History of Domestic Experiments in KOREA

경북대학교 물리학과 김홍주

KFCC brainstorming workshop

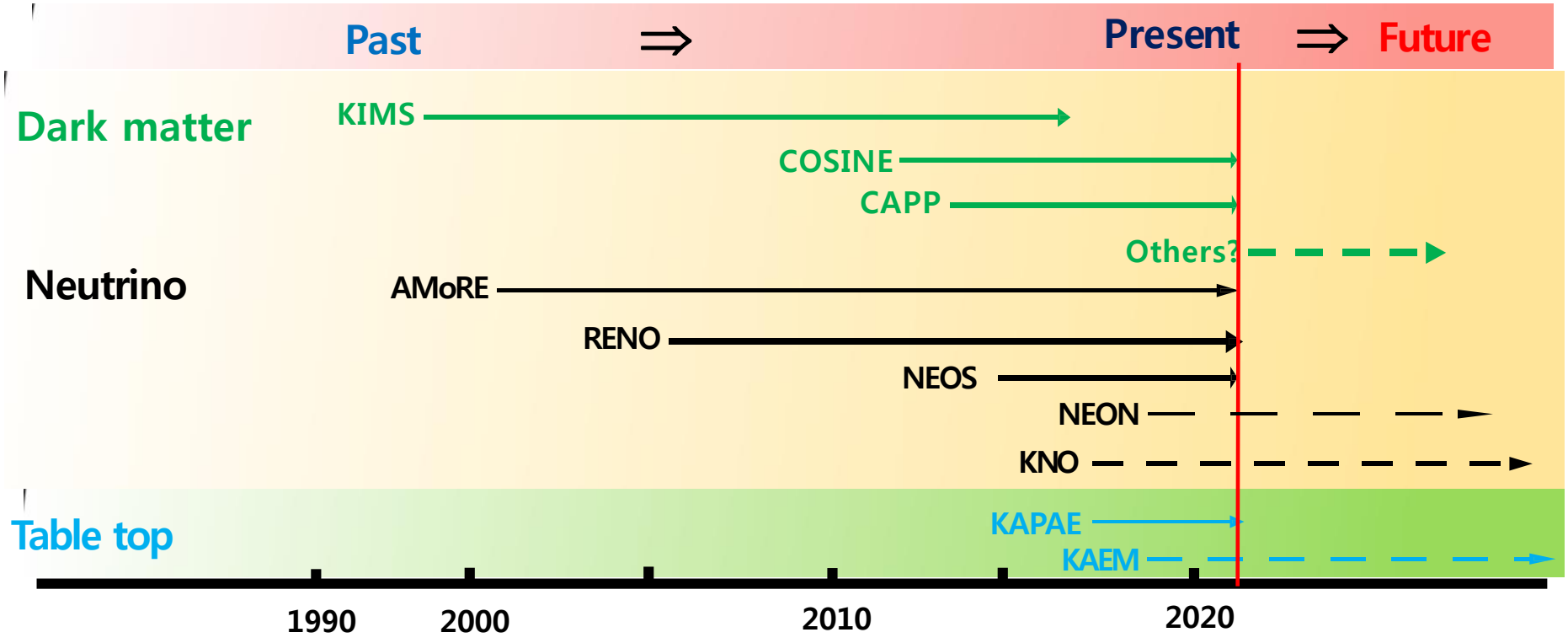
12-14, Nov, 2021, Kyungju

Experiment in KOREA

Past, current and future

It is not full overview but with my bias,
excuse me if I miss some activities

Brief history of domestic experiments
(Including R&D periods)
(Purely personal view)



History of KIMS (Korean Invisible Mass Search)

- 1997 : First discussion on WIMP search (cryogenic detector).
- 1997-2002 : Feasibility studies on CsI(Tl) crystals for DM search.
  (H. J. Kim, S. K. Kim, Y. D. Kim ICHEP98, NIMA 457 (2001) 471
- 2000 : Creative Research Funding approved (PI : S.K. KIM)
- 2000 : ChyungPyung (CPL) underground lab was eastabilished.
- 2003 : Construction of Y2L.
- 2005. 12 – 2006. 3 4 CsI crystal ran → limits (PLB paper)
- H. S. Lee et al. (KIMS Collaboration), Phys. Rev. Lett. 99, 091301 (2007).
- 2009. 9 – 2012. 8. 12 CsI crystals → limits, modulations.
- 2012. 10 – 2013. 12 12 CsI crystals in test mode. → PMT upgrades.
- 2012. New limits of KIMS, PRL (2012), AP (2012)
- 2014. Low mass dark matter search, PRD (2014)
- 2015 – Now Test facility for COSINE-100 experiments

KIMS (Korea Invisible Mass Search)

KIMS collaboration members

Seoul National University: H.C.Bhang, J.H.Choi, S.H. Choi, K.W.Kim, S.C.Kim, S.K.Kim, J.H.Lee,J.I.Lee , J.K.Lee, M.J.Lee, S.J.Lee, J.Li, X.Li, S.S.Myung,S.L.Olsen, I.S.Seong

Sejong University: U.G.Kang, Y.D.Kim

Kyungpook National University: H.J.Kim, J.H.So, J.Y.Lee

Yonsei University: Y.J.Kwon

Ewha Womans University: I.S.Hahn

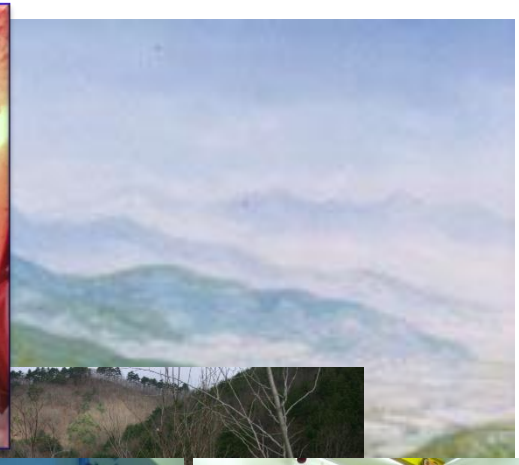
Seoul City University : Douglas Leonard

Korea Research Institute of Standard Sciences : Y.H.Kim, K.B.Lee, M.K. Lee

Tsinghua University : Y.Li, Q.Yue, J. Li

Early R&D for KIMS at CPL (1997-2002)

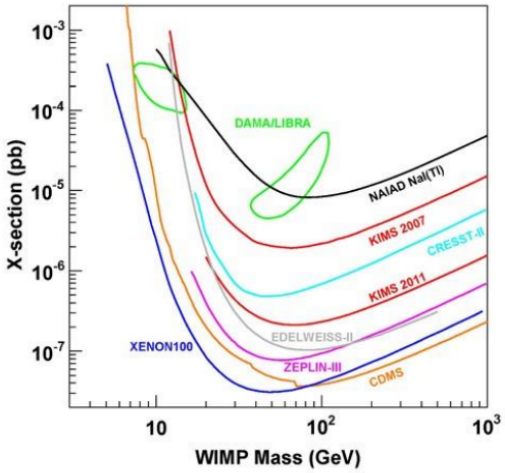
Darkmatter search in Korea



KIMS

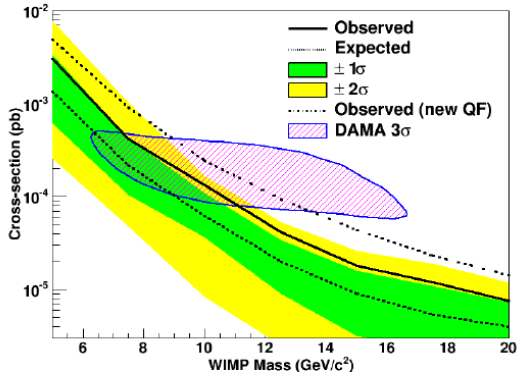
KIMS (Korea Invisible Mass Search) CsI experiment

PRL 108 181301 (2012)

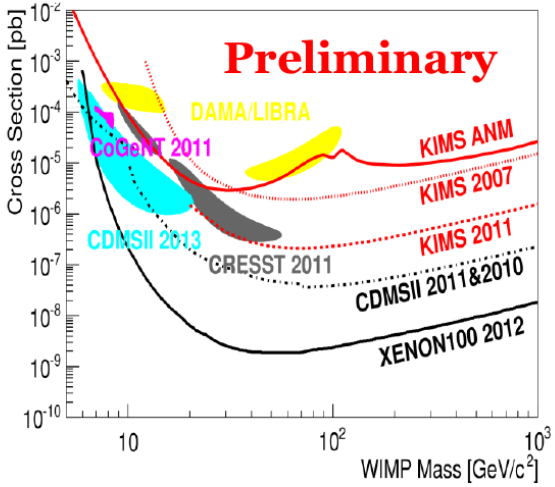


- 12 low-background **CsI crystals** (104.4 kg)
- 2.5 year data (2009-2012)
- Background : 2~3 count/kg/day/keV (dru)
- Model-independent rejection of DAMA signals interpreted as WIMP-Iodine interaction

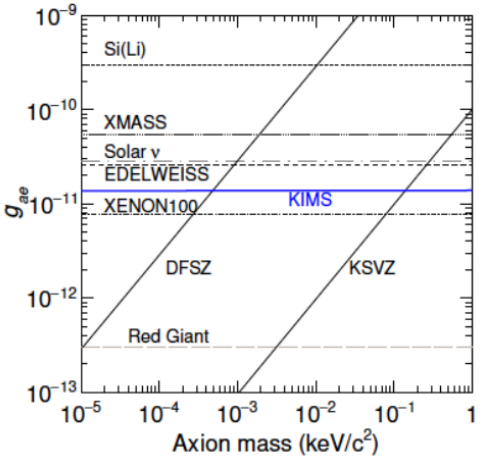
PRD 90 052006 (2014)



Annual Modulation



JHEP 06 011 (2016)



COSINE collaboration (Since 2015)

KIMS and DM-Ice joint effort to search for dark matter interactions in NaI(Tl) scintillating crystals.
(Goal to **test DAMA/LIBRA experiment**)

