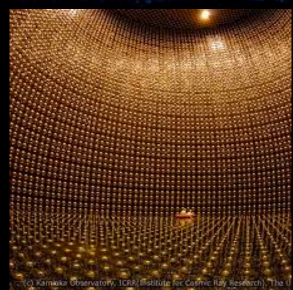
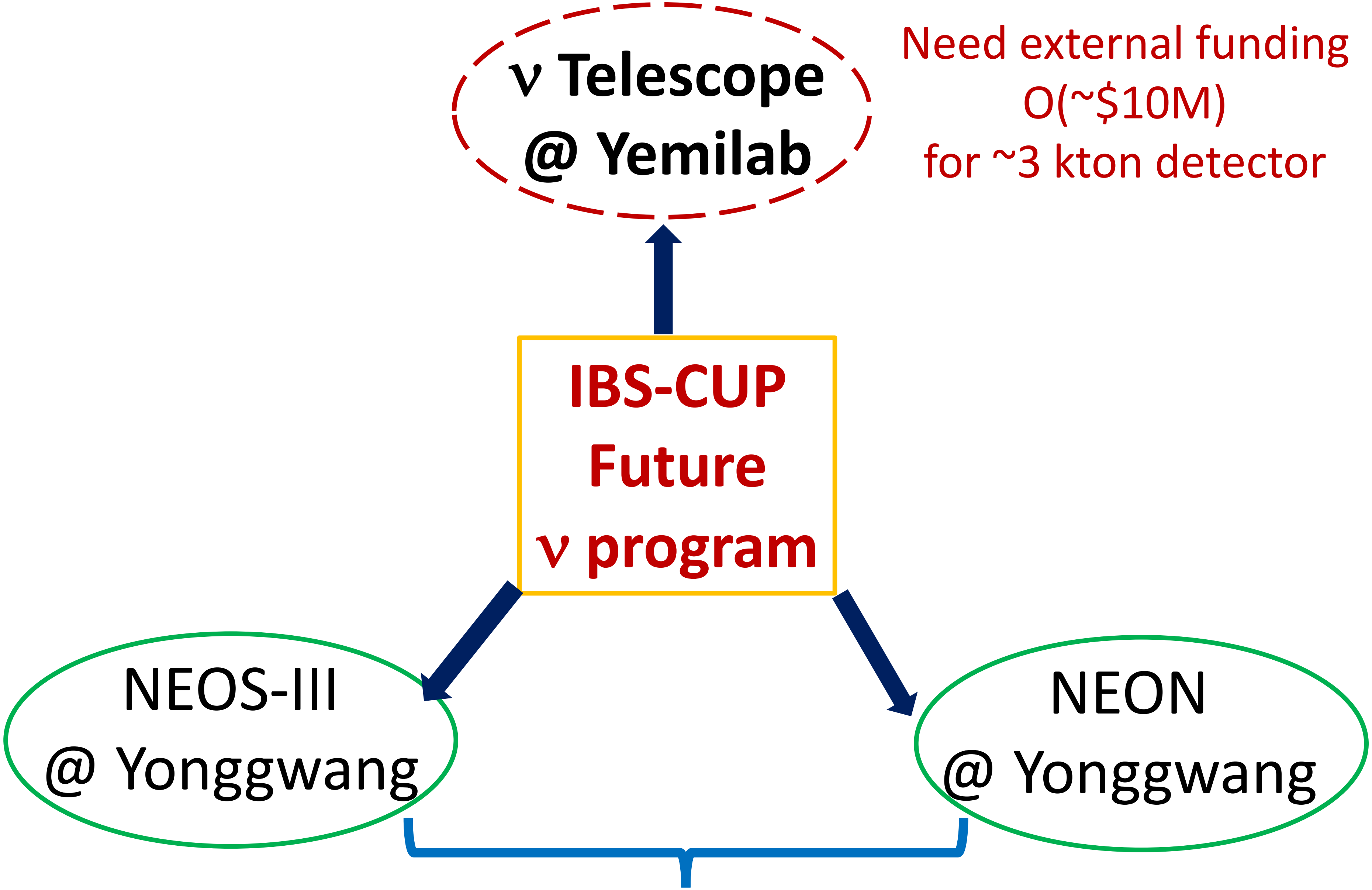
IBS-CUP
Future Neutrino Program

2019 HEP Roadmap Meeting
@ IBS HQ

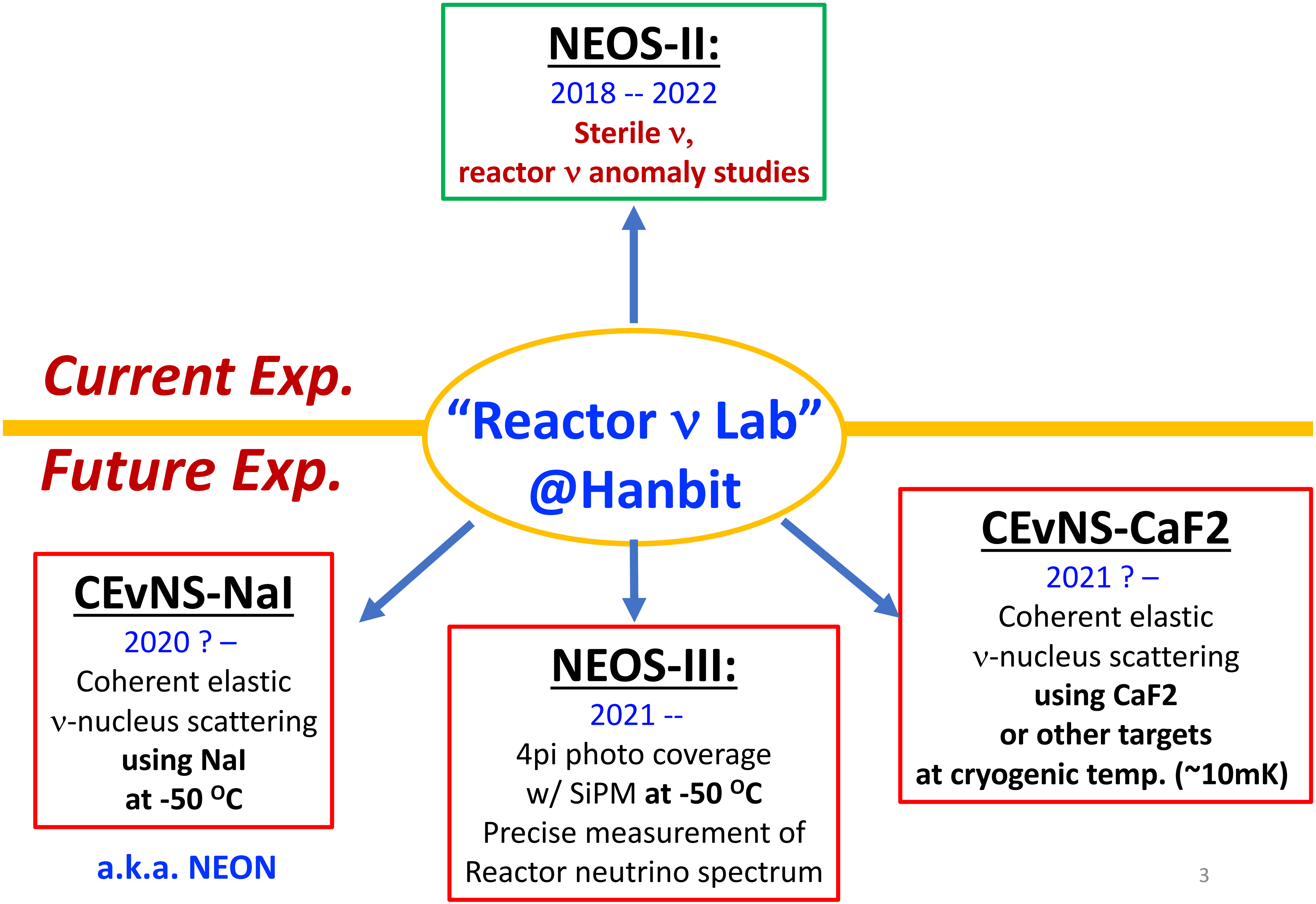


Sunny (Seon-Hee) Seo
서선희 @ IBS-CUP

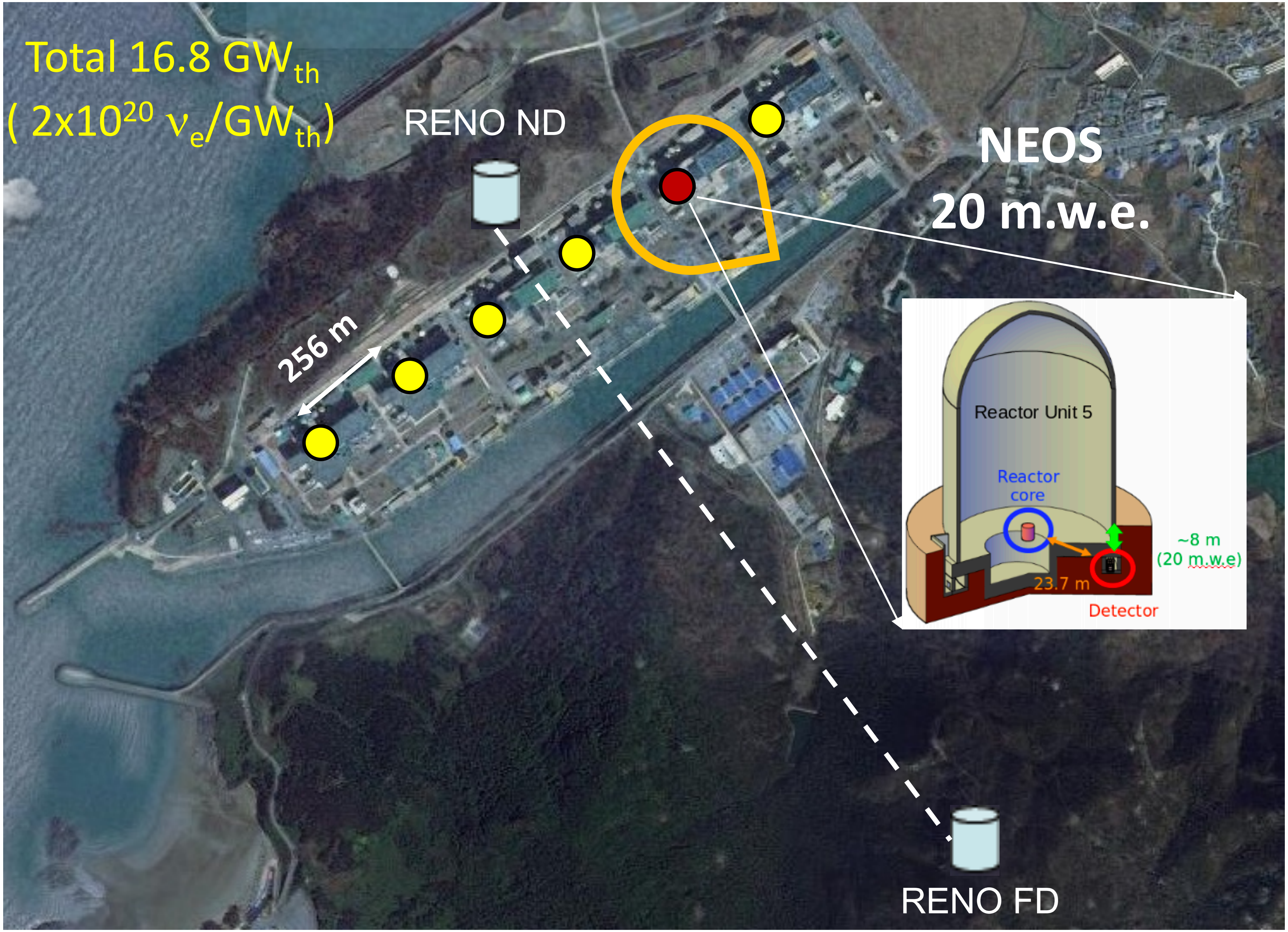
2019.09.20



These two can be covered by IBS-CUP funding.

