

Center for Underground Physics (CUP) - Director's report -



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2023. 9. 15

Underground Physics Workshop, SNU

Goal of CUP

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**AMORE
COSINE
NEOS
NEON
LZ
GBAR
SK**

**Creativity &
Cooperation**

**New Domestic &
International
Collaboration**

**IBS Support &
Infrastructure**

**Previous
Labs &
Techniques**

**2000 -
KIMS, RENO, XMASS**

- **Discovery of Dark Matter and Neutrino Physics**
- **Construct world class underground laboratory**
- **Nurturing next generation astroparticle physicists**
- **World class research facility for ultra-rare events**

Milestones of CUP

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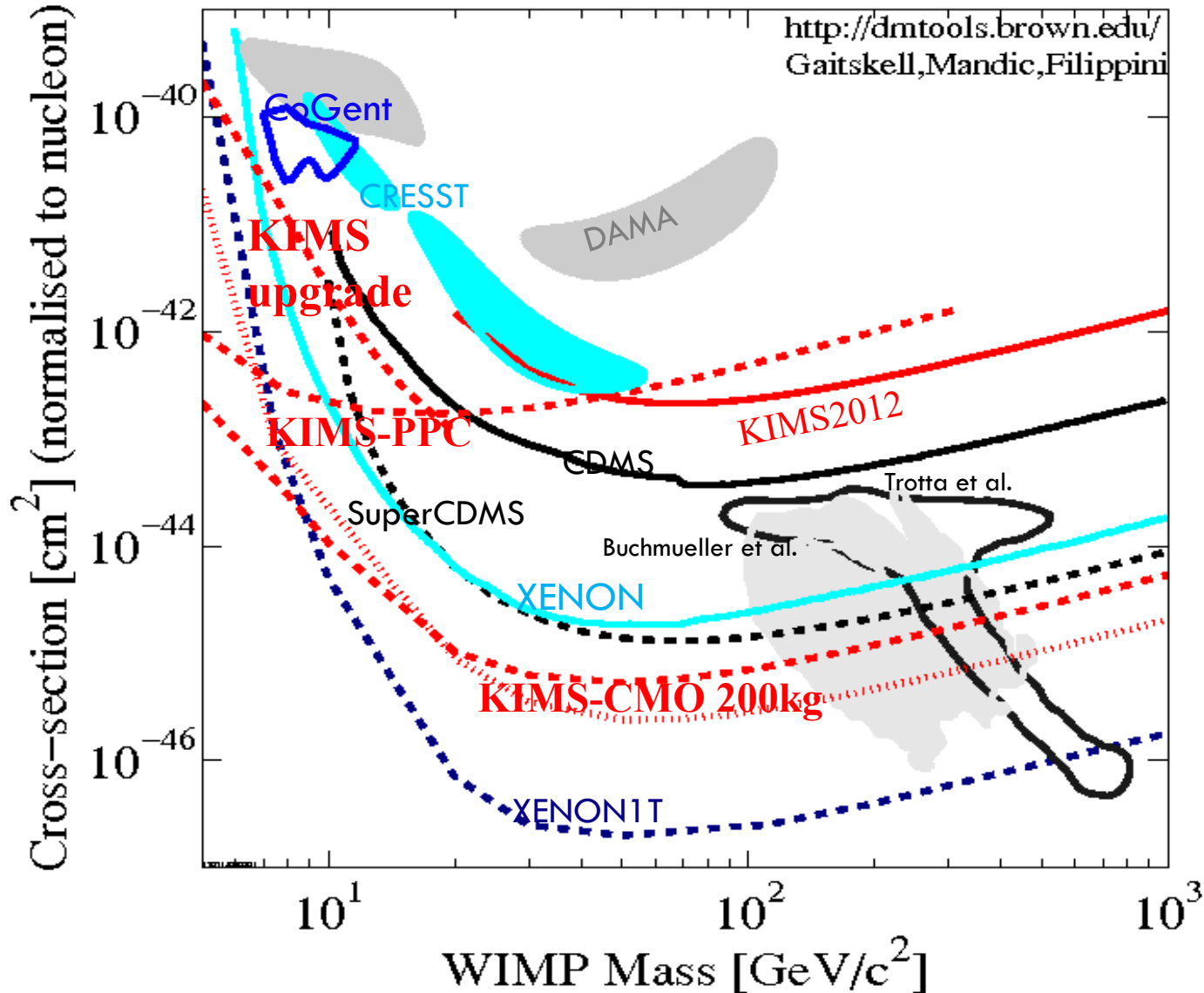
- 2012. 2. 29 Submitted an IBS director application
- 2012. 9. 27 Resubmitted the proposal.
- 2013. 3. 6 Submitted a full proposal of CUNPA
- 2013. 3. 18 Symposium @ Ewha Womans University
- 2013. 7. 1 Began CUNPA
- 2013. 8. 22 Kick-off meeting
- 2013. 11 Changed to CUP
- 2014. 4 KT1 lab
- 2014. 12 Y2L A5 lab
- 2015. 10. 27 Midterm Evaluation