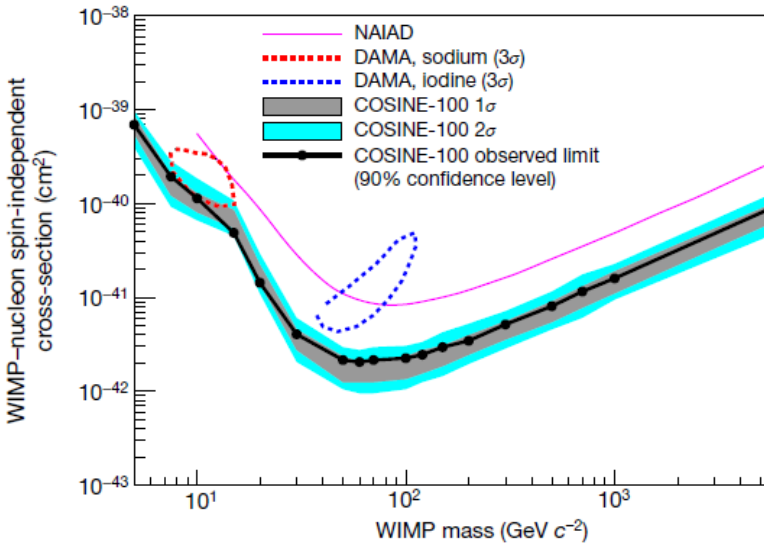
Data taking 2016 : Nature 2018

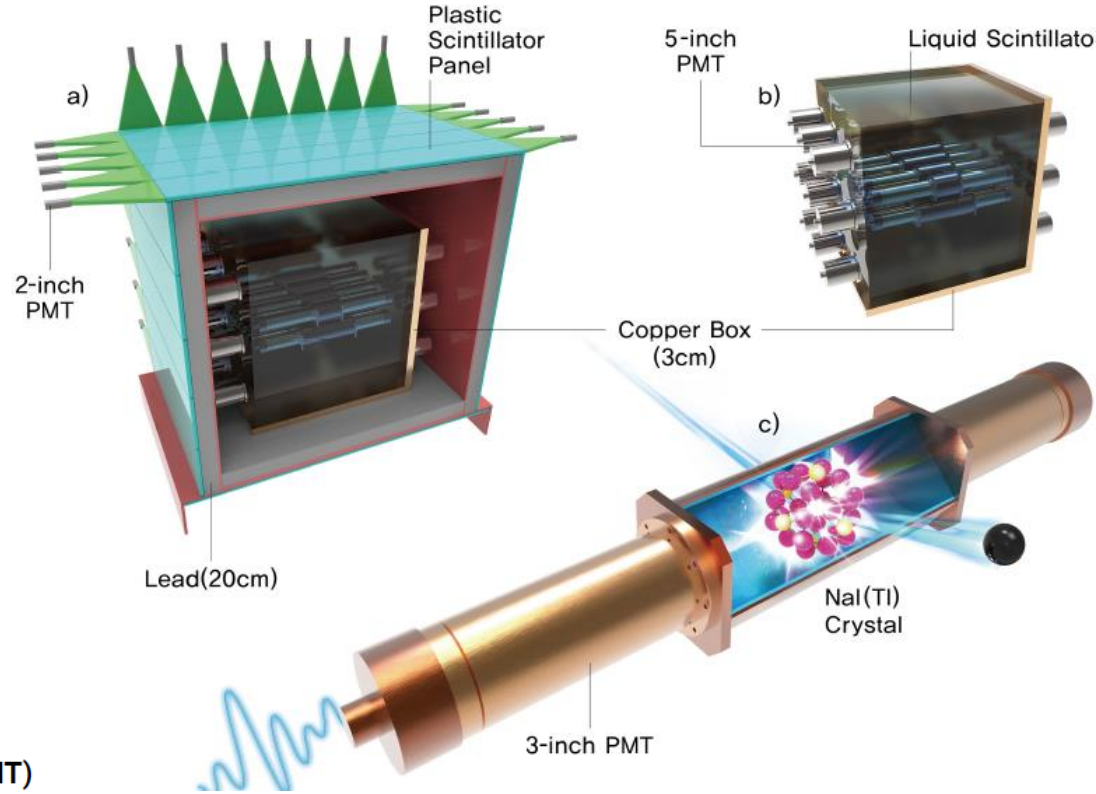
LETTER

https://doi.org/10.1038/s41586-018-0739-1

An experiment to search for dark-matter interactions using sodium iodide detectors

The COSINE-100 Collaboration*





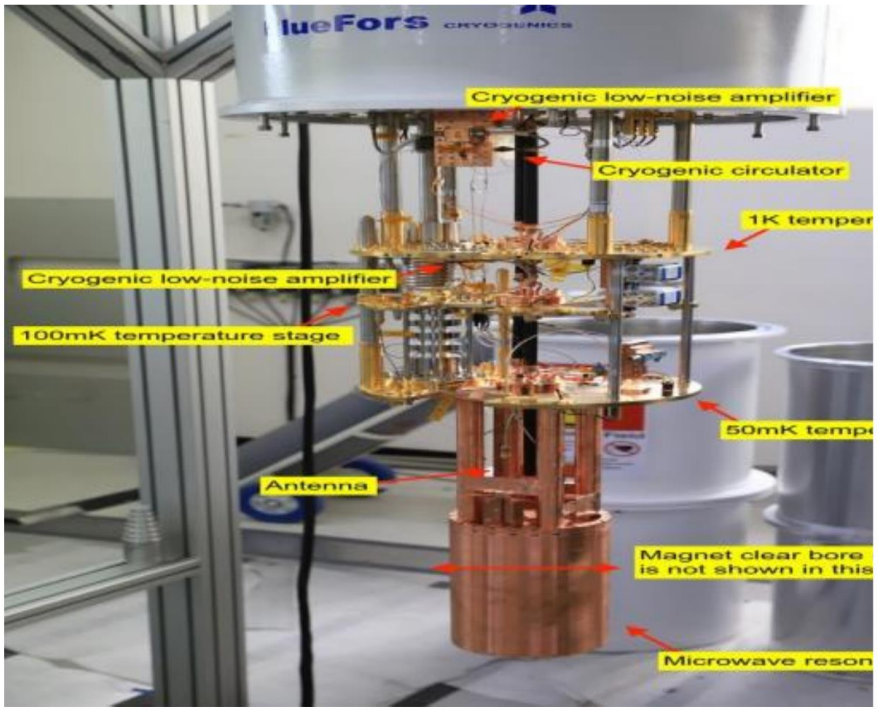
섬광검출기와 PMT (Scintillation detector & PMT)

Speaker: Dr Jongwon Lee (고려대학교)

IBS/CAPP (from 2013)

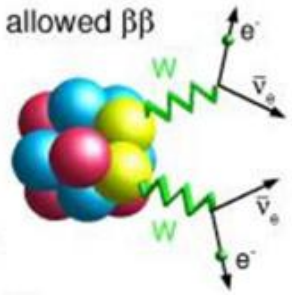
11/13/2021 Center for Axion and Precision Physics Research> ibs

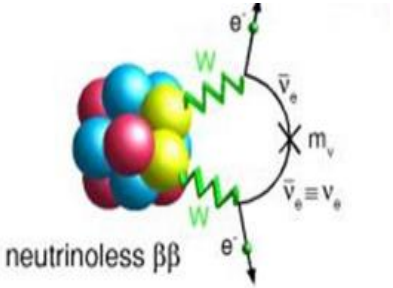
First High-Sensitivity Dark Matter Axion Hunting Results from South Korea

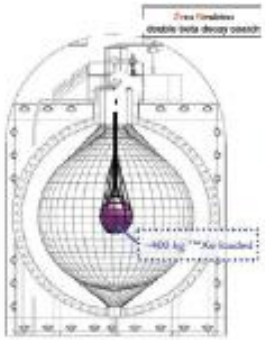


click

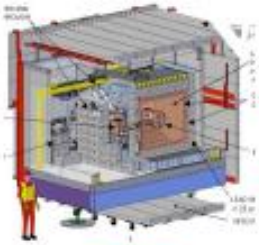
Current experiments of 0ν ββ search…







EXO

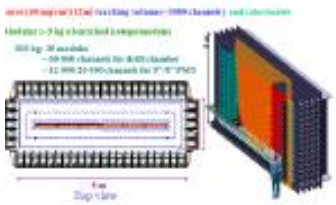


CUORE

CANDLES

GERDA

Kamland-Zen



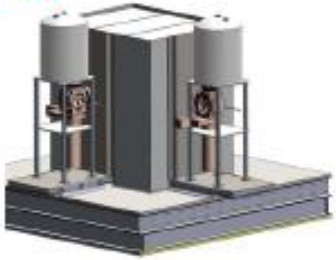
Super NEMO

COBRA

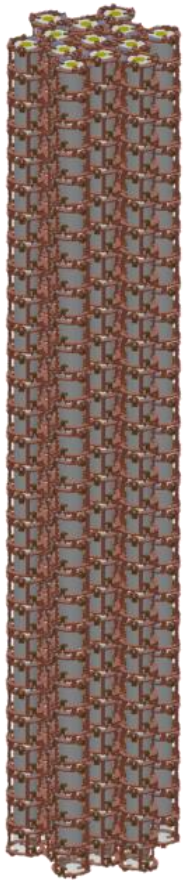
NEXT

LUCIFER

SNO+

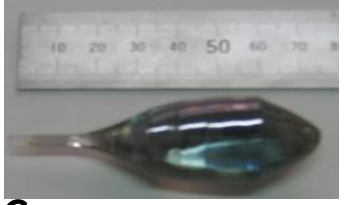


MAJORANA

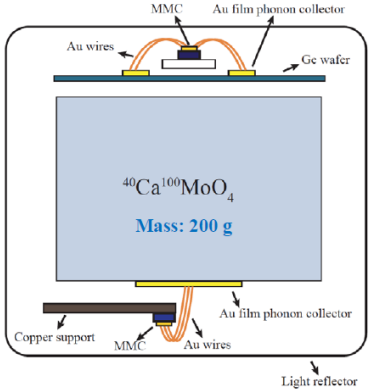


AMoRE

Brief History of AMoRE



1) 2002 : First idea and try to grow CaMoO4(CMO) in Korea.
2) 2003- 2004 : 1st Conference presentation (VIETNAM2004)
3) 2005-2007 : Large CMO with 1st ISTC project
4) 2007 : CMO R&D in cryogenic temperature started.
5) 2009 : AMORE collaboration formed
6) 2010-12 : $^{48depl}Ca^{100}MoO4$ internal background study
7) 2013 : AMoRE funded (CUP, IBS PI: Y.D. Kim)
8) 2014 : Upgrade of Y2L lab for AMoRE-pilot and AMoRE-I
9) 2020 :AMoRE-I started



	Pilot	Phase I	Phase II
Mass	1.9 kg	6 kg	200 kg
Bkg [keV ·kg· year]$^{-1}$	$<10^{-2}$	$<10^{-3}$	$<10^{-4}$
$T_{1/2}$ Sensitivity [years]	$\sim10^{24}$	$\sim10^{25}$	$\sim8 \times 10^{26}$
$<m_{\beta\beta}>$ Sensitivity [meV]	400-700	100-300	13-25
Location	Y2L (700 m depth)		Yemi
Schedule	2016-8	2019 - 2021	2022- 2026

AMoRE collaboration

V. Alenkov et al.,Technical Design Report for the AMoRE 0ν2β Decay Search Experiment, arXiv:1512.05957v1

- 107 members from
- 25 institutes in
- 9 countries.