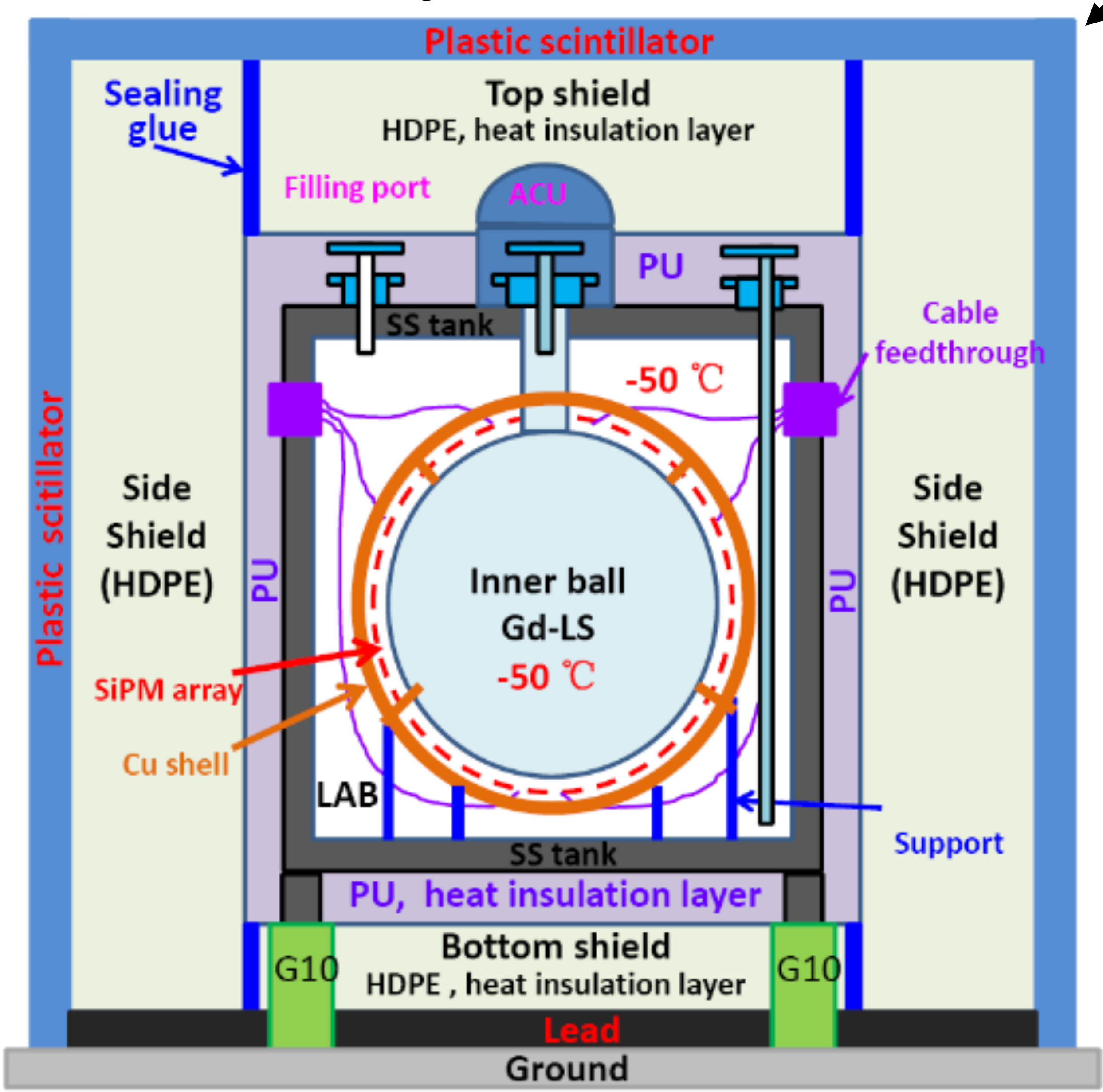

NEOS-II:
2018 -- 2022
Sterile ν,
reactor ν anomaly studies
Current Exp.
"Reactor ν Lab"
@Hanbit
Future Exp.
CEvNS-NaI
2020 ? –
Coherent elastic
ν-nucleus scattering
using NaI
at -50 °C
a.k.a. NEON
NEOS-III:
2021 --
4pi photo coverage
w/ SiPM at -50 °C
Precise measurement of
Reactor neutrino spectrum
CEvNS-CaF2
2021 ? –
Coherent elastic
ν-nucleus scattering
using CaF2
or other targets
at cryogenic temp. (~10mK)

NEOS Site


Total 16.8 GW$_{th}$
(2x10^{20} ν_e/GW$_{th}$)
RENO ND
NEOS
20 m.w.e.
256 m
Reactor Unit 5
Reactor core
~8 m
(20 m.w.e)
23.7 m
Detector
RENO FD

NEOS-III Concept: Similar to JUNO-TAO

Image credit: J. Cao

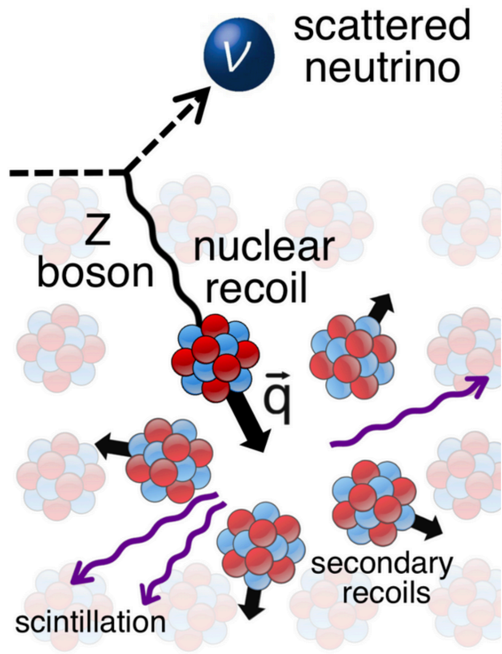


We have more overburden.
→ Less background

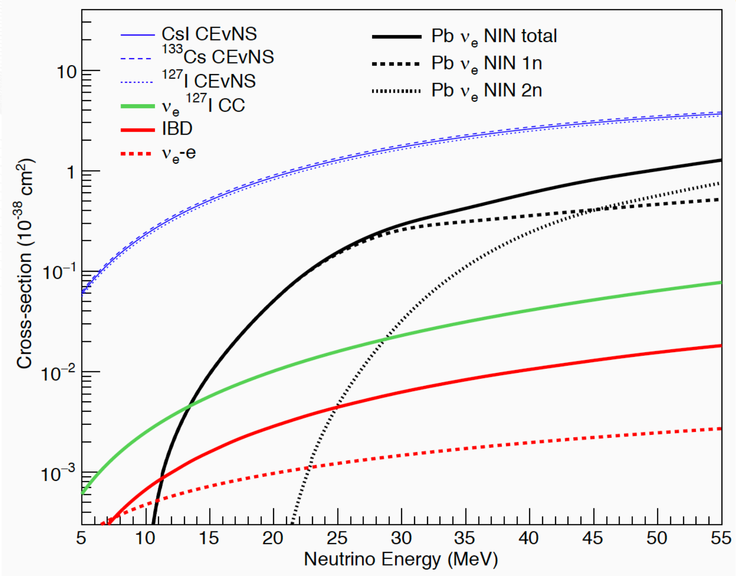
Precise measurement of reactor ν spectrum

CEvNS

Coherent Elastic veutrino-Nucleus Scattering



coherent up to E_ν~ 50 MeV



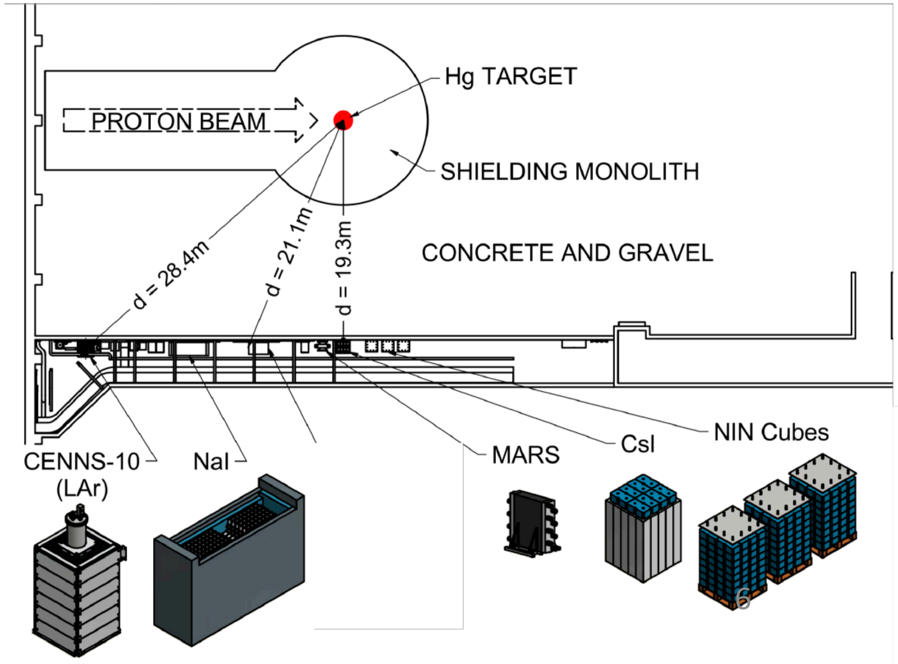
Observed in 2017

by COHERENT @OAK RIDGE NL

CEvNS does exists
However, nobody doubt that !!!

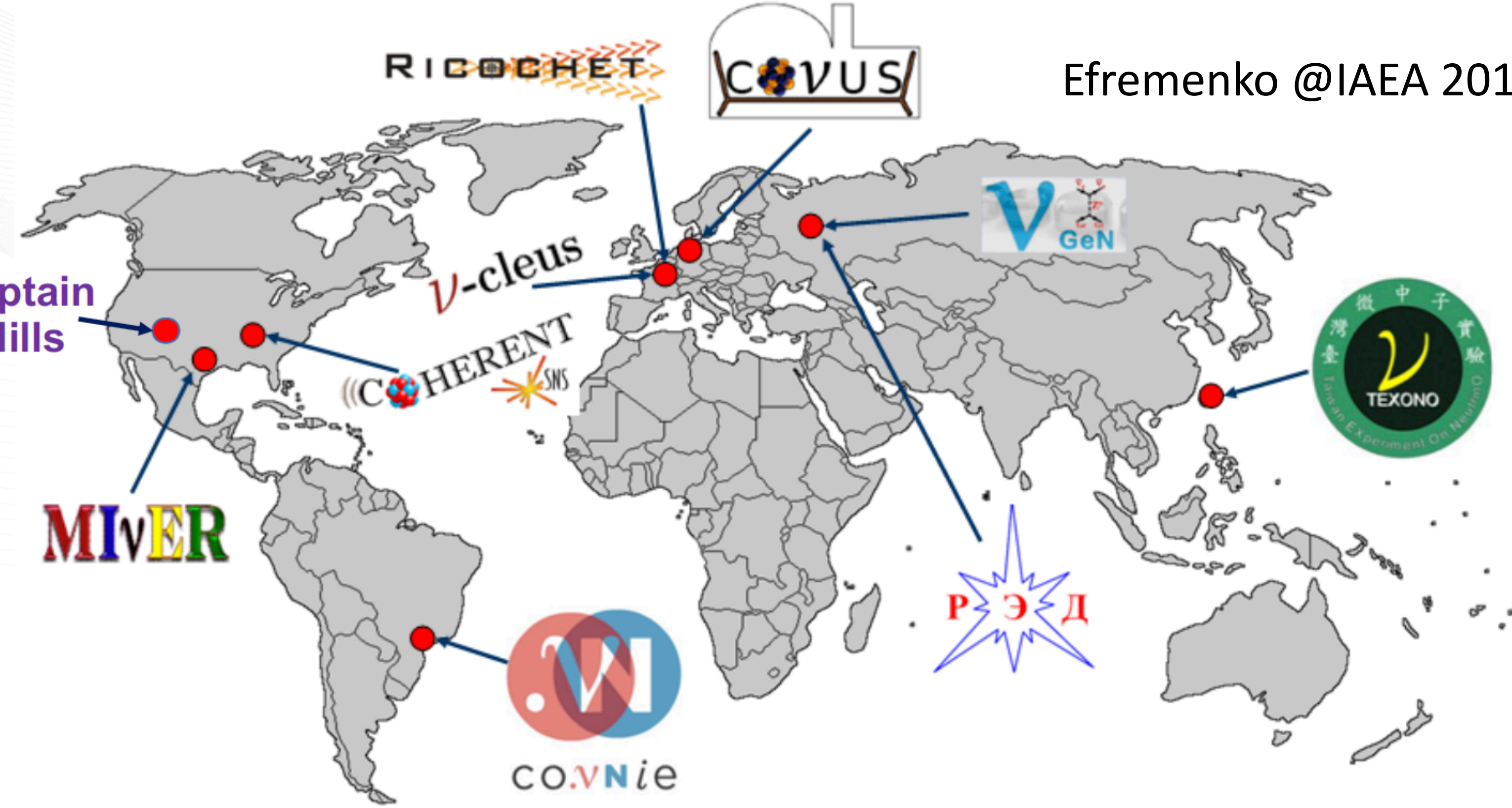
1974
Freedman

"It's a real thrill that something that I predicted 43 years ago has been realized experimentally,"



World Wide Efforts to Detect CEvNS

Efremenko @IAEA 2019



Except COHERENT and CM collaborations, all others attempting to use nuclear reactors as a neutrino source

Nuclear reactors give large flux, but low energy neutrinos with a constant flux

Various detector technologies are being investigated. We heard first indication of positive signal from the Conus experiment last year

OAK RIDGE National Laboratory

- ❑ NEON: **CEvNS-NaI** @Hanbit → see HSLee's talk at DM session
- ❑ **CEvNS-CaF2** cryogenic temp. @Hanbit: R&D by CUP Low-temp group

Future Exp.

1st Korean neutrino telescope at a few kton scale.
Good demonstrator for KNO
w/ successful WbLS R&D.

arXiv:1903.05368

$~30 M project

w/ 50~100 kton detector,
very interesting physics
can be achieved.