WIMP search perspectives & KIMS

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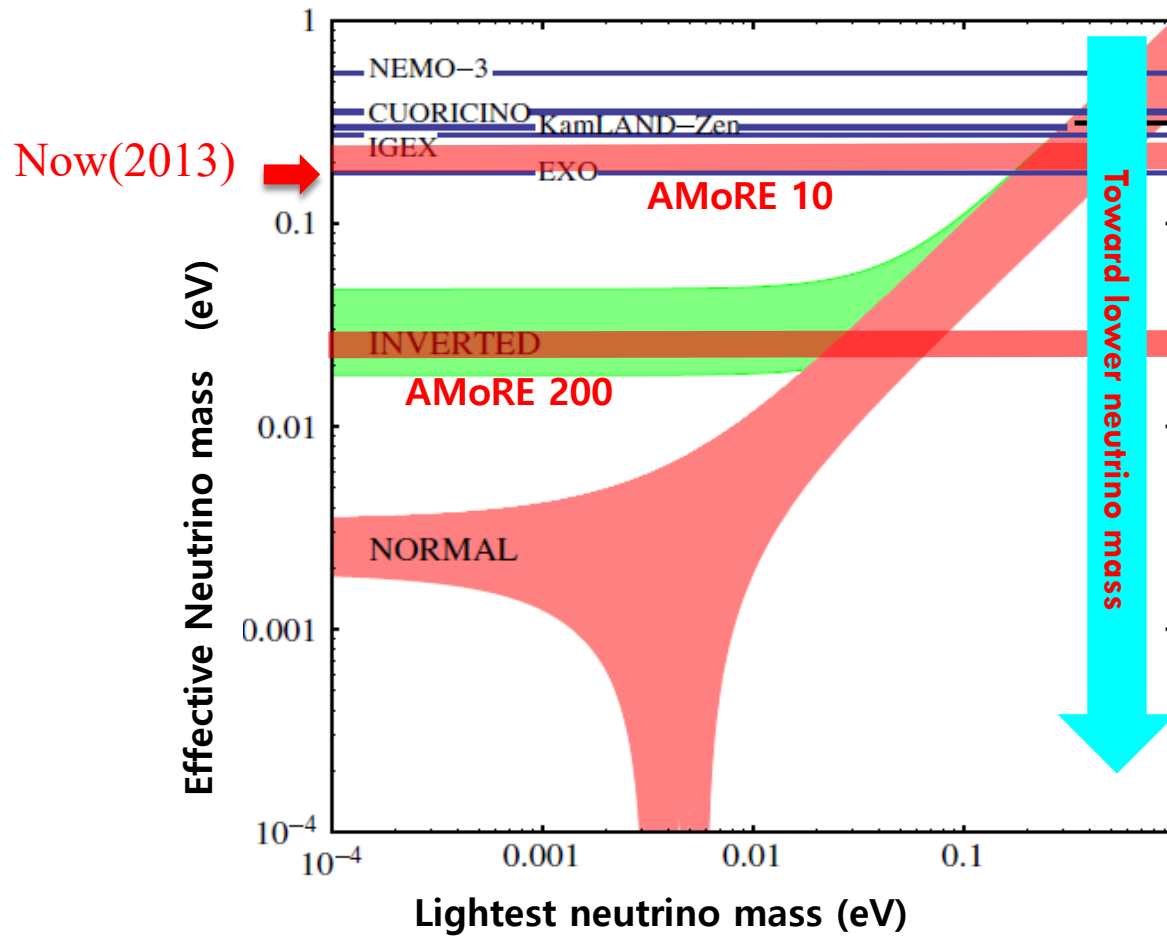
2013 proposal



AMoRE Sensitivity on effective neutrino mass

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2013 proposal



KT1

6



Y2L-A5

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Milestones of CUP