Center for Underground Physics, Institute of Basic Science (CUP/IBS), Kyungpook National University (KNU), Soongsil University (SSU), Seoul National University (SNU), Ehwa Womans University (EWU), Semyung University (SMU), Sejong University (SJU), Korea Research Institute of Standards and Science (KRISS), Chung-Ang University (CAU)

JSC FOMOS-Materials (FOMOS), Baksan Neutrino Observatory of INR RAS (BNO), National Research Nuclear University (NRNU), Nikolaev Institute of Inorganic Chemistry (NIIC)

Physikalisch-Technische Bundesanstalt (PTB), Kirchhoff-Institute for Physics (KIP)

Institute for Nuclear Research (INR)

Tsinghua University (THU)

Nakhon Pathom Rajabhat University (NPRU)

Institut Teknologi Bandung (ITB), University of Mataram (UM)

Abdul Wali Khan University (AWKUM), Kohat University of Science and Technology (KUST)

India Institute of Science (IISc)

AMoRE-II: Mo crystals grown and tested

CMO (FOMOS)

Total: 3.387 kg

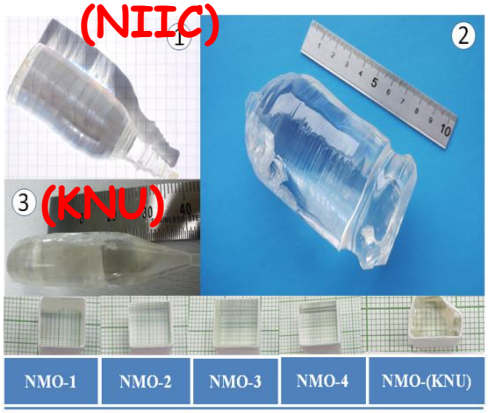
CMO (CUP)

NMO (KNU)

Ø40 mm X 100 mm

(NIIC)

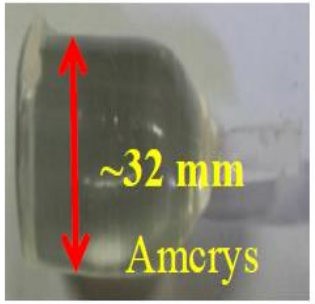
(KNU)



PMO (NIIC)

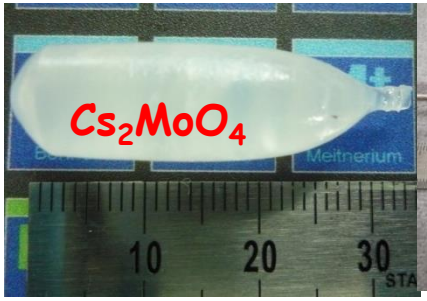
LMO (KNU)

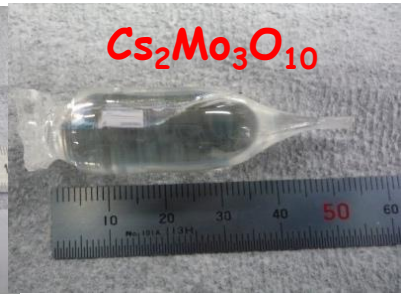
AMCRYS



CMO (NIIC)

CMO (CARAT)





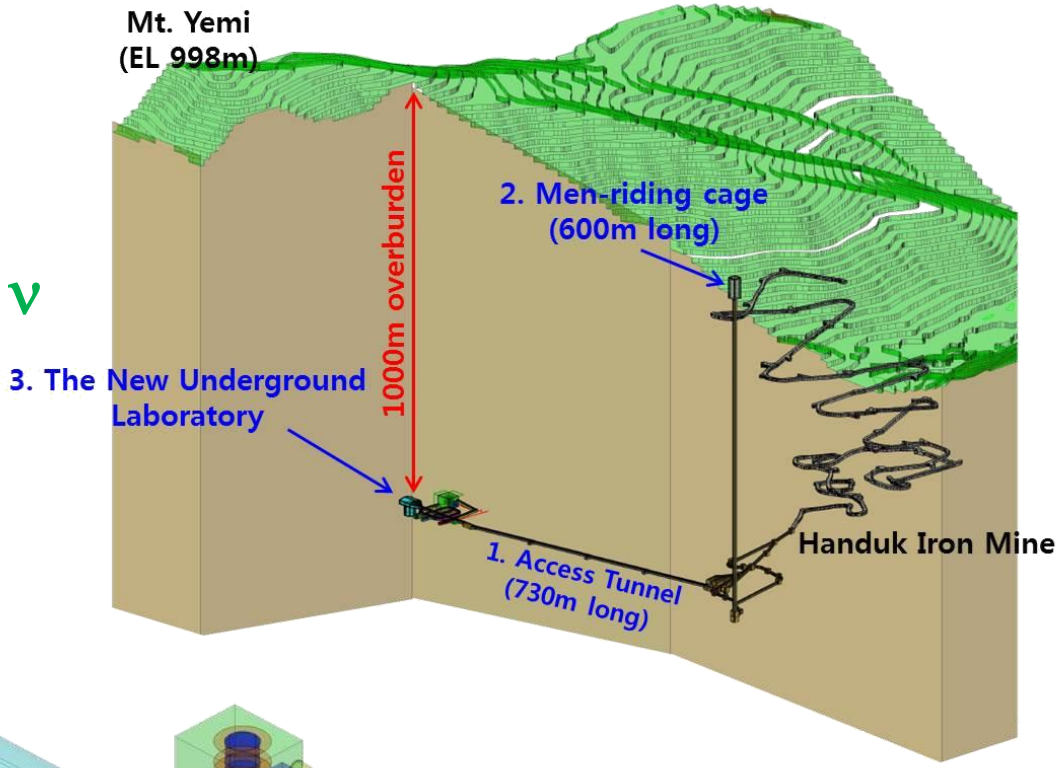
LMO (CUP)

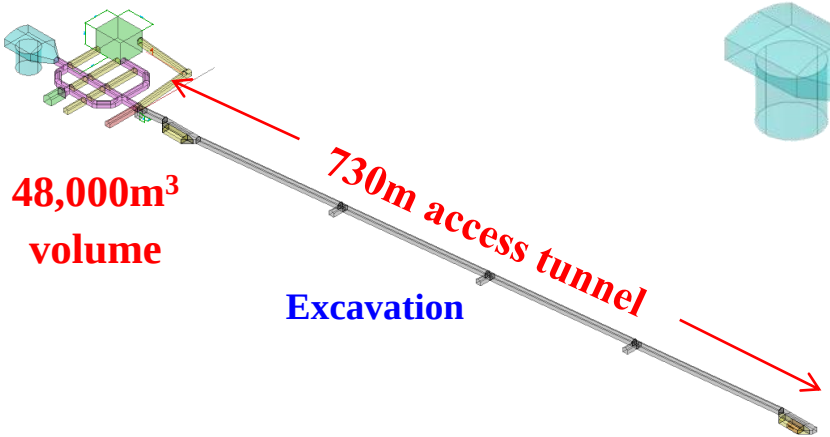
Yemi Underground Laboratory (by 2022)

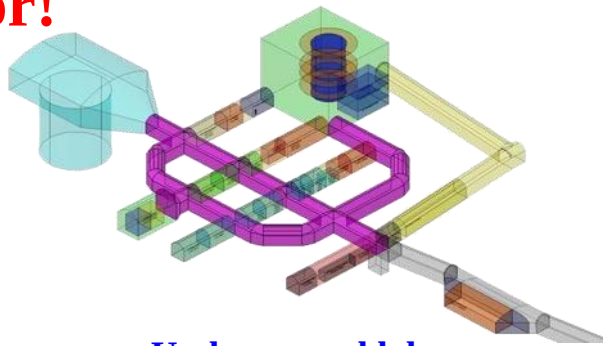
- **Experiment**
  - **Dark matter search**
  - **AMoRE**
  - **Rare decay experiment**

Future possibility

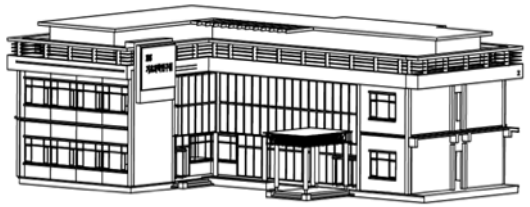
- **k-Ton LSC for DB, solar ν**
- IsoDAR
- **Ton scale DB exp.**
- **Dark photon exp.**
- **New dark matter search**
- **New idea with detector!**