"ν Telescope"
@Yemilab

WbLS R&D

2020 –
WbLS stability,
Purification,
LAPPD, etc.
Prototype construction

WbLS Telescope:

2022 ? --
Precise measurement of
Solar neutrino fluxes,
Solar upturn,
Nucleon decay,
New physics

or

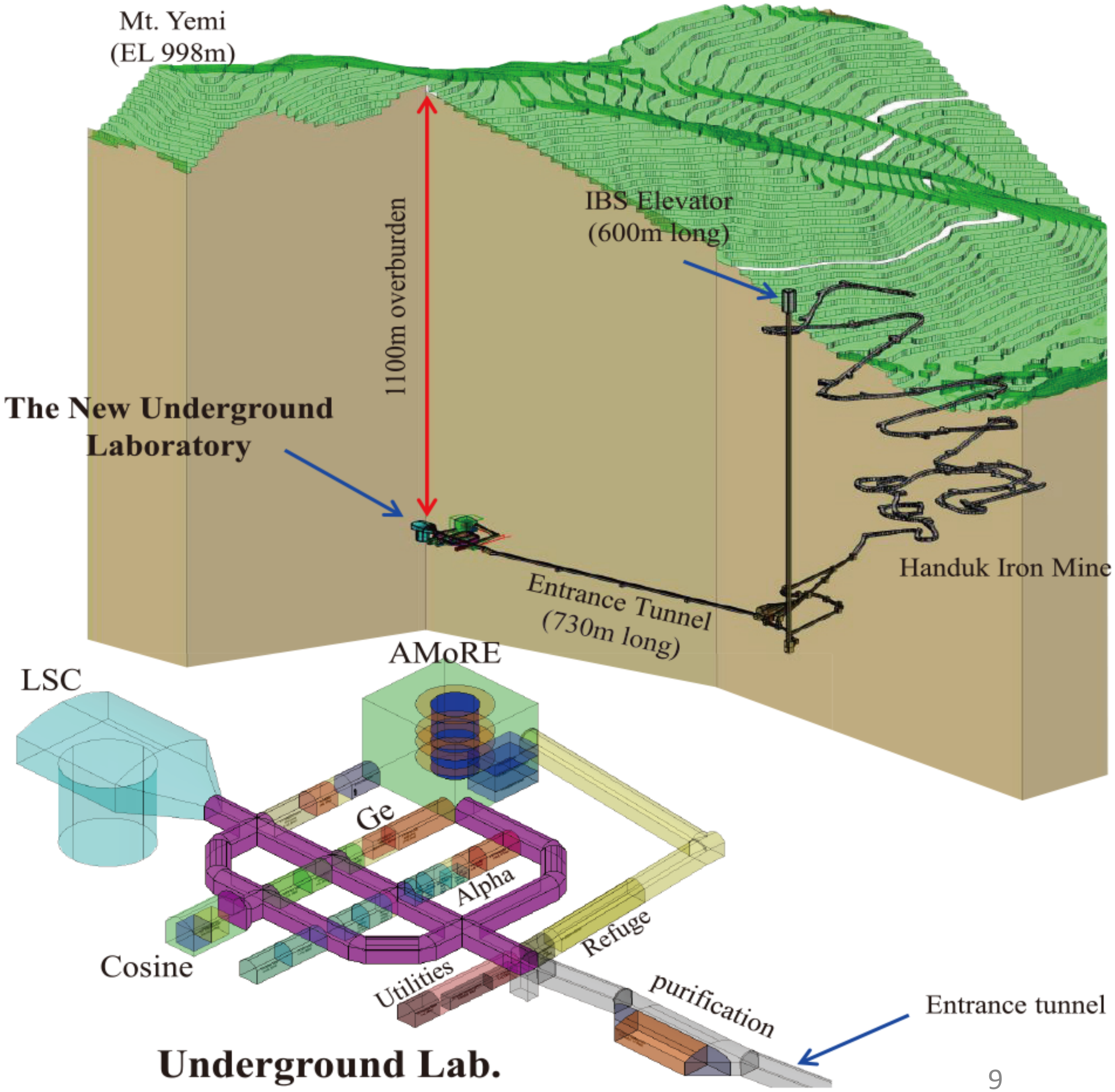
LS Telescope

2022 ? –
Precise measurement of
Solar neutrino fluxes,
Solar upturn,
Nucleon decay,
New physics

Yemilab @Handuk iron mine

~1 km depth

To be completed
at the end of 2020

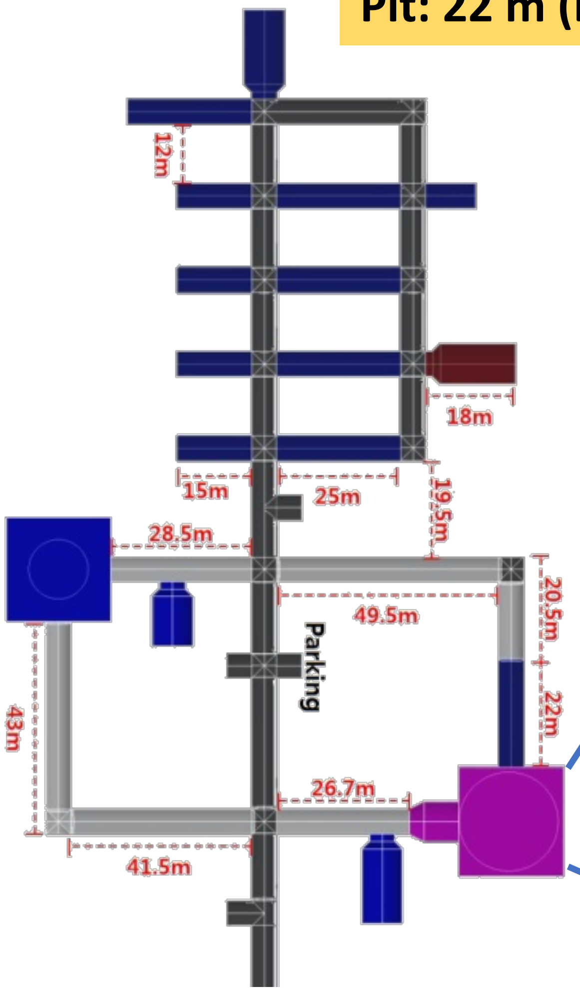


LSC @Yemilab

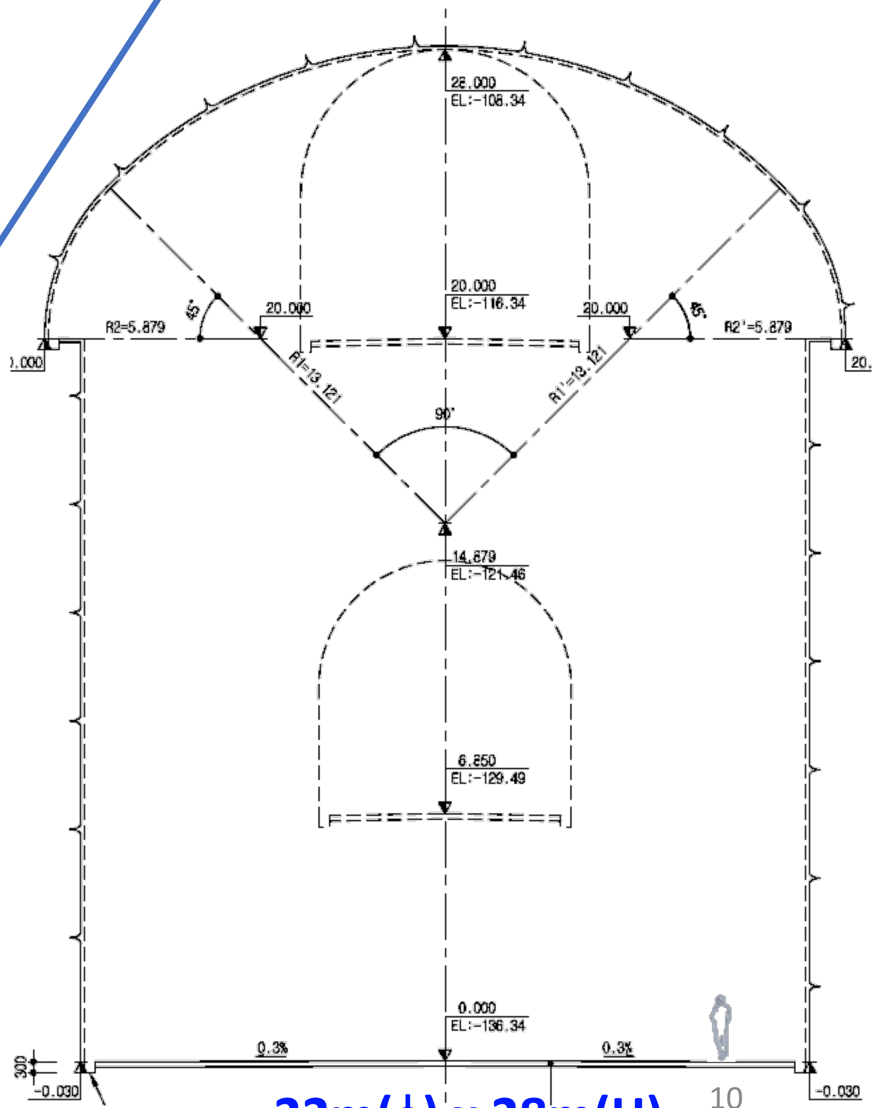
LSC = Liquid Scintillator Counter

~3 kton

Pit: 22 m (D) x 20 m (H)

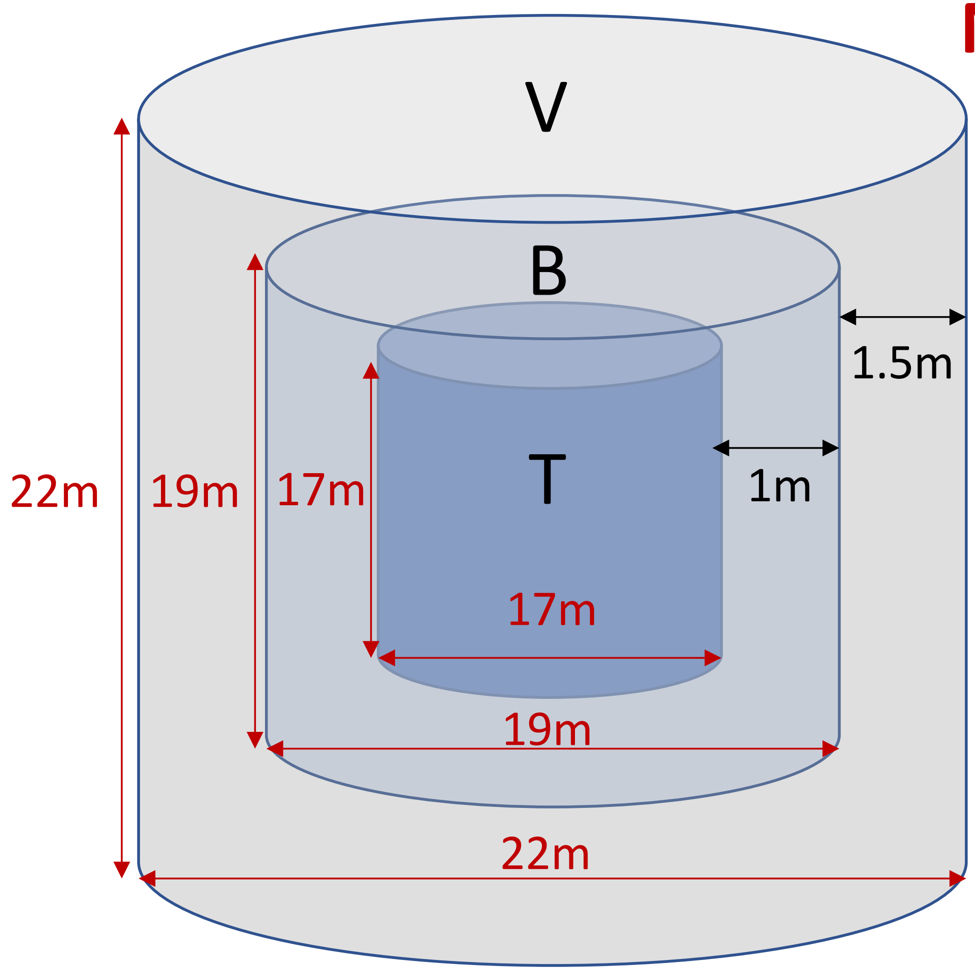


LSC Hall



22m(ϕ) x 28m(H)

Detector Concept (I)



