg
- Reactor on data = 365 days
- Reactor off data = 100 days
- Light yield = 25 NPE/keV
- QF from fit of Lindhard model
- Threshold = 4 NPE

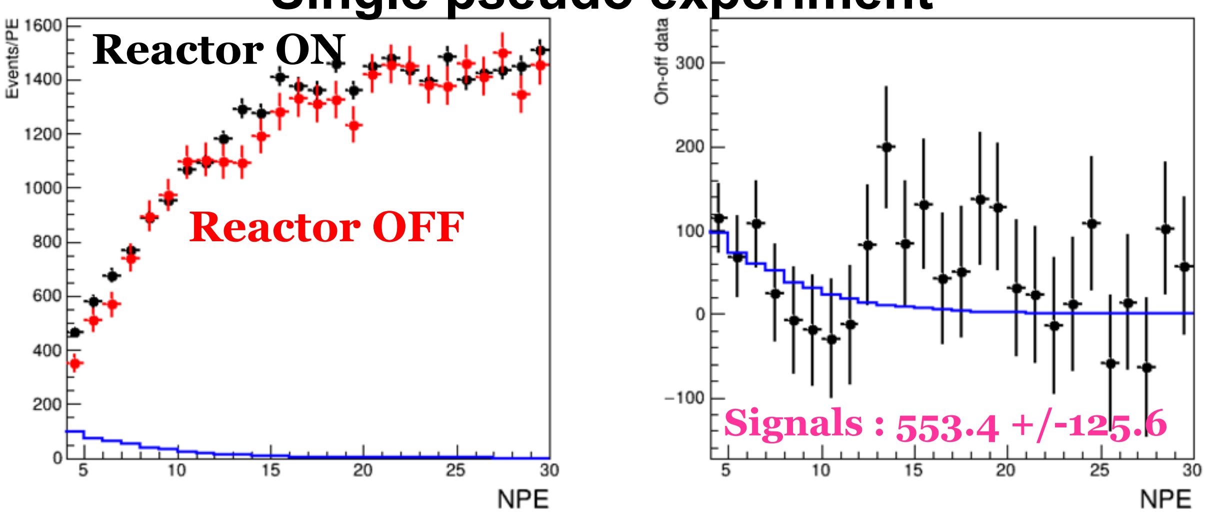
Expected Signals



1000 Pseudo experiments

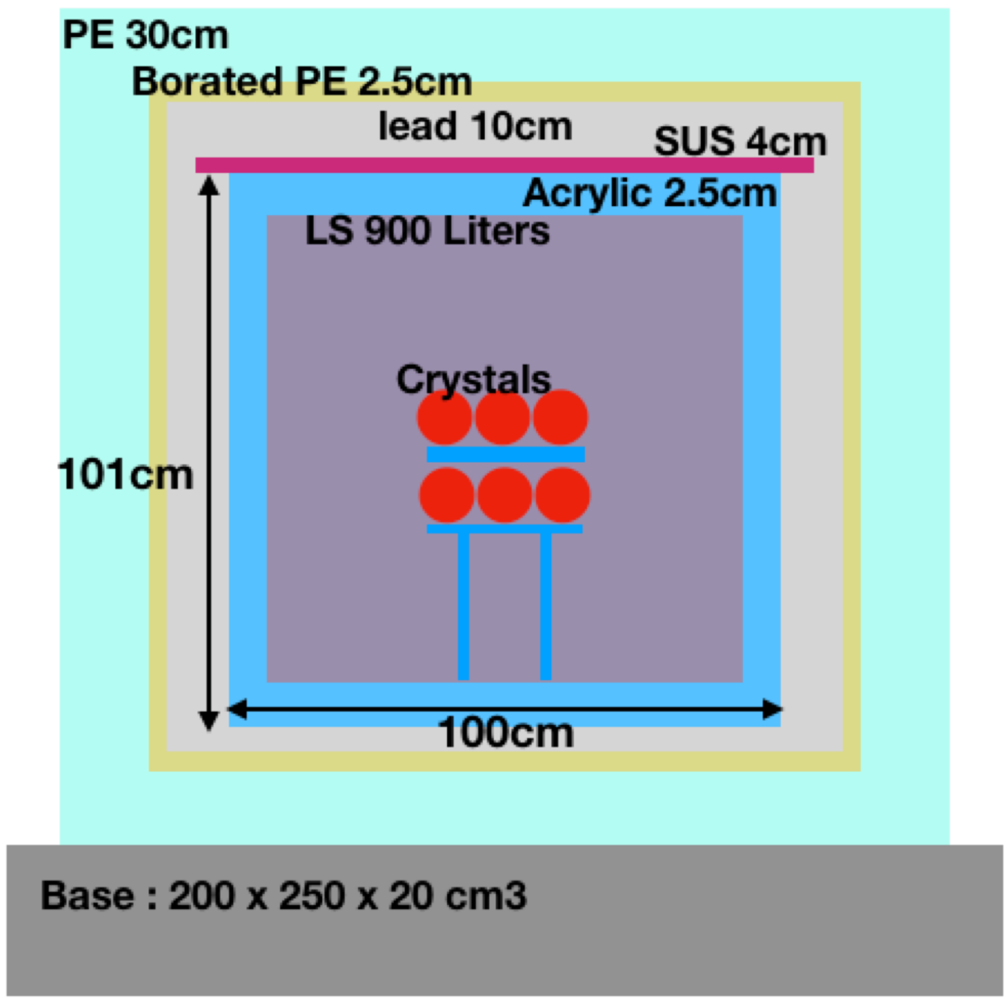


Single pseudo experiment



NEON shielding & preparation

NEON @ CUP basement

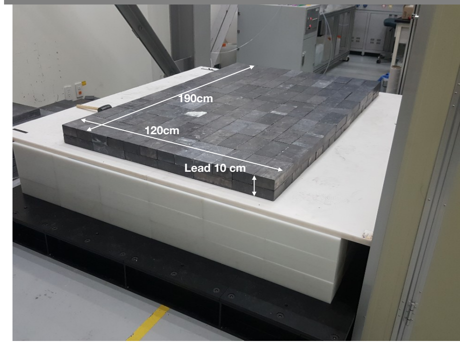


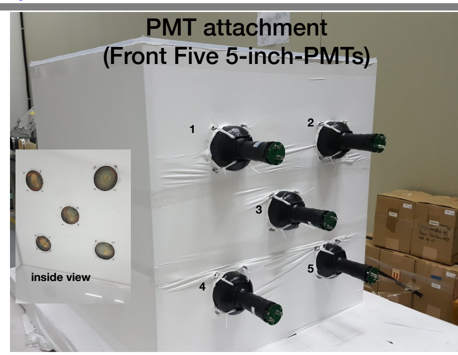
All commercial NaI(Tl) crystals
Total 14.8 kg

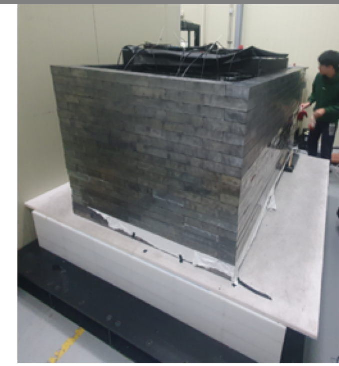
NaI (3"X4")	3 units ready
NaI (3"X8")	3 units on delivery
PMTs	ready
Cables	ready
LS	On the production
Acrylic box	ready
Sus bars	ready
Lead	ready
Borated PE	ready
Preamps	ready
FADCs	ready
DAQ	ready but debugging
Slow monitoring	Working on it

Pre-installation at IBS HQ

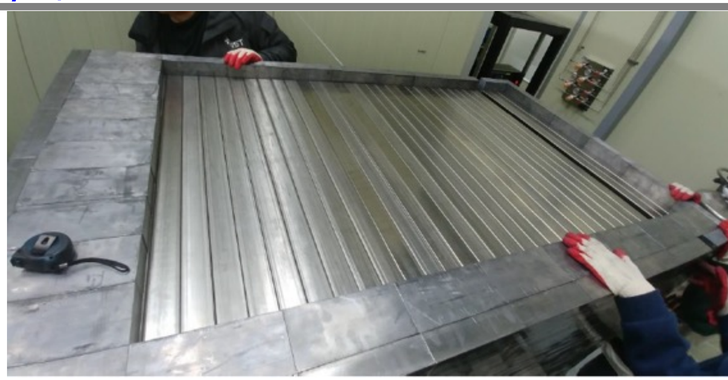
Jan/6 (2020) **Jan/20** **Feb/3**

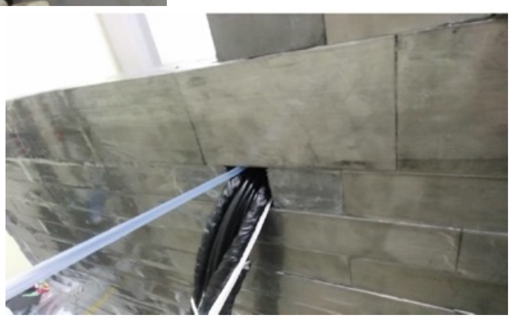


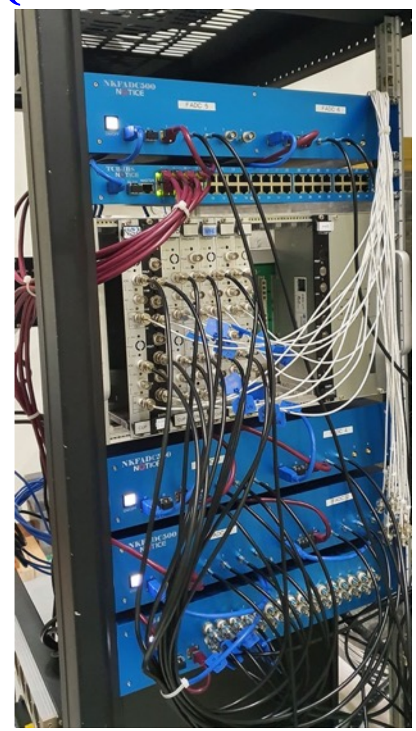




Feb/17 **Feb/21** **DAQ (same as COSINE-100**







Dry run (without liquid scintillator)
just started (Feb/21th/2020)

Strategy of NEON experiment

2019	2020	2021	2022	2023	2024	2025
NEON-pilot						
		NEON-phase 1				
				NEON-phase 2		

- NEON-pilot (~2021)
  - ❖ ~15 kg commercial crystals (~ 10 dru background)
  - ❖ Install at March-April 2020
  - ❖ Demonstration of detector performance to observe CEνNS using reactor
- NEON-phase1 (~2023)
  - ❖ ~50 kg COSINE-100 quality crystals (~3dru background)
  - ❖ Observation of CEνNS and start precision measurement
- NEON-phase2 (~2025)
  - ❖ ~100 kg purified crystals (<1dru background)
  - ❖ Precision measurement and explore new physics interaction

<Body growth>

Y.D Kim's talk

Conclusion

- NEON is newcomer for CEνNS from reactor neutrino
- NEON use conventional NaI(Tl) detector taking advantage of good development from COSINE experiment as well as reactor measurement experience from NEOS experiment
- NEON-pilot is about ready to be installed in reactor
  - This March to April depending on power company plan

Stay tune !!