Underground lab



Surface office/lab

RENO Collaboration

8 institutions and 35 physicists in Korea

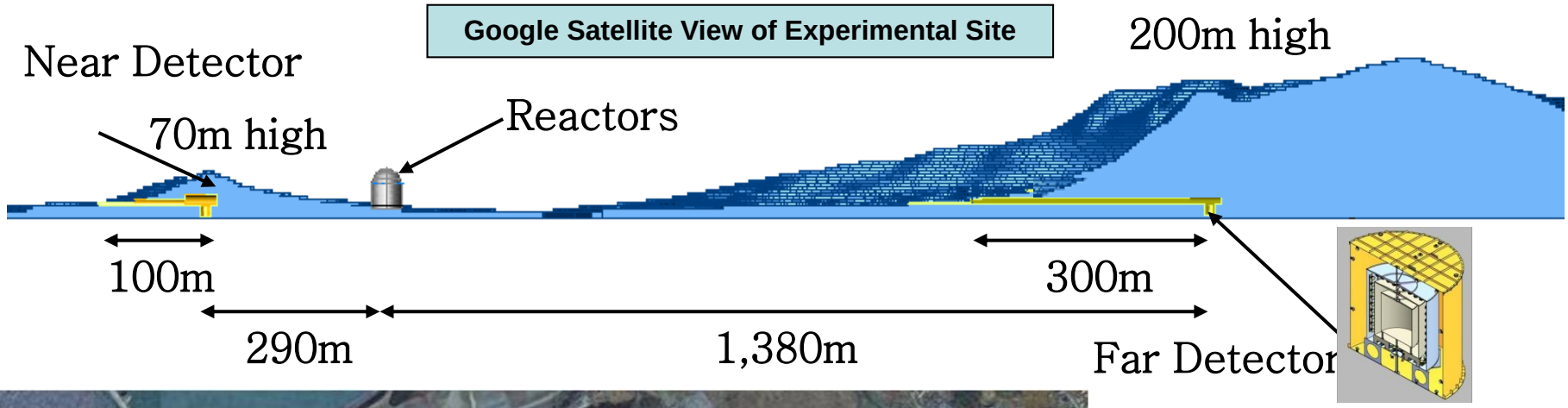
- Chonnam National University
- Dongshin University
- GIST
- KAIST
- Kyungpook National University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University

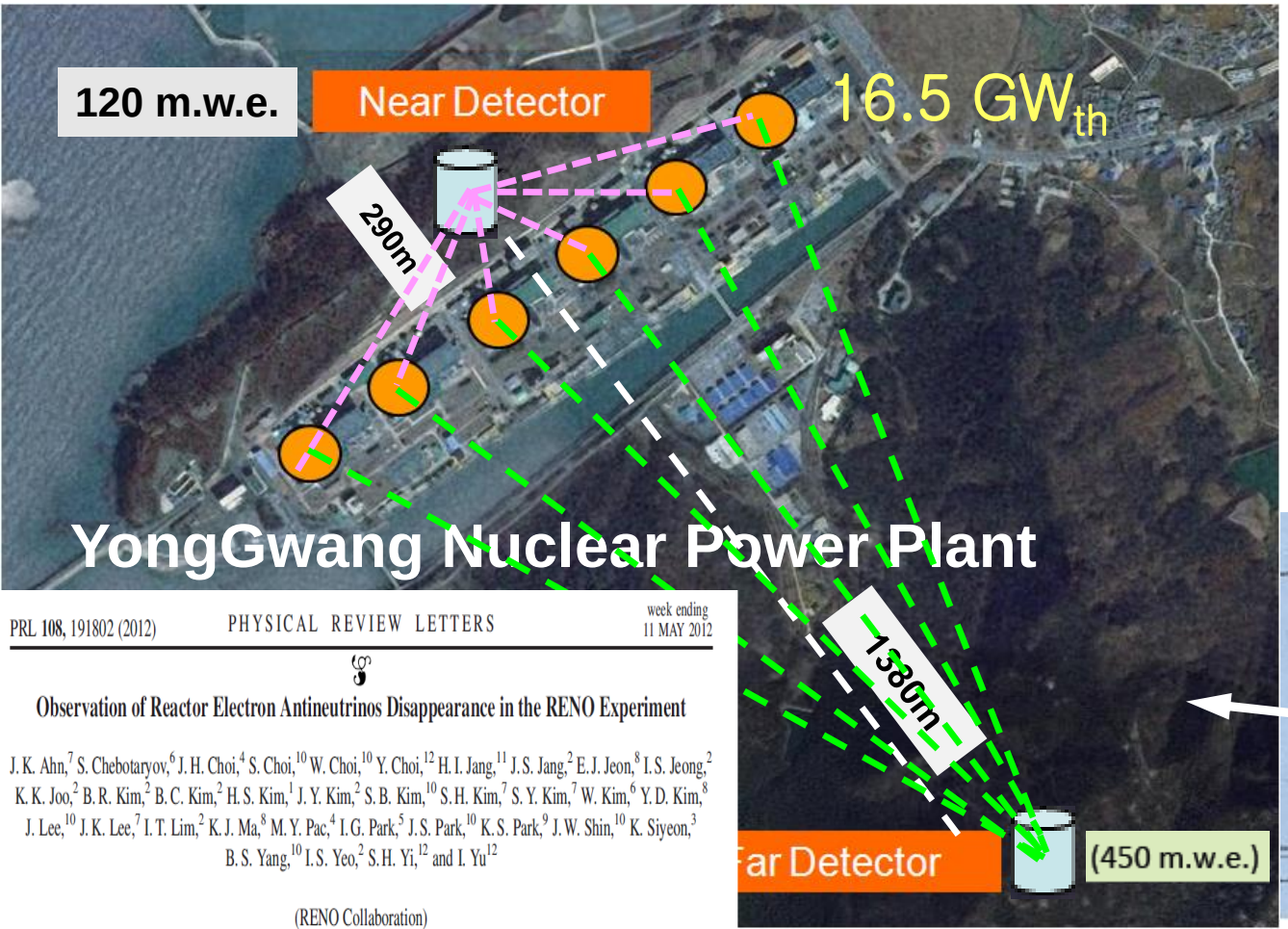
- **Total cost : $10M**
- Start of project : **2006**
- The first experiment running with both near & far detectors since **Aug. 2011**

YongGwang (靈光) :

New name: Hanbit

Reactor Experiment for Neutrino





RENO

ν θ_{13}

ν_e ν_μ ν_τ

KNRC

Korea Neutrino Research Center

PI : S.B. Kim

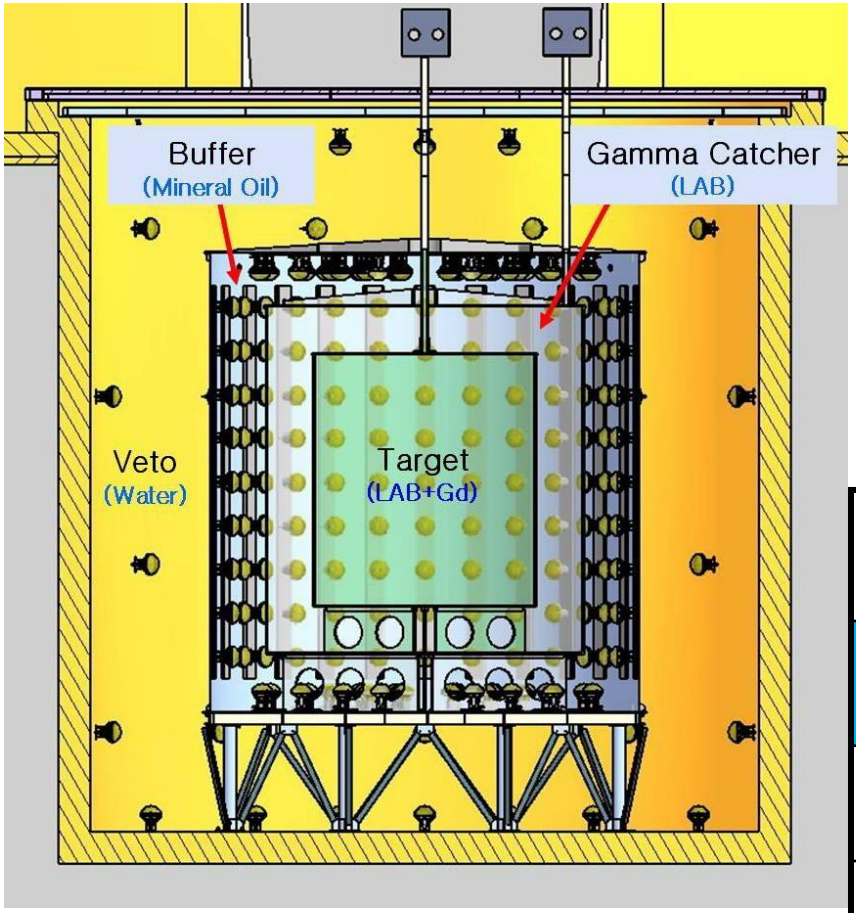
PRL 108, 191802 (2012) PHYSICAL REVIEW LETTERS week ending 11 MAY 2012

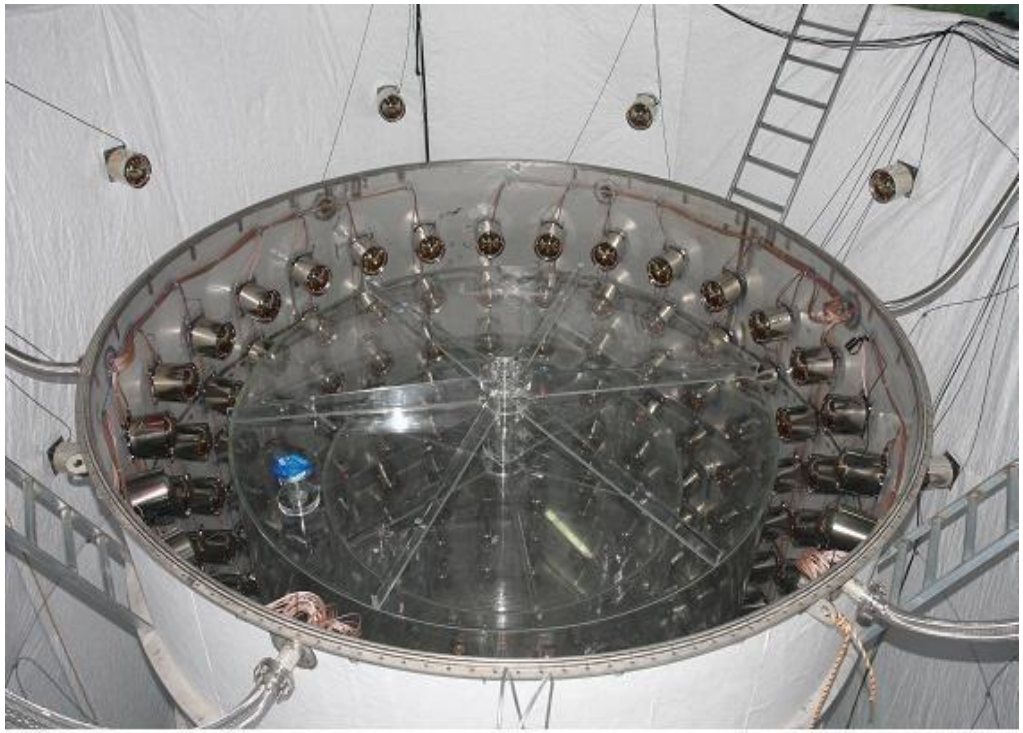
Observation of Reactor Electron Antineutrinos Disappearance in the RENO Experiment