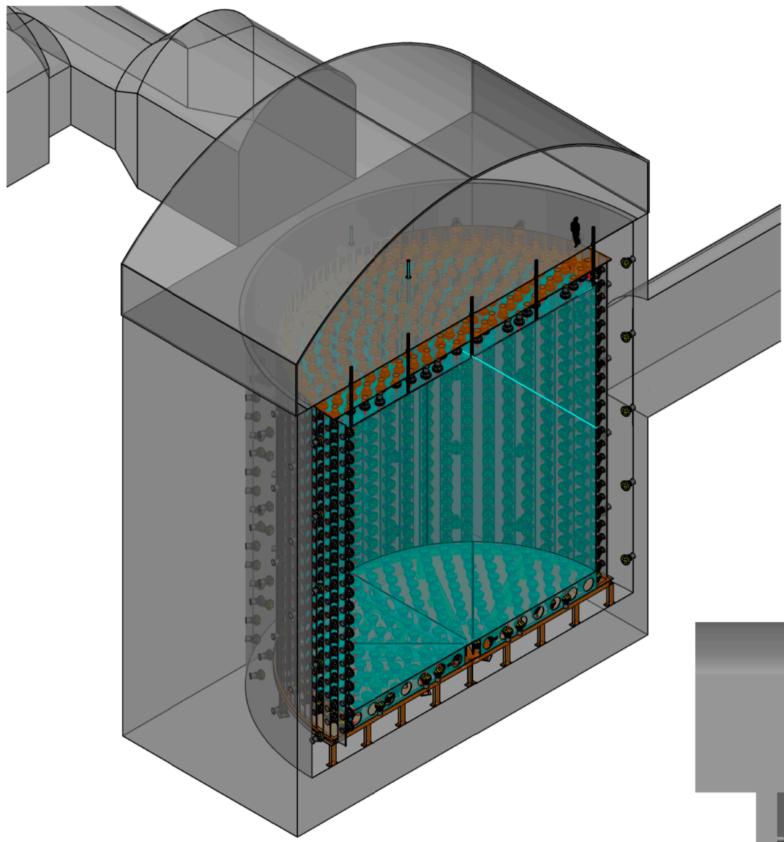
Neutrino Telescope @Yemilab

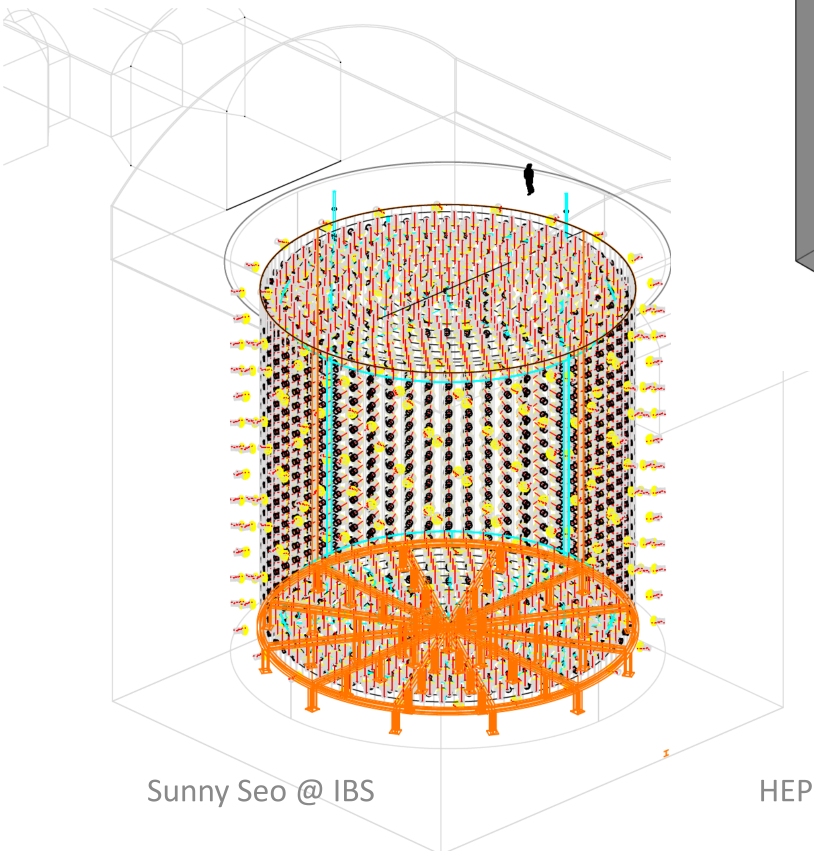
Target: 3.29 kton
Buffer: 1.44 kton
Veto: 2.96 kton

2000(3000,4000) x 20 inch PMTs = 20% (30, 40)% coverage

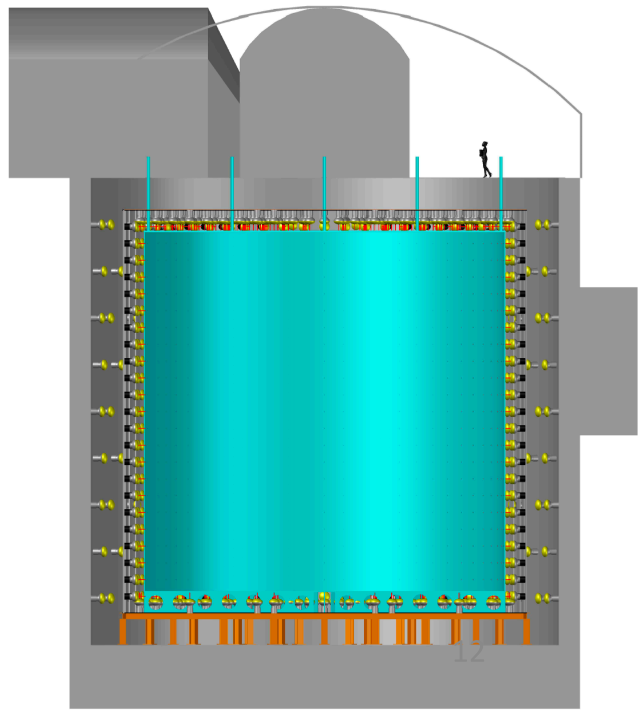
3000 x 5백만원 = 150억
4000 x 5백만원 = 200억

Detector Concept (II)





Credit: K.S. Park



ν Target Options

We can build

Liquid Scintillator (LS)

or

Water-based LS (WbLS) Detector

for the ν telescope at Yemilab.

WbLS Detector at Yemilab

arXiv:1903.05368

Neutrino Telescope at Yemilab, Korea

Seon-Hee Seo*

Center for Underground Physics,

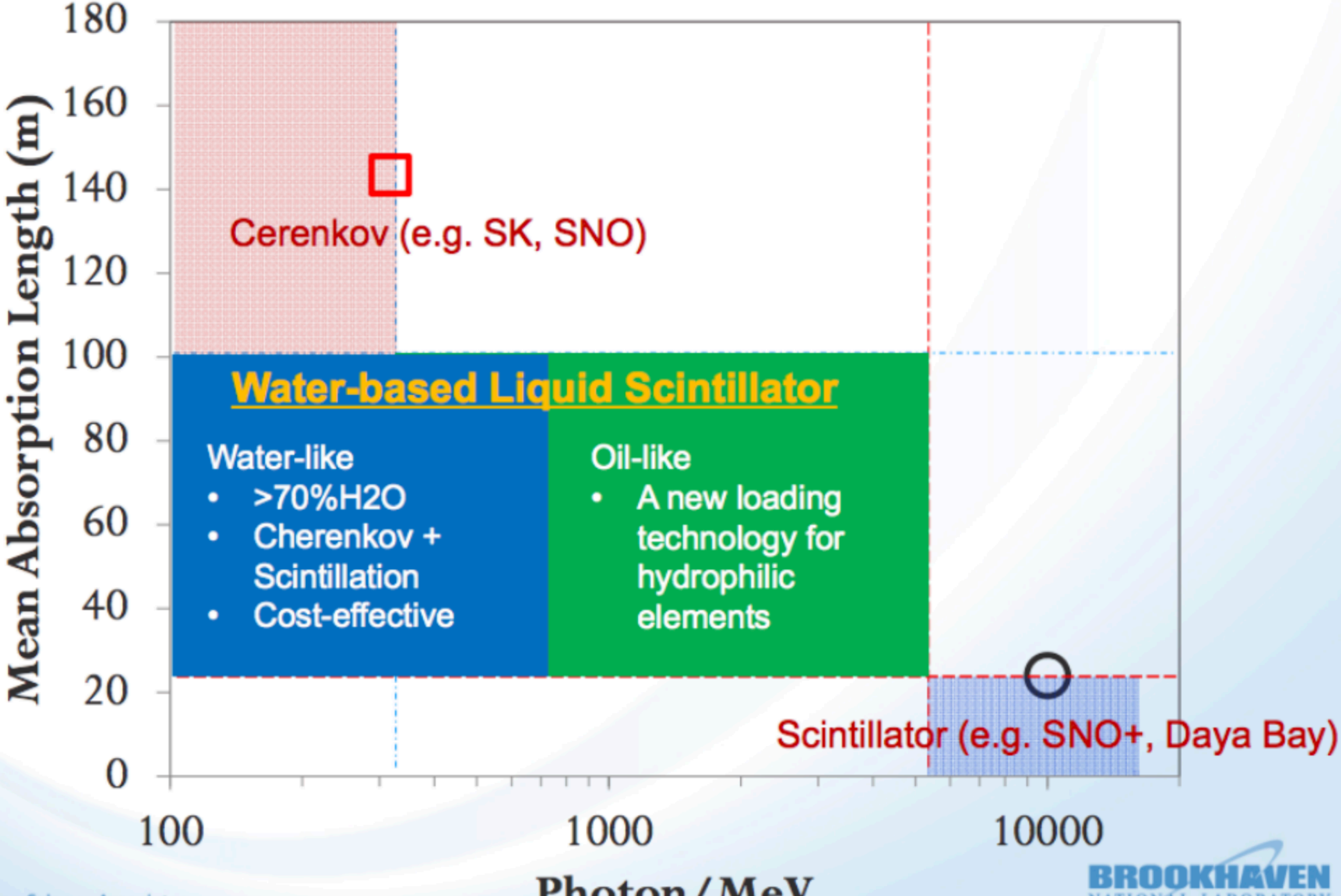
Institute for Basic Science,

55 Expo-ro Yuseong-gu, Daejeon 34126, Korea

(Dated: March 13, 2019)

A new underground lab, Yemilab, is being constructed in Handuk iron mine, Korea. The default design of Yemilab includes a space for a future neutrino experiment. We propose to build a water-based liquid scintillator (WbLS) detector of 4∼5 kiloton size at the Yemilab. The WbLS technology combines the benefits from both water and liquid scintillator (LS) in a single detector so that low energy physics and rare event searches can have higher sensitivities due to the larger size detector with increased light yield. No experiment has ever used a WbLS technology since it still needs some R&D studies, as currently being performed by THEIA group. If this technology works successfully with kiloton scale detector at Yemilab then it can be applied to future T2HKK (Hyper-K 2^{nd} detector in Korea) to improve its physics potentials especially in the low energy region.

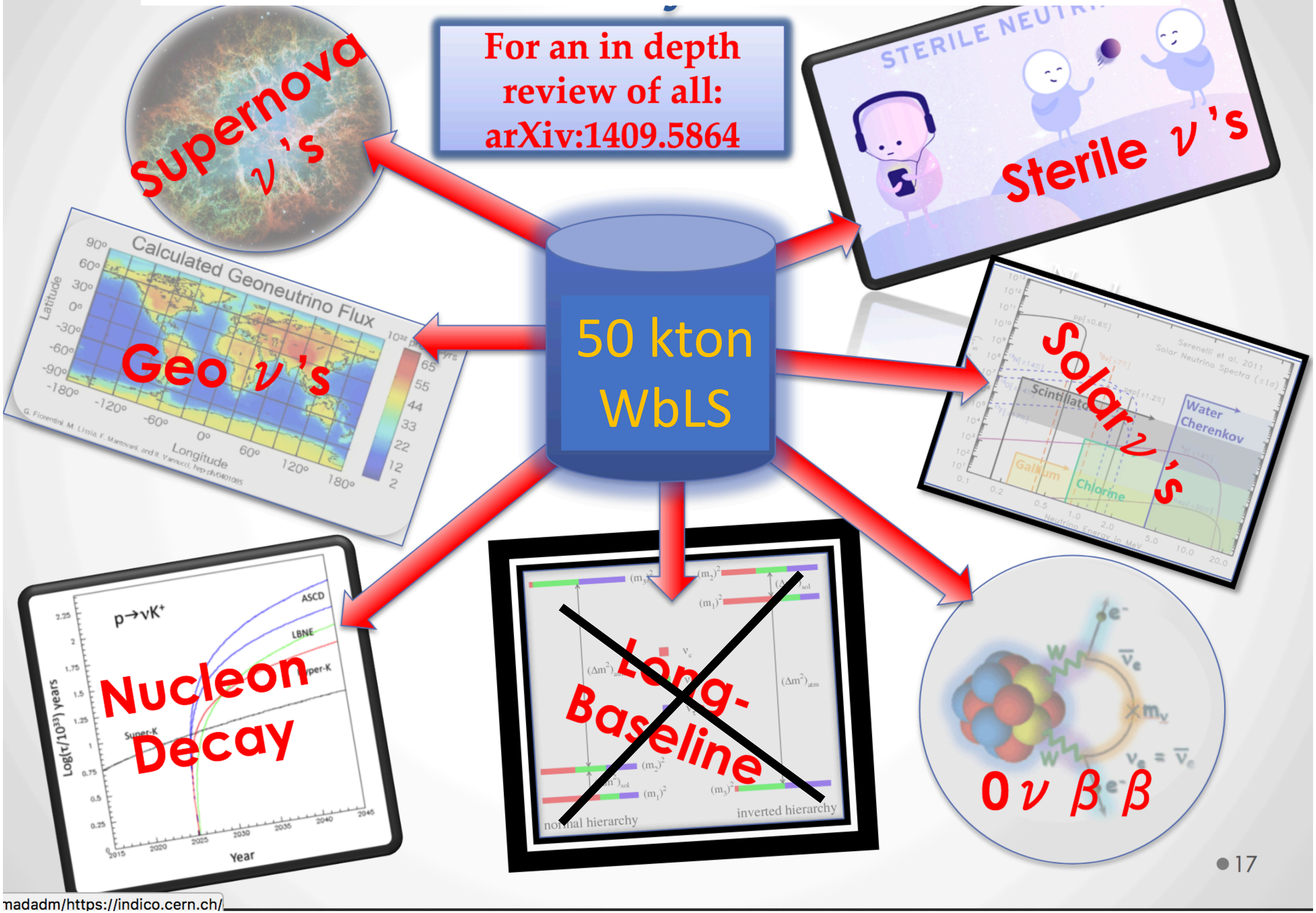
WbLS - Tunability



Comparison

	Water	LS	WbLS
New Tech	X	X	O
Light Yield	X	O	Δ
Absorption length	O	X	Δ
Scalability	O	X (Max. 20kton)	Δ
Directionality	O	X	Δ
Budget	$	$$$	$$