J. K. Ahn,[7] S. Chebotaryov,[6] J. H. Choi,[4] S. Choi,[10] W. Choi,[10] Y. Choi,[12] H. I. Jang,[11] J. S. Jang,[2] E. J. Jeon,[8] I. S. Jeong,[2] K. K. Joo,[2] B. R. Kim,[2] B. C. Kim,[2] H. S. Kim,[1] J. Y. Kim,[2] S. B. Kim,[10] S. H. Kim,[7] S. Y. Kim,[7] W. Kim,[6] Y. D. Kim,[8] J. Lee,[10] J. K. Lee,[7] I. T. Lim,[2] K. J. Ma,[8] M. Y. Pac,[4] I. G. Park,[5] J. S. Park,[10] K. S. Park,[9] J. W. Shin,[10] K. Siyeon,[3] B. S. Yang,[10] I. S. Yeo,[2] S. H. Yi,[12] and I. Yu[12]

(RENO Collaboration)

RENO Detector



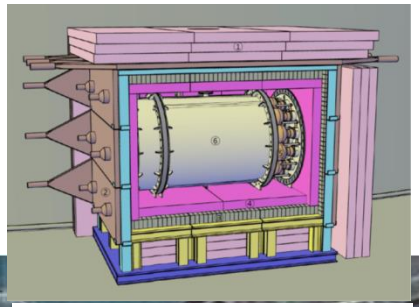


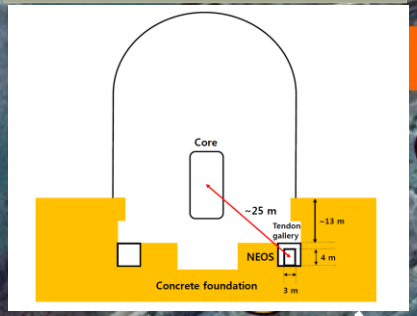
	Thick (cm)	vessel	Material	Mass (tons)
Target	140	Acrylic (10mm)	Gd(0.1%) +LS	15.4
Gamma catcher	60	Acrylic (15mm)	LS	27.5
Buffer	70	SUS(5mm)	Mineral oil	59.2
Veto	150	Steel (15mm)	water	354.7

total ~460 tons

- **Inner PMTs: 354 10" PMTs**
  - solid angle coverage = ~14%
- **Outer PMTs: ~ 67 10" PMTs**

NEOS (NEutrino Oscillation at Short-baseline) Experiment





Sterile Neutrino Search at the NEOS Experiment

Y. J. Ko,[1] B. R. Kim,[2] J. Y. Kim,[3] B. Y. Han,[4] C. H. Jang,[1] E. J. Jeon,[5] K. K. Joo,[2] H. J. Kim,[6] H. S. Kim,[3] Y. D. Kim,[5,3,7] Jaison Lee,[5,*] J. Y. Lee,[6] M. H. Lee,[5] Y. M. Oh,[5,†] H. K. Park,[5,7] H. S. Park,[8] K. S. Park,[5] K. M. Seo,[3] Kim Siyeon,[1] and G. M. Sun[4]

NEON Collaboration

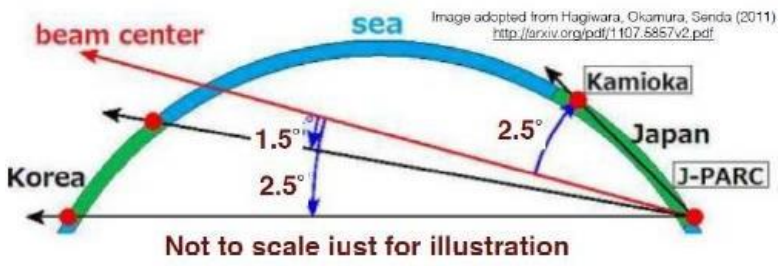
~ 15 people who are all active members of COSINE-100 and/or NEOS

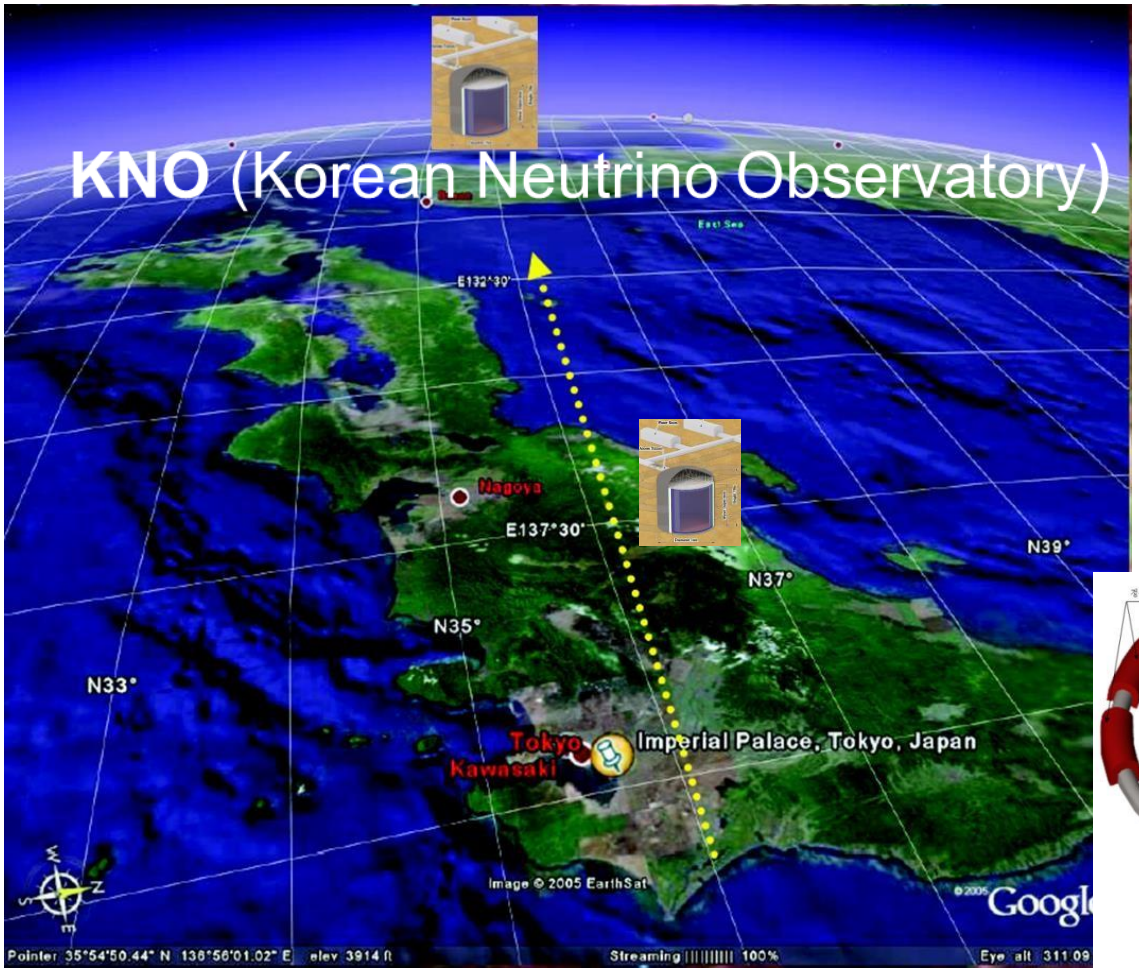
Aim to observe CEνNS from reactor $\bar{\nu}_e$ using NaI(Tl) detector

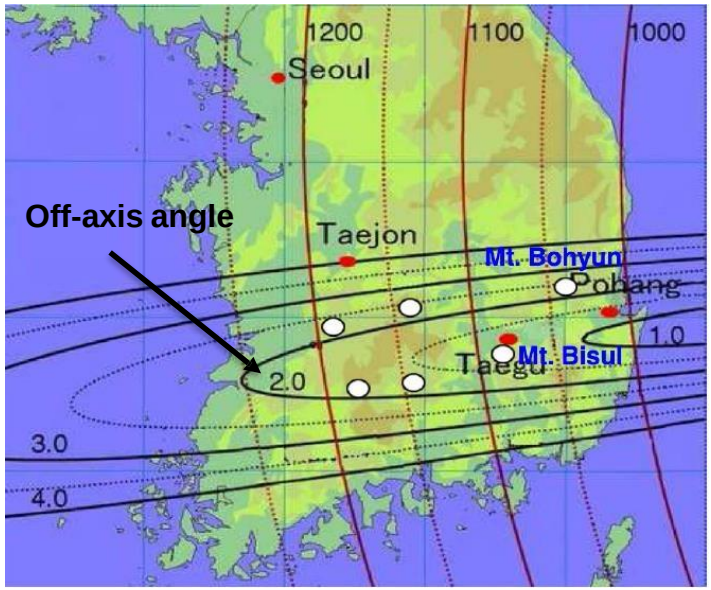
Can take an advantage of COSINE-100 and NEOS experiences