WbLS Future Neutrino Detector @Yemilab

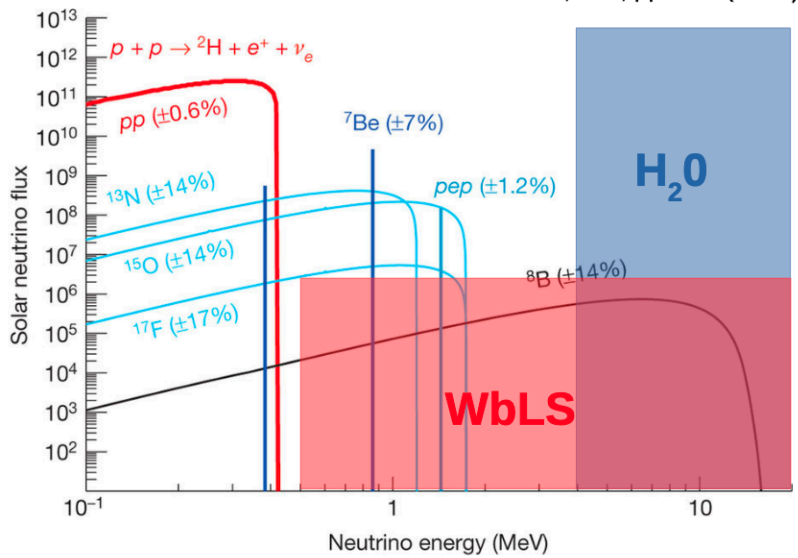


madadm/https://indico.cern.ch/

Solar ν Studies

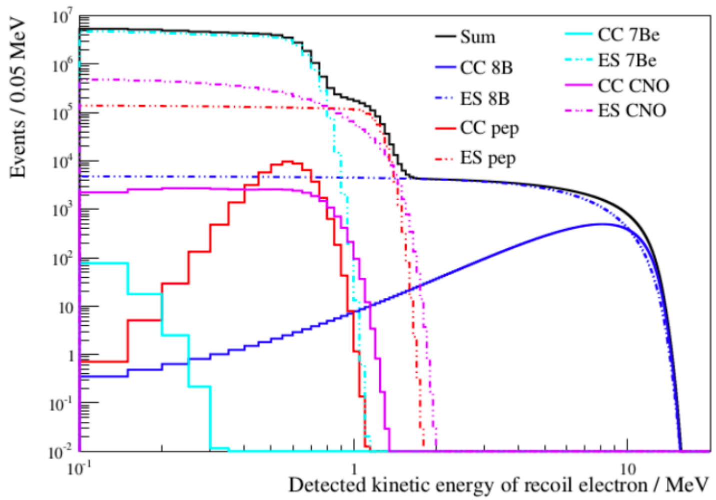
- The addition of scintillation dramatically **lowers the detection threshold**
  - Increases sensitivity to a wider range of solar ν's
  - Keeps directional information with Cherenkov
- Measuring the CNO and pep components of the solar flux allows to:
  - Study **solar metallicity**
  - Study **neutrino oscillations** and matter effects
- Isotope loading (^{7}Li, ^{71}Ga, ^{37}Cl) allows the detection of **charged current interactions** and not only elastic scatterings

Nature, 512, pp. 383 (2014)

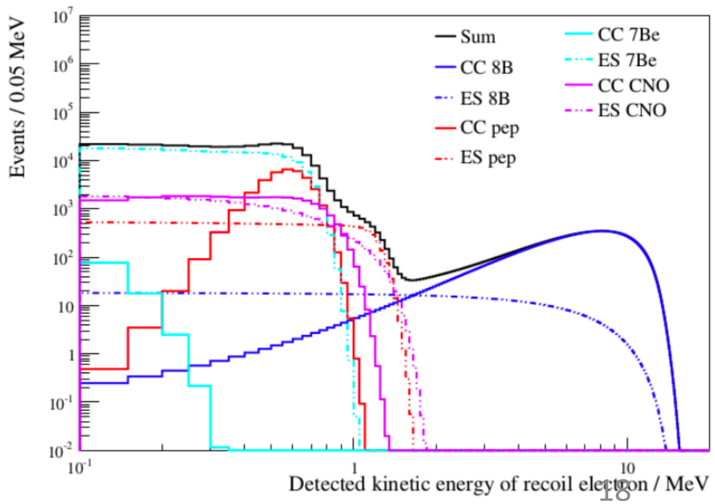


Predicted solar neutrino spectra in 30 kT Theia loaded with 1% ^{7}Li

More details: arXiv:1409.5864

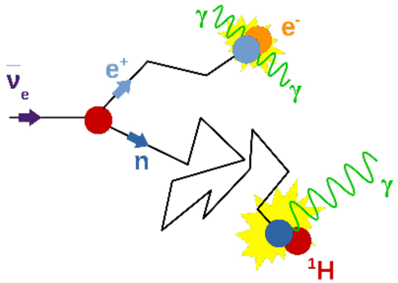


No directionality cut

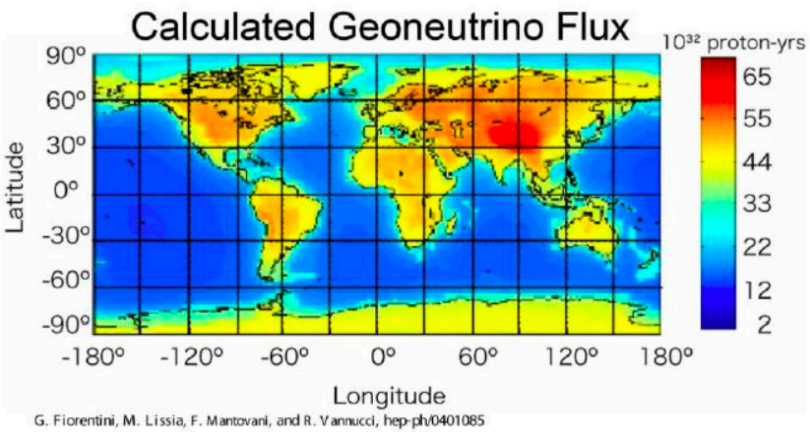


Directionality cut (to cut ES events)

Geo & Supernova Burst/Relic ν



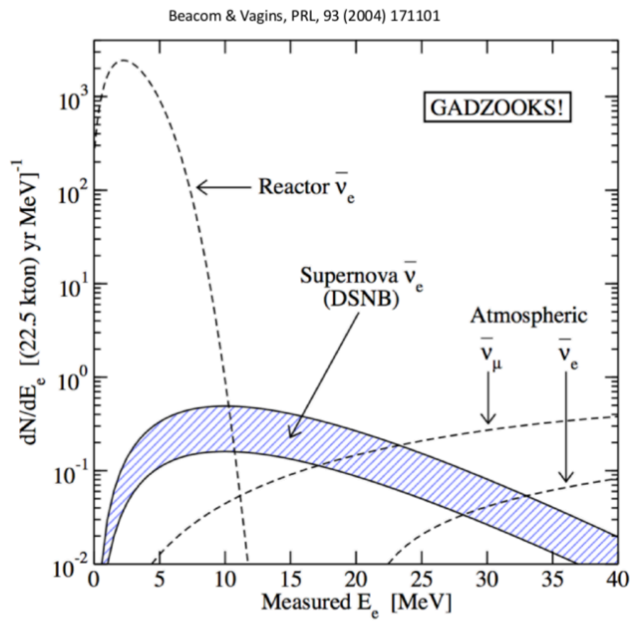
Antineutrinos detected through **Inverse Beta Decay** on H
→ Coincidence (e^+,n)



- A total of ~100 geoneutrinos have been detected by Borexino and KamLAND so far
- Given its size and low threshold, Theia would detect **the same number in a few months**
- Beneficial isotope loading: **Gd, Li, B**

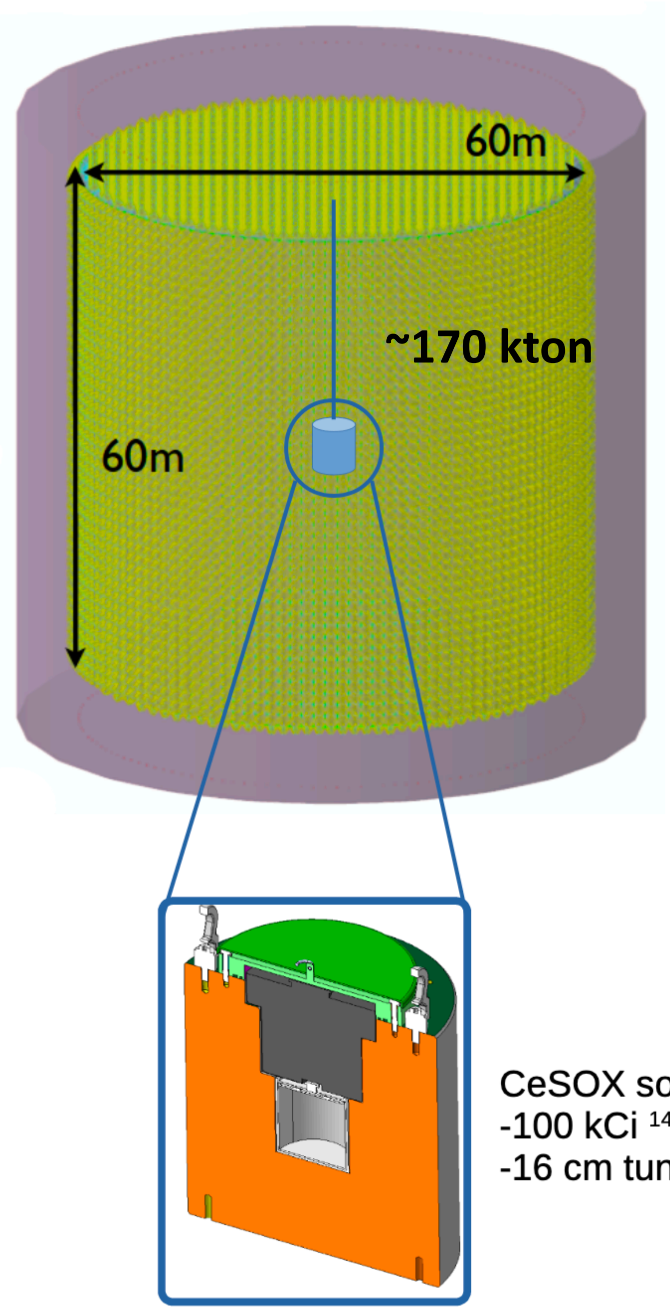
50 kton WbLS

- **~8000 events** for a 10 kpc SN
- Ability to tag IBD neutrons:
  → Selection of ES events and good angular reconstruction (~3°)
  → Crucial input for astronomers



- **Diffuse Supernova Background**:
  → About 1 event/10kt/year expected

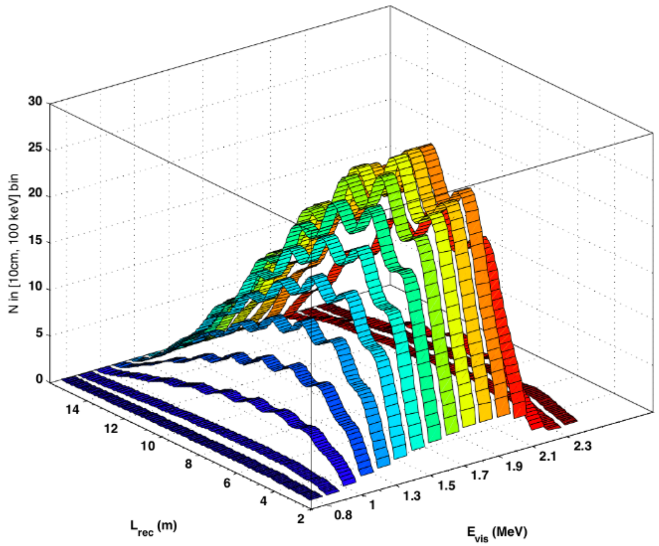
Sterile ν Search



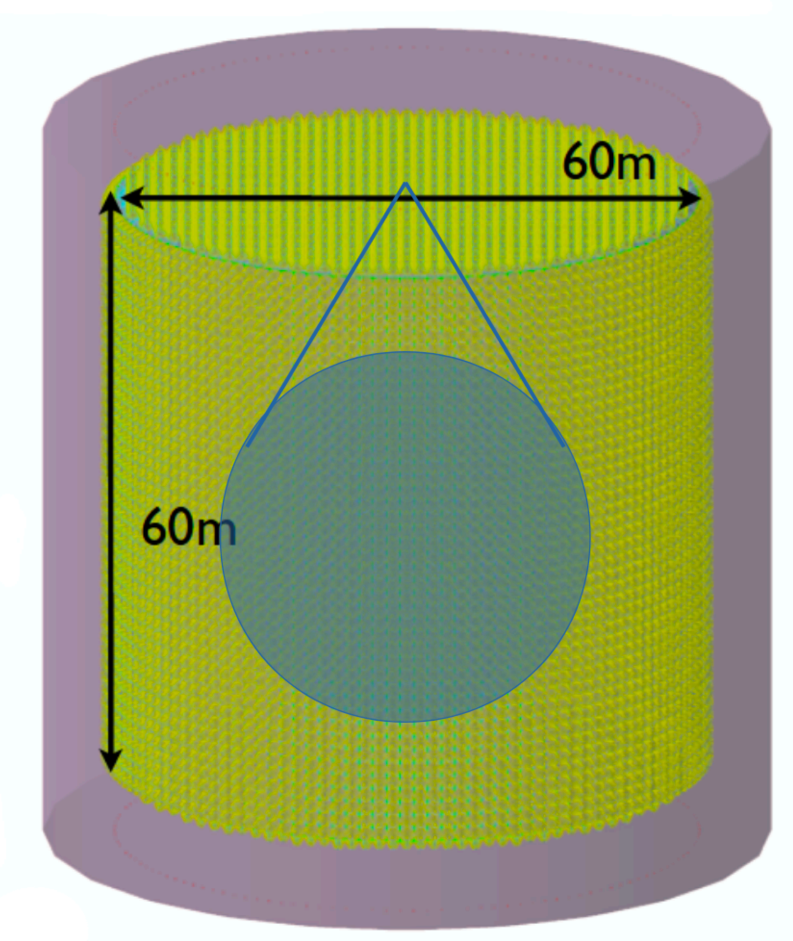
CeSOX source design:
-100 kCi ^{144}Ce-^{144}Pr
-16 cm tungsten shield

- Hypothetical **eV-scale sterile neutrino** whose existence is accessible through **short baseline oscillations**
- Concept from **CeSOX/CeLAND** (Phys.Rev.Lett. 107 (2011) 201801):
  - Intense radioactive source in or next to Theia
  - Observation of a deficit and a spectral distortion as a function of distance
  - Requires good energy and position reconstruction
- **IsoDAR/DAEδALUS**: High intensity ^{8}Li decay at rest

Energy spectrum distortion as a function of distance in CeSOX

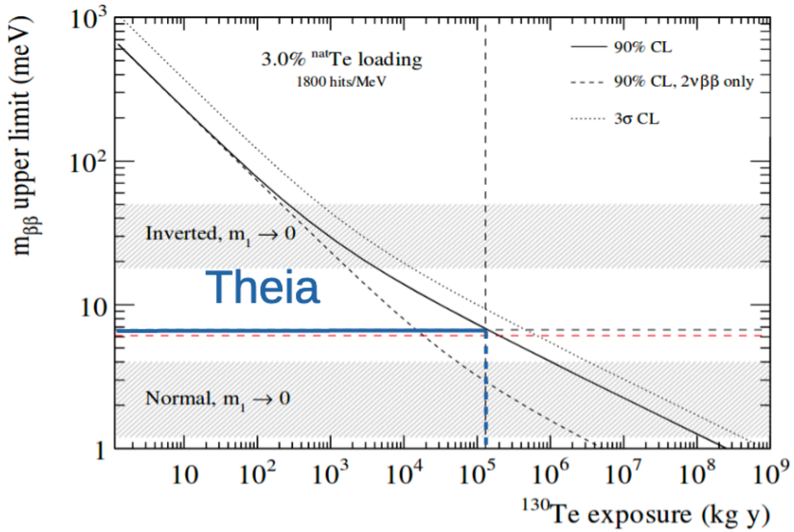


0ν2ββ Search



- 0ν2β approaches:
  - **Entire detector** filled with WBLS loaded with a 2β isotope
    → "SNO+-like"
  - **Only inner balloon** filled but with a higher concentration of 2β isotope
    → "KamLAND-Zen-like"
- **Fiducialization** and **tagging techniques** (triple coincidence, directionality, etc..) greatly reduce backgrounds
- Isotopes in consideration: **^{136}Xe and ^{130}Te**
- **Goal: Reach $T^{0\nu2\beta}_{1/2}$ ~ 10^{28} years**

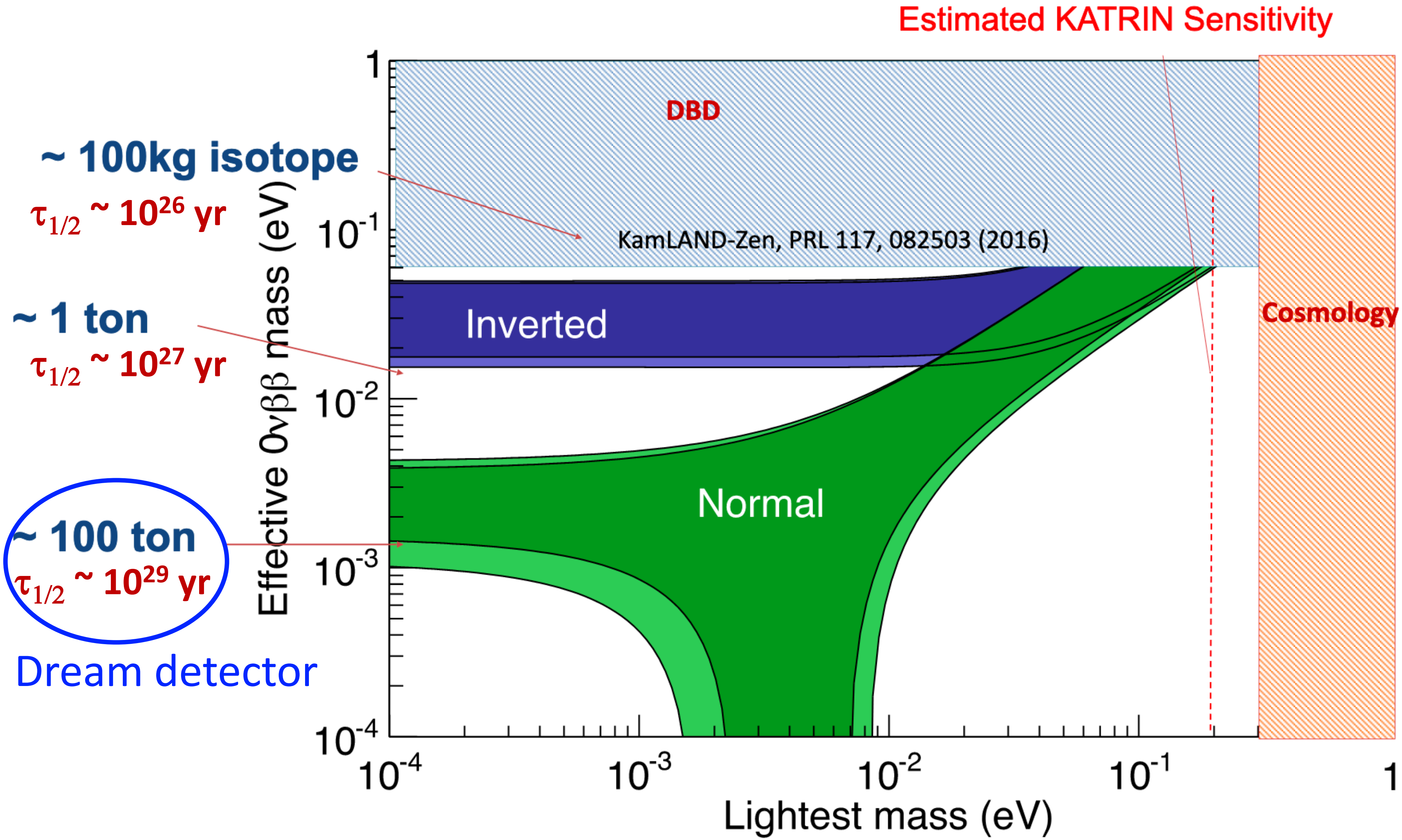
Assumptions:
- 8 m balloon
- 3% Te loading
(300 tonnes)



Limit on $T^{0\nu2\beta}_{1/2}$ = 1.2 x 10^{28} years

Theia will completely probe the IH part of the mass phase space!

… and start probing the NH part with a higher isotope loading!



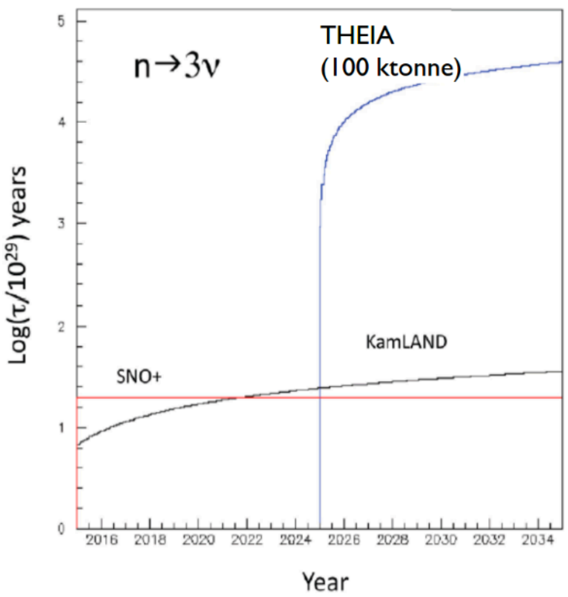
~ 1 ton next generation experiments:

nEXO, NEXT-2.0, PandaX-III 1t, Kamland2-ZEN, SNO+-II, LEGEND-1000, CUPID

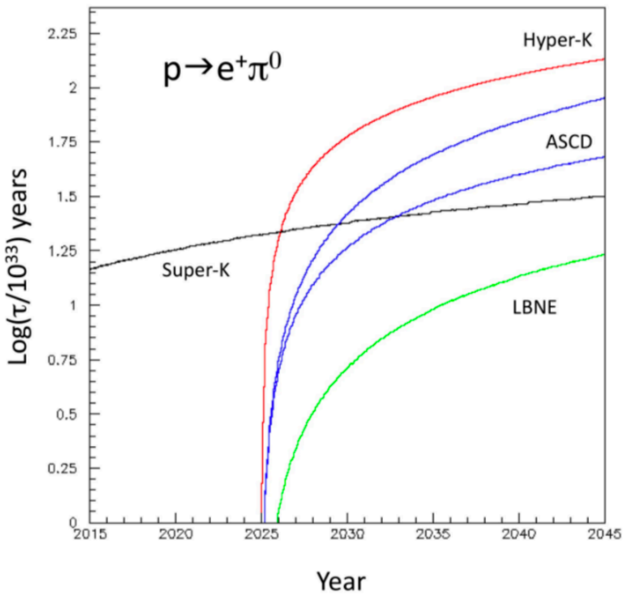
Nucleon Decay

- **Huge size**, **deep location** and **scintillation light** make Theia an impressive nucleon decay detector
- Scintillation light allows the **observation of K^+** created upon a proton decay as well as the gammas emitted upon an **invisible neutron or proton decay** (~6 MeV)
- **Neutron tagging** enhances Theia's sensitivity for proton decay and can be further improved by **isotope loading**