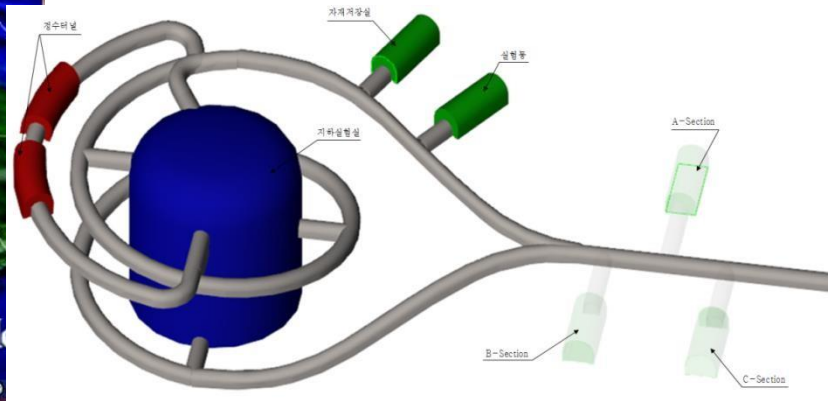
KNO

J-PARC off-axis neutrino beam comes to Korea



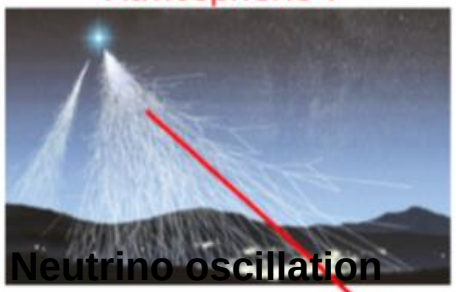


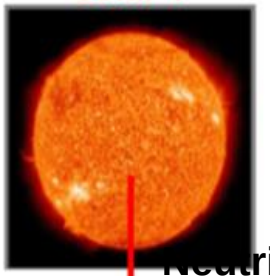


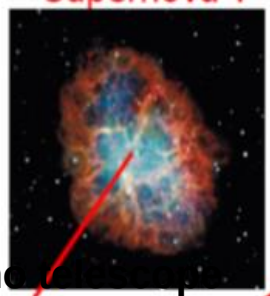


Baseline ~1100km: next oscillation maxima in Korea

Korean Neutrino Observatory (KNO)

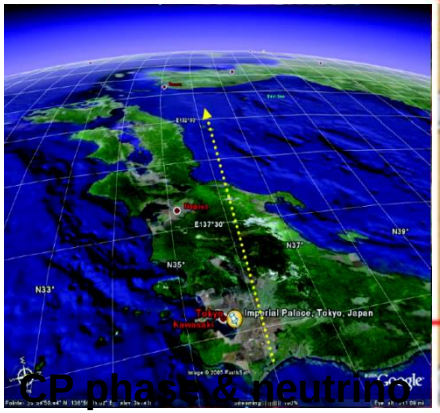




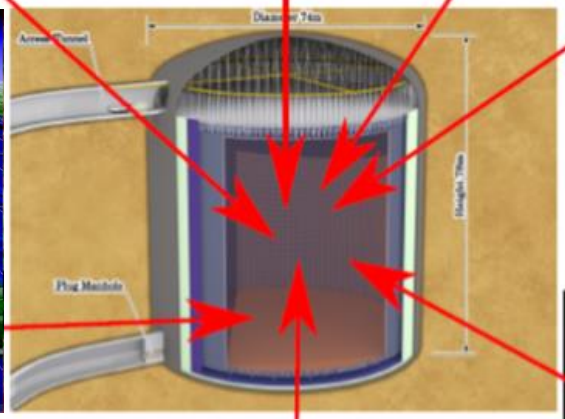


Neutrino oscillation

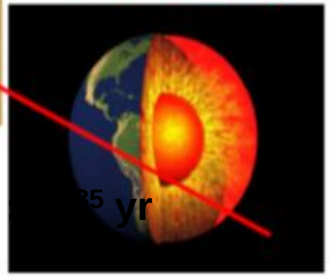
Neutrino

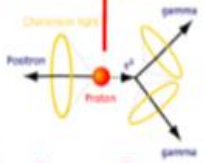


CP phase & neutrino mass ordering at 2nd oscillation maximum



New step to geo-science





Lifetime 35 yr

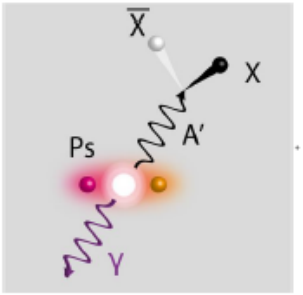
Nucleon Decay

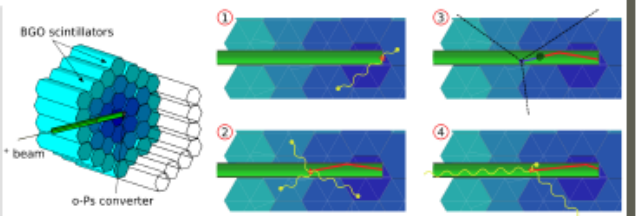
KNU Advanced Positronium Annihilation Experiment (KAPAE)

The Final Goal

- Positronium: C-violation & QED test & rare decay
- Invisible decay
  - → Experimentally interesting branching ratio of the order of 10^{-8}
  - → Extra-demensions
  - → Milli-Charged particles
  - → Darkmatter of a mirror particle type
  - → Axion
  - → Dark photon

Search of invisible decay





Searching for light dark matter through Positronium decay

Eur. Phys. J. D (2018) 72: 44

First search for invisible decays of orthopositronium confined in a vacuum cavity

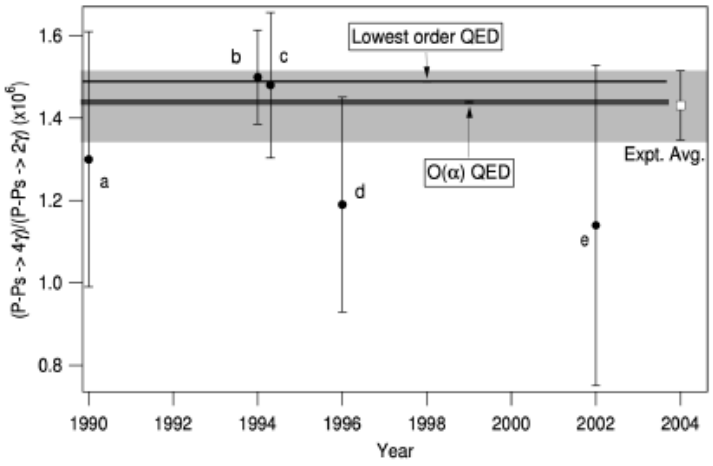
PHYS. REV. D 97, 092008 (2018)

Search for C-violation

- C-violation
  - o-Ps -> 4 γ search
  - o-Ps -> 2 γ search

- Approximate calculation
  10^{8} → ~10^{-7} (10^{-6}) : 10 times improvement

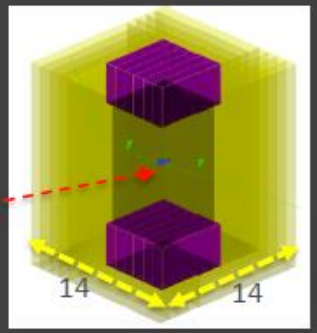
High order QED process Rare decay



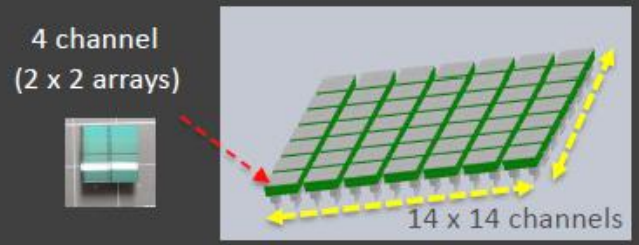
Positronium decay experiment

Full Design of Detector

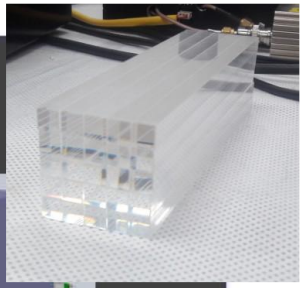
- The trigger part is surrounded by the gamma detection part with an array of 14 x 14 BGO scintillators (7.5 x 7.5 x 150 mm^3)

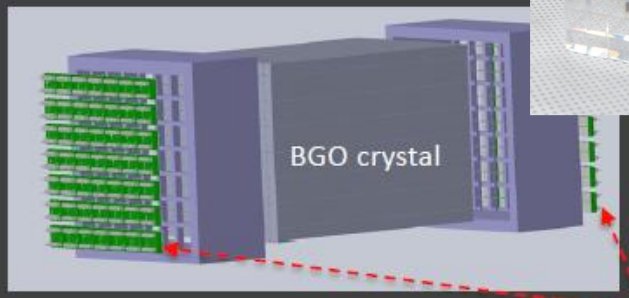


- For dual readout both sides of the BGO scintillators are coupled with 7 x 7 arrangement of 2 x 2 arrays for a total of 14 x 14 SiPMs

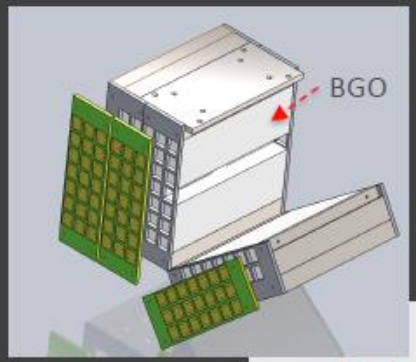


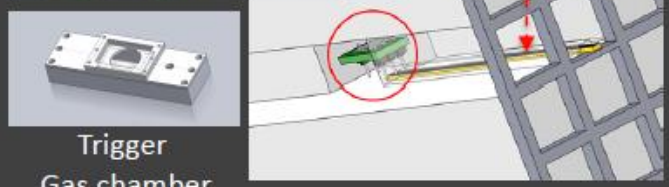
1st Design





2nd Design

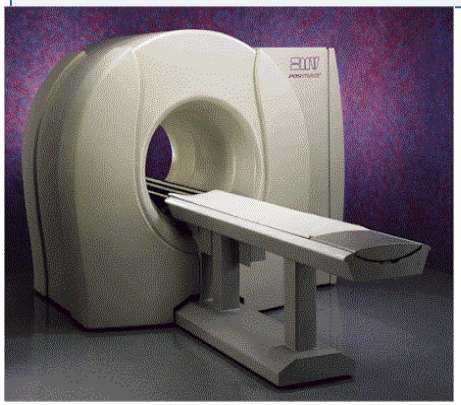




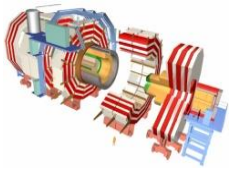
My research with scintillators over 20 years

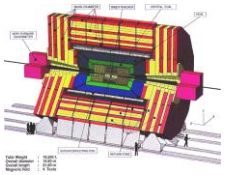
Application of Scintillators

Medical application



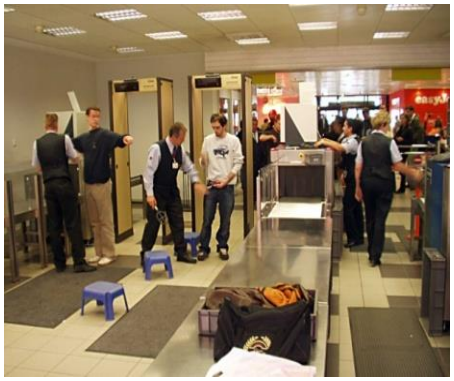
High energy physics





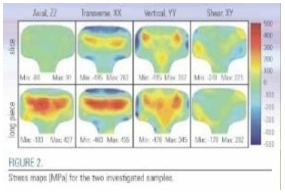
Astro-particle physics, ...

Security check

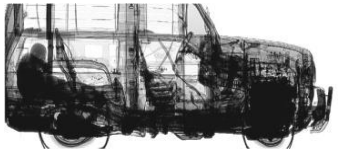


X-ray scanning

Nondestructive analysis



Board inspection

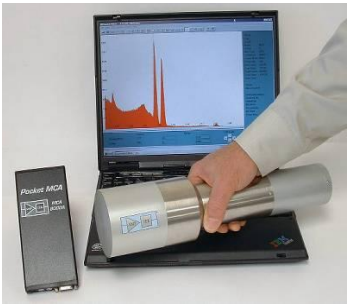


Radiation monitoring

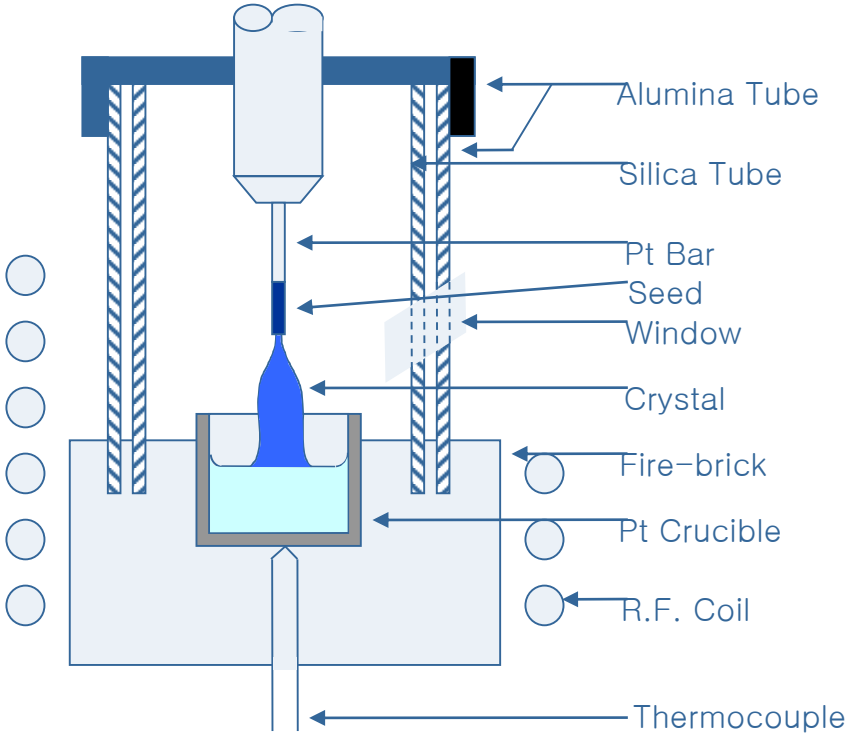
Scintillation Detectors

Scintillation Surveymeter

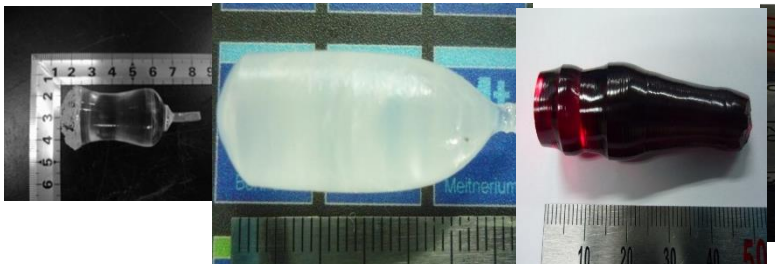
NaI(Tl) Spectrometer

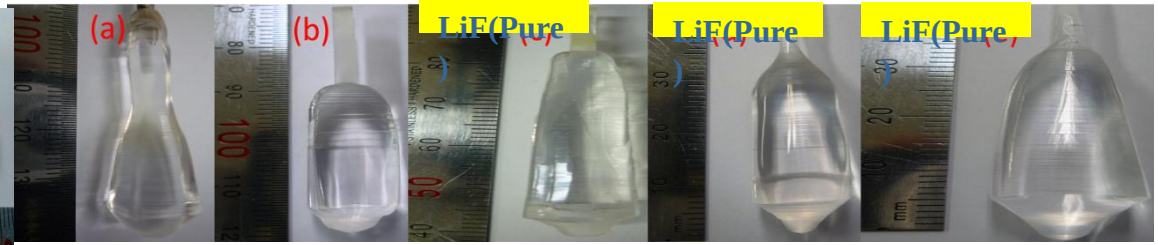


Crystal growing system with Czochalski method

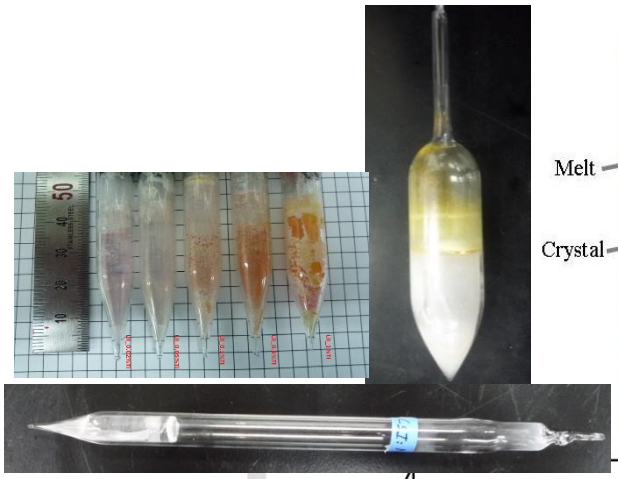


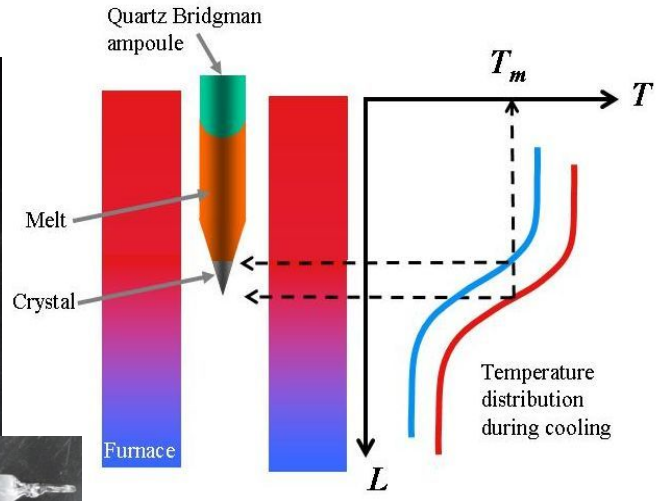
At KNU



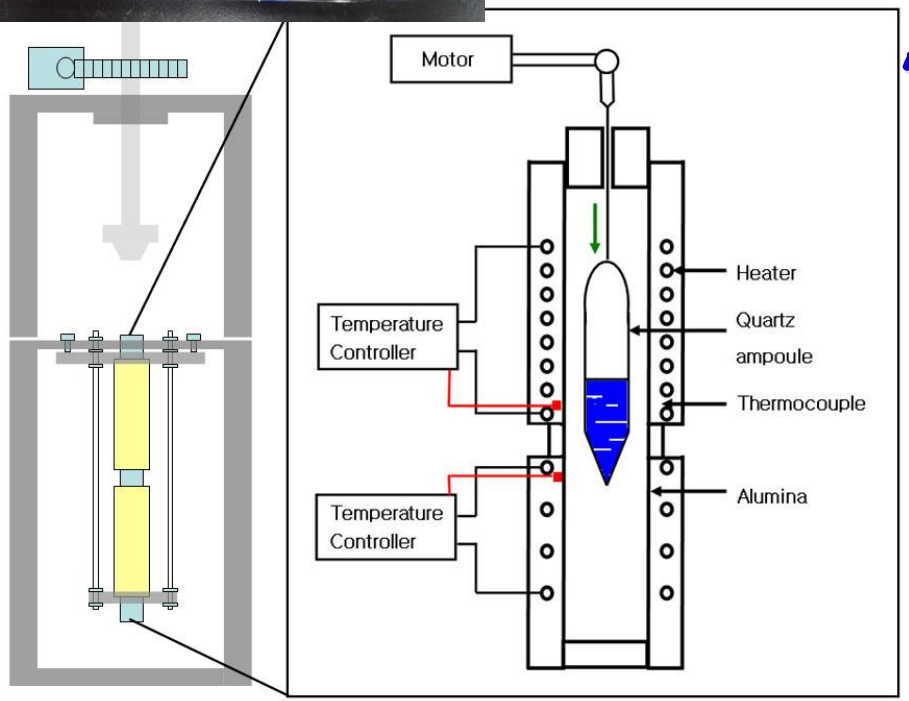


Bridgman Crystal Growing Methods

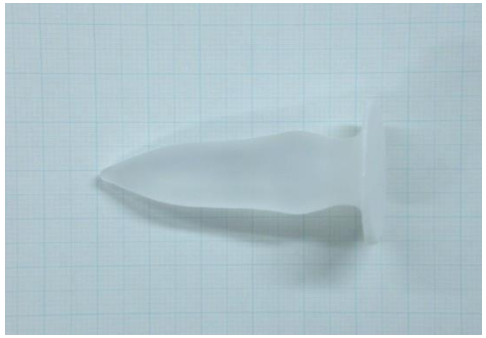




At KN



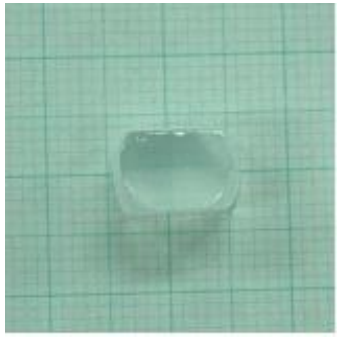
Crystals growing research at KNU over 20 years