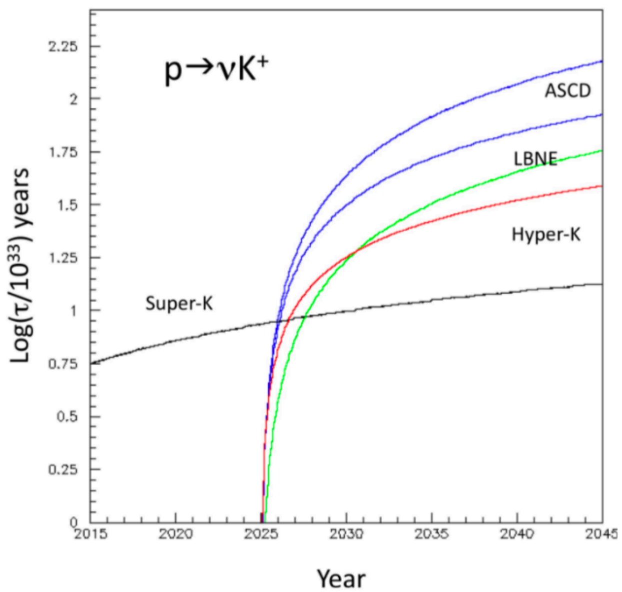
$n \rightarrow 3\nu$



$p \rightarrow e^+\pi^0$

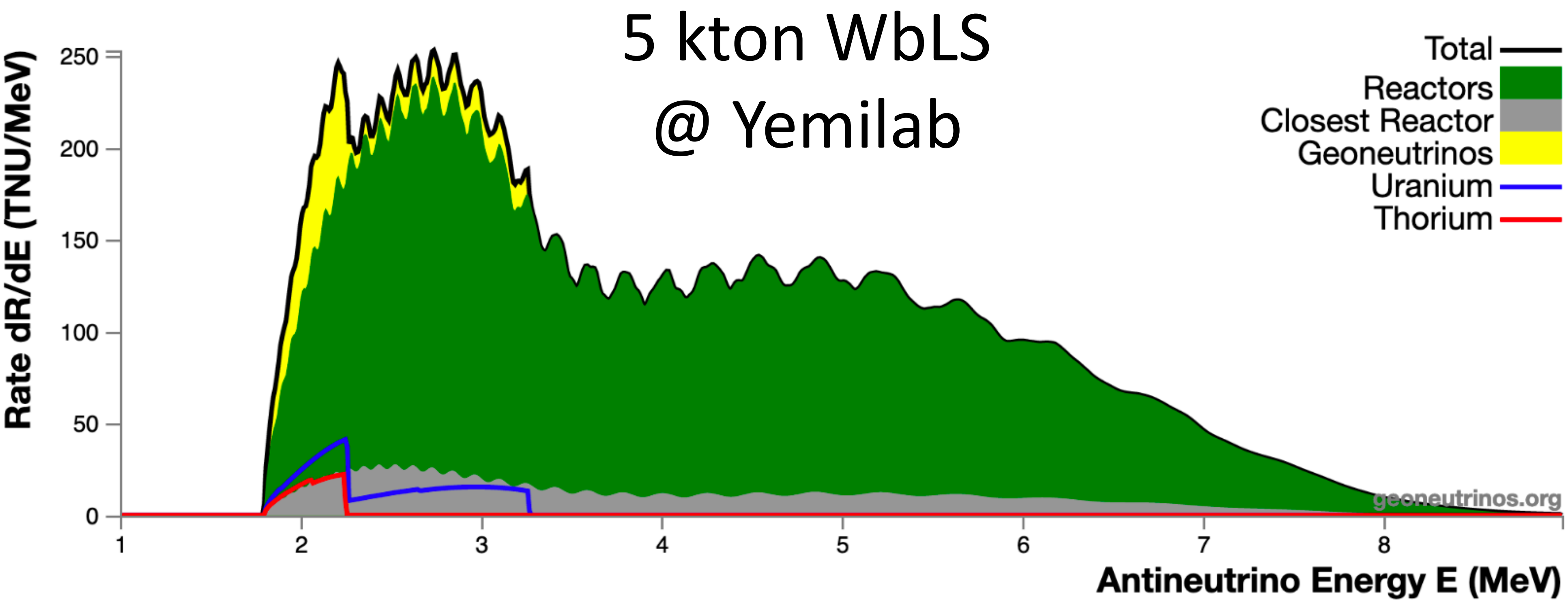


$p \rightarrow \nu K^+$



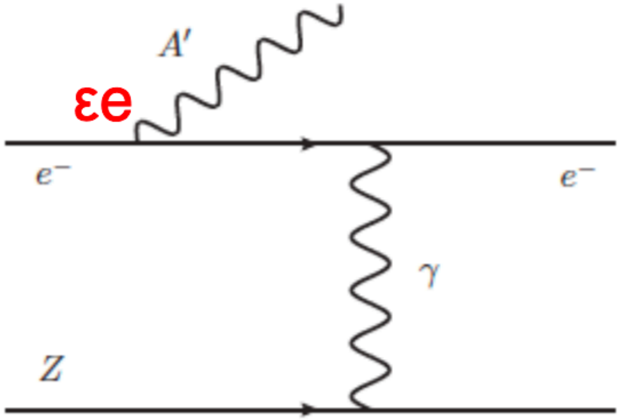
ASCD: Theia 100kT WbLS (+neutron tagging)

Reactor ν Studies



- Closest reactor complex: Hanul (~65 km)
- ~2,000 neutrinos/year with ν oscillation (100% detection efficiency, 5 kton WbLS)

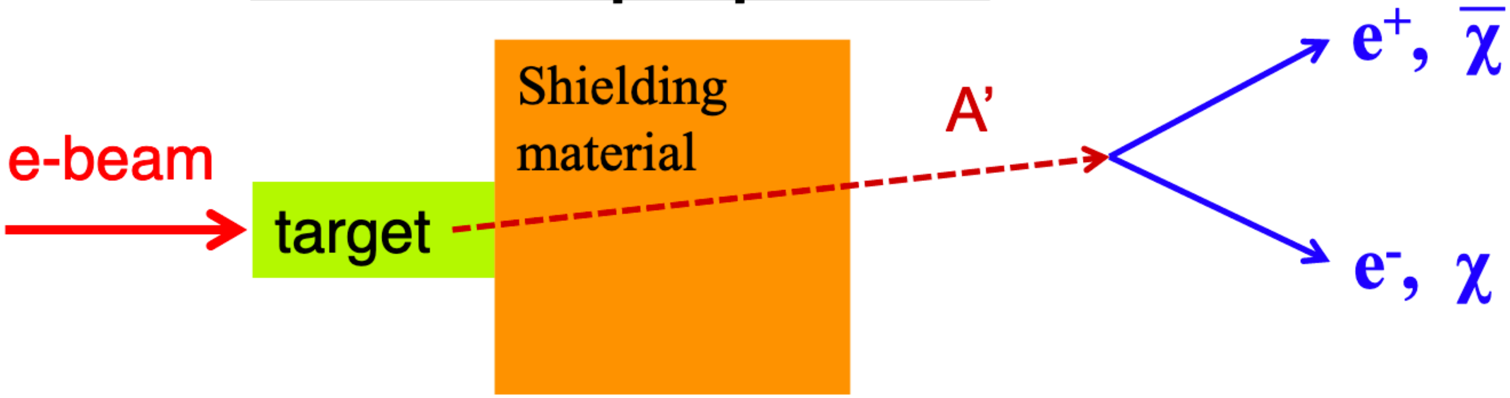
Dark Photon Search (I)



See H. Park's talk
at Dark Matter session

Production rate: ~ $\varepsilon^2 \sigma_{brem}$

e-beam dump experiment

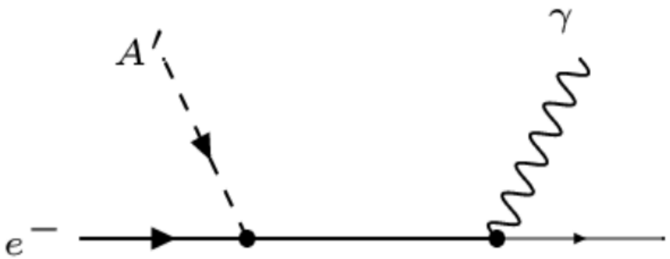


- $m_{A'} > 2\,m_e$: A' -> e+ e-
- $m_{A'} < 2\,m_e$: A' -> 3 γ (Highly suppressed)

~ 10 keV < $m_{A'}$ < 1 MeV -> Dark-Photon Dark Matter

Dark Photon Search (II)

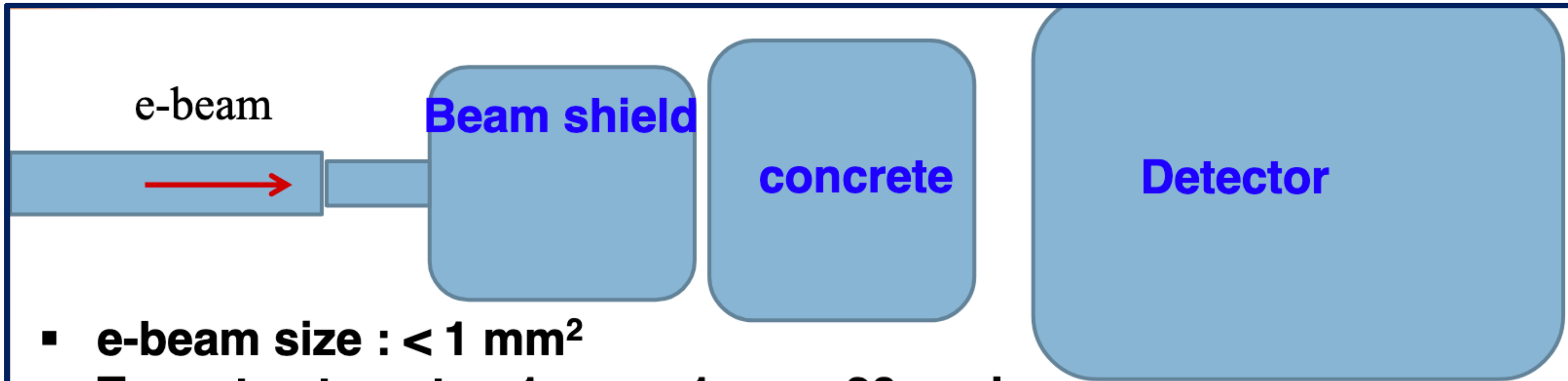
- **We are searching for $m_{A'} < 1$ MeV**
  - A' detection with Compton-like process



- $\sigma \sim \alpha^2\varepsilon^2$

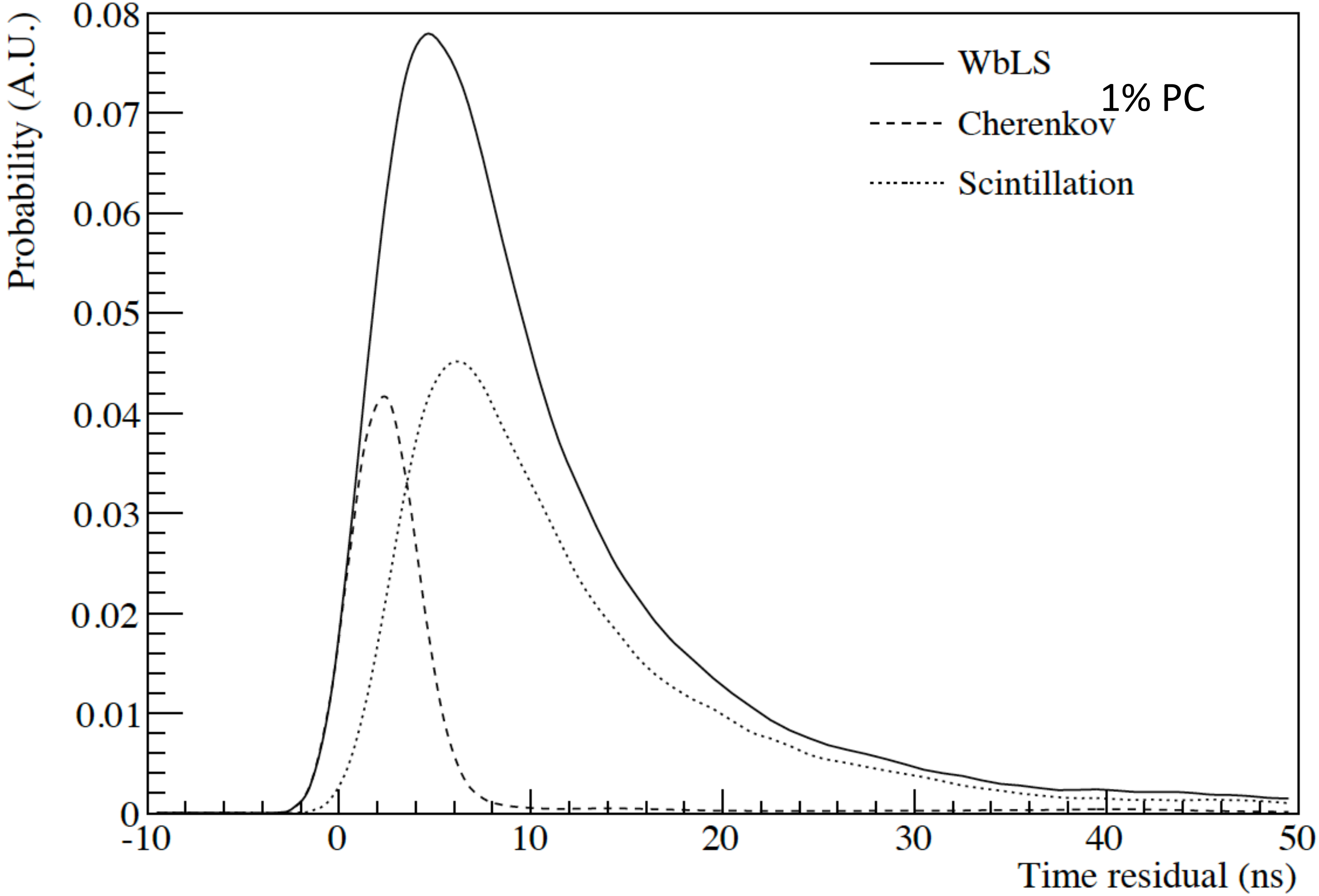
See H. Park's talk at Dark Matter session