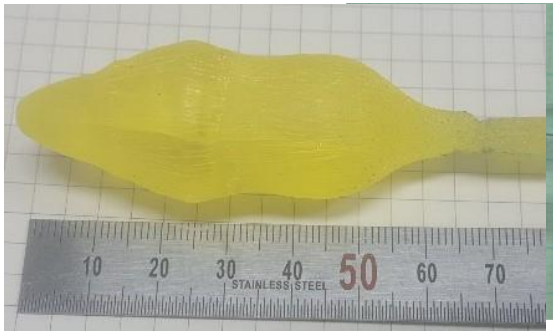
$SrCl_2(Eu)$

$CeCl_3$

$LaCl_3(Ce)$

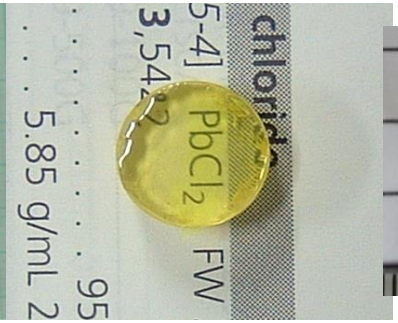


$CeBr_3$



GAGG:Ce

$Ba_{0.2}Sr_{0.8}Cl_2$



$PbCl_2:Eu^{2+}$

BGSO

- NaI:Tl, CsI(Tl, Co3, Na), BGO, BSO, BGSO, SrWO4, CaMoO4, SrMoO4 et al.
- New material : BaSrCl2, CsCe2Cl7, Cs(Rb)2Li(Na)CeCl6, Cs2LiGd(Lu)Cl(Br)6:Ce, Li6Lu(Gd,Y)(Bo3)3, NaGd(Wo4)3, LiBaF3, ZnMnTe, Tl-based scintillators et al.

Scintillator Development

Invited Article

The quest for high resolution γ-ray scintillators

Optical Materials: X 1 (2019) 100021

Pieter Dorenbos

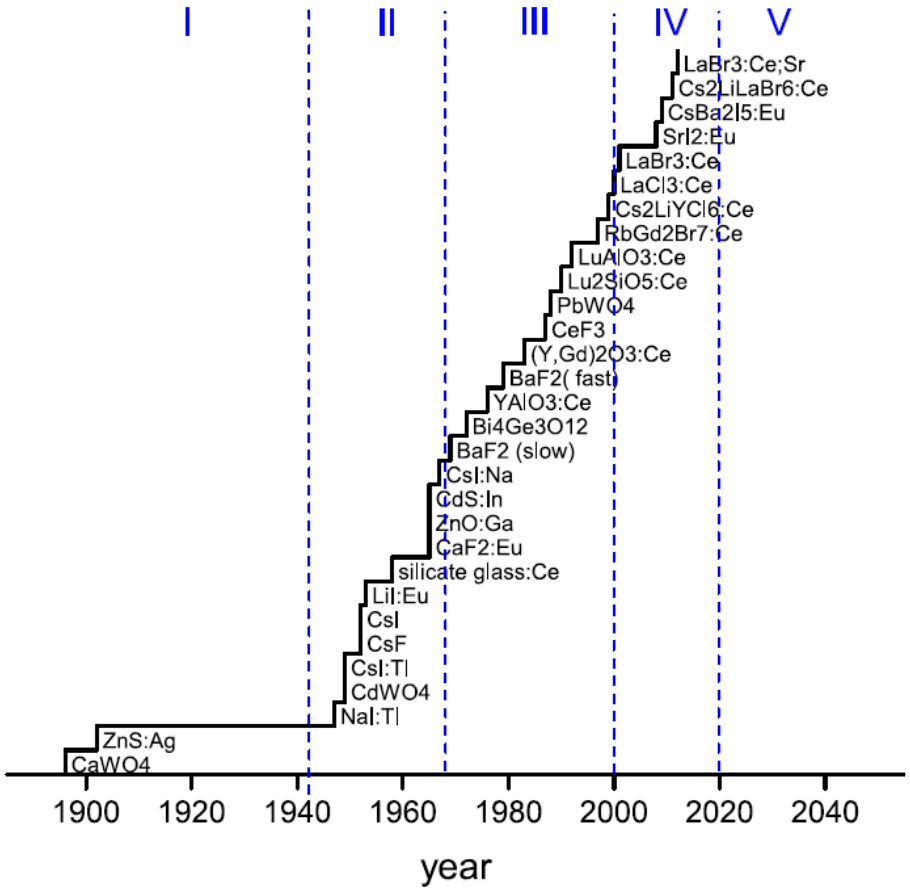


Fig. 2. History of scintillator discovery that distinguishes phases I to IV and phase V for future discoveries.

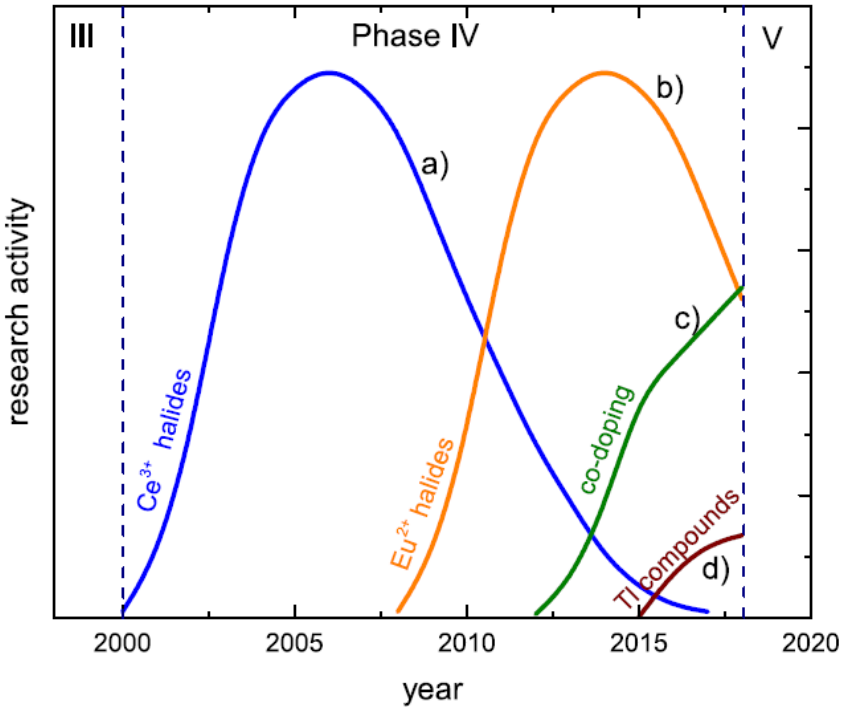


Fig. 4. Main lines of research during phase IV of scintillator discovery. a) The research on Ce^{3+} activated halide compounds inspired by the discovery of $LaBr_3:Ce^{3+}$, b) the research on Eu^{2+} doped halide compounds initiated by the re-discovery of $SrI_2;Eu^{2+}$, c) the increased research on co-doped scintillators stimulated by discovery of Sr^{2+} co-doped $LaBr_3:Ce^{3+}$, d) the research on Ce^{3+} activated Tl-based compounds initiated by $Tl_2LiGdCl_6$.

Discovered Tl-based novel scintillators

- The pioneer research work on the discovery and development of Tl-based scintillators was started in 2009 by our research group and published $Tl_2LiGdCl_6$:Ce as 1st paper in 2015.
- The pioneer research work on the discovery and development of Tl-based scintillators was started in 2009 by our research group and published $Tl_2LiGdCl_6$:Ce as 1st paper in 2015.

Elpasolites

- $Tl_2LiGdCl_6$:Ce [1]
- $Tl_2LiGdBr_6$:Ce [2]
- Tl_2LiYCl_6:Ce [3-6]
- $Tl_2LiLuCl_6$:Ce [7]
- $Tl_2LiScCl_6$ [8]

Ternary Halides

- Tl_2LaCl_5:Ce [9-12]
- Tl_2LaBr_5:Ce [13]
- Tl_2GdCl_5:Ce [14, 15]
- $TlGd_2Cl_7$:Ce [16]
- $TlSr_2Br_5$ [17]
- $TlSr_2I_5$:Eu [18, 19]
- $TlCaCl_3$ [20]
- Tl_2HfCl_6 [21-24]
- Tl_2ZrCl_6 [25,26]
- $TlAlF_4$ [27, 28]
- $TlMgCl_3$ [29]
- $TlCdCl_3$ [30]
- $TlCaI_3$ [31]

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ORIGINAL PAPER

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Discovery, Crystal Growth, and Scintillation Properties of Novel Tl-Based Scintillators

HongJoo Kim, Gul Rooh, Arshad Khan, Phan Quoc Vuong, and Sunghwan Kim*

In my opinion, domestic experiments need to be balanced with foreign experiments and grow with small & large scale