- X-section is dominant in ~ 1 MeV



- **e-beam size : < 1 mm^2**
- **Tungsten target: ~ 1 cm x 1 cm x 20 cm long**
- **Beam shield with iron: 1 m x 1m x ~ 2 m**
- **Concrete: ~ 1 m thick**
- **Beam window and target can be melted with 1 MW beam power: 1 MW/1 mm^2**

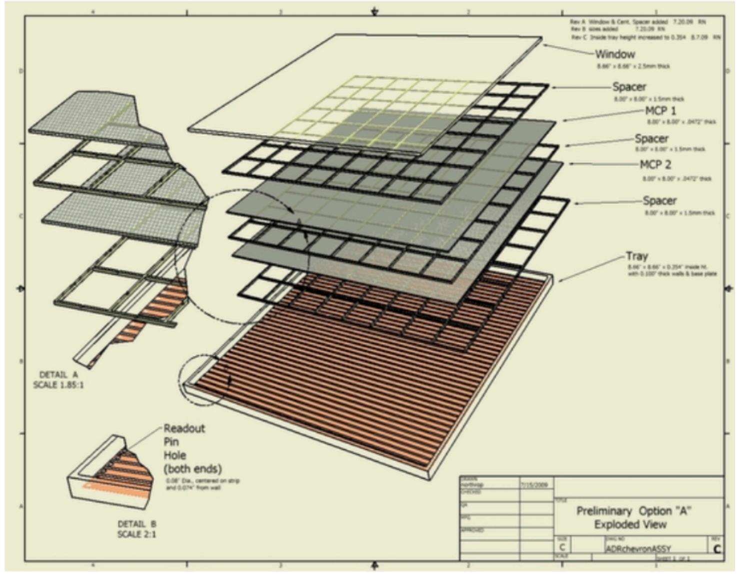
Time profile of PMT hits from Cherenkov and scintillation light

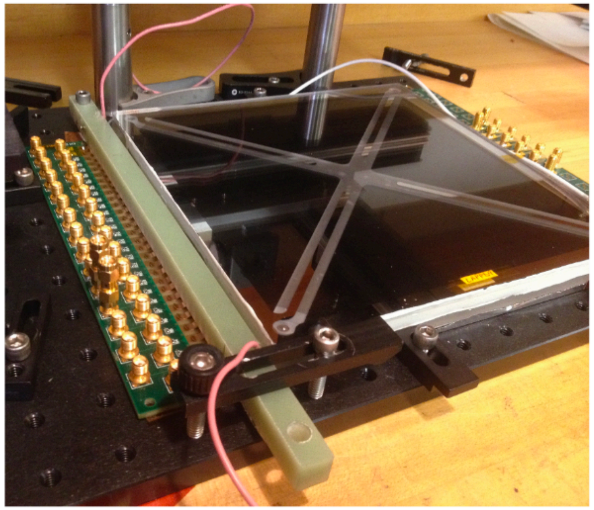


Large Area Picosecond PhotoDetector

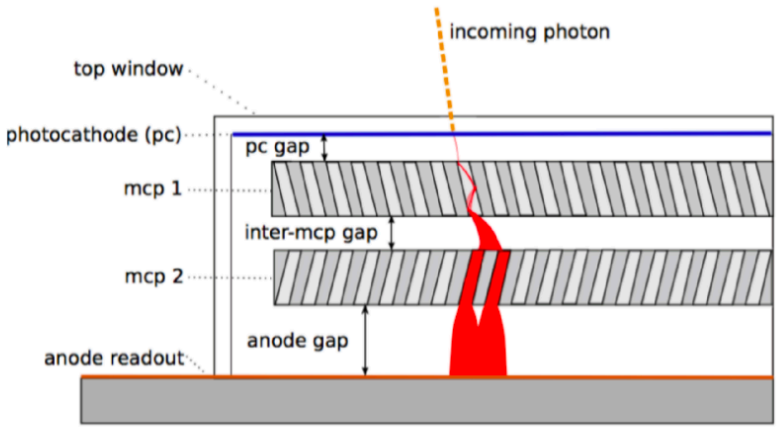
LAPPD

- Large, flat **MCP-based** photosensors
  - Time resolution: **~60 picoseconds**
  - Spatial resolution: **< 1 cm**
- Design includes an **intrinsic PSEC-4 readout** system
- Manufactured by the **Incom company**, being tested extensively at **Iowa State University** and expected to be deployed in the **ANNIE** detector
- **More information**: A Brief Technical History of the Large-Area Picosecond Photodetector (LAPPD) Collaboration, arXiv:1603.01843





R&D



Conclusion for WbLS ν Telescope

- ❑ Water-based Liquid Scintillator (WbLS) combines the advantages of both water and liquid scintillator: directionality, lower absorption, good energy resolution, low energy threshold

- ❑ WbLS: environment friendly, cost effective, large detector

- ❑ WbLS is not a proven technology yet: R&D on-going (USA, Germany)
- ❑ Fast timing and high efficient photo detector R&D is also needed.

- ❑ If successful then it covers broad physics programs: solar ν, nucleon decay, 0νDBD, Supernova (relic) ν, Geo, dark γ, etc

- ❑ If WbLS R&D successful, can be applied to KNO.

Why Important ?

- Developing new technologies

WbLS, LAPPDs, water+oil purification system, etc

- The first neutrino telescope in Korea

~3 kton

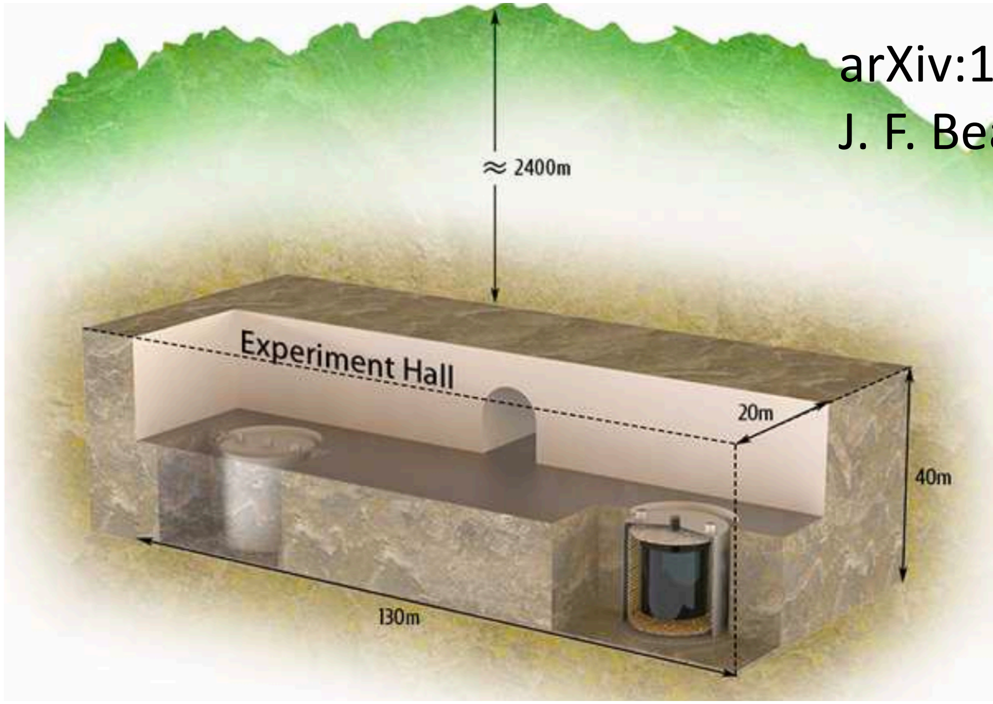
- Good demonstrator for KNO

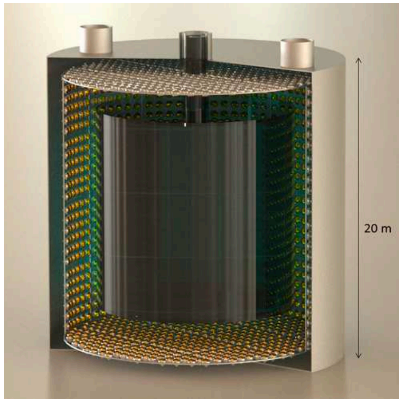
~3 kton vs. 260 kton

China @Jinping

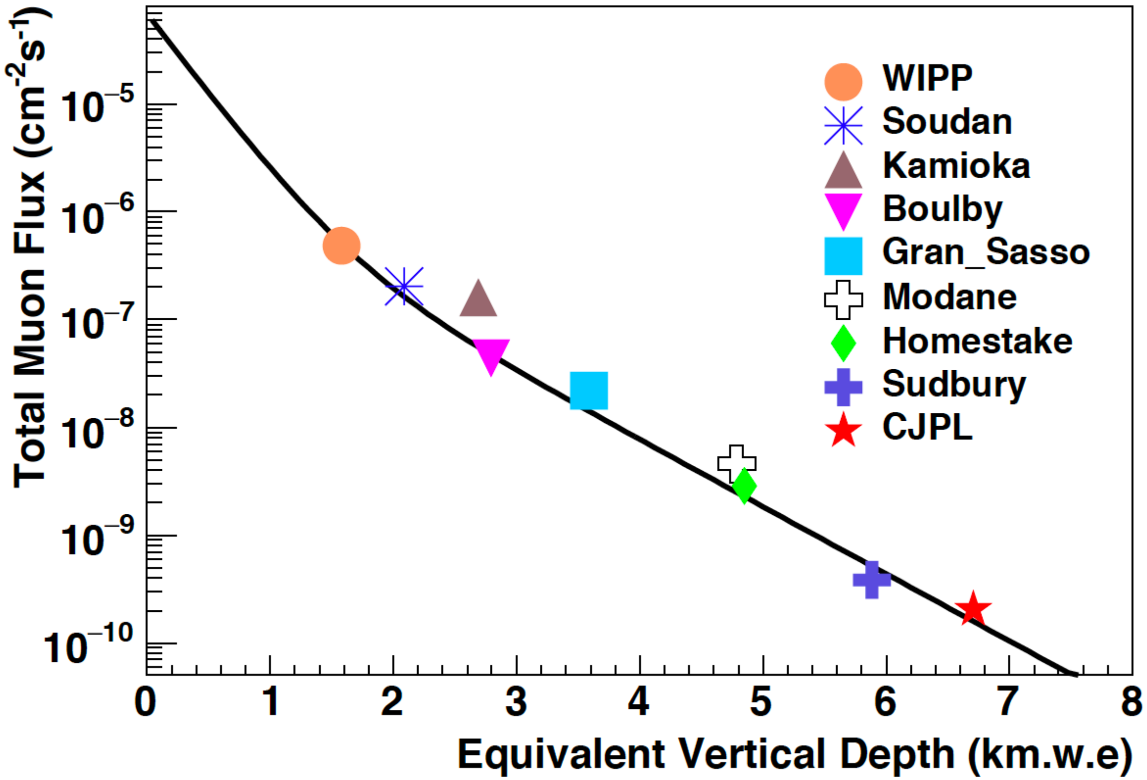
1~4 kton LS or water-based LS

arXiv:1602.01733
J. F. Beacom et al.





OR



Benefits

- To build up more experts on ν physics.

  Good preparation for KNO

- Developing new technologies

  WbLS, LAPPDs, water+oil purification system, etc

- Multi-messenger neutrino astronomy for more than 10 years

- Precise measurements of solar ν fluxes

Plan

- Proof of concept (POC): 50~100 kg WbLS @ surface
- Prototype: ~3 ton WbLS (D: 2.2m, H: 2.2m cylinder)
  @ surface or J-PARC for beam test
- Full detector: ~3 kton (D: 17 m, H: 17 m cylinder) WbLS
  @Yemilab

Rough Timeline & Budget (I)

❑ Phase 1 (2020 -- 2022)

- **POC: 50~100 kg WbLS**
- Budget: ~$0.2M
- 2020 – 2021: WbLS R&D and construction
- 2021 – 2022: PMT test using POC at surface

❑ Phase 2 (2022 -- 2024)

- **Prototype: ~3 ton WbLS**
- Budget: ~$2M
- 2022–2023: construction of the prototype detector
- 2023–2024: fine-tuning, taking data at surface

Rough Timeline & Budget (II)

❑ Phase 3 (2024 --)

- **Full 3 kton WbLS**
- Budget: $20 ~ $40M, 2k~4k PMTs
- 2024 – 2024: arcylic/STS vessel production
- 2025 – 2025: PMT installation
- 2026: Fill liquid, Electronics installation
  and start data-taking @Yemilab

❑ Phase 4 (2023 --)

- **KNO 260 kton WbLS Detector ??**

(** beyond scope of this proposal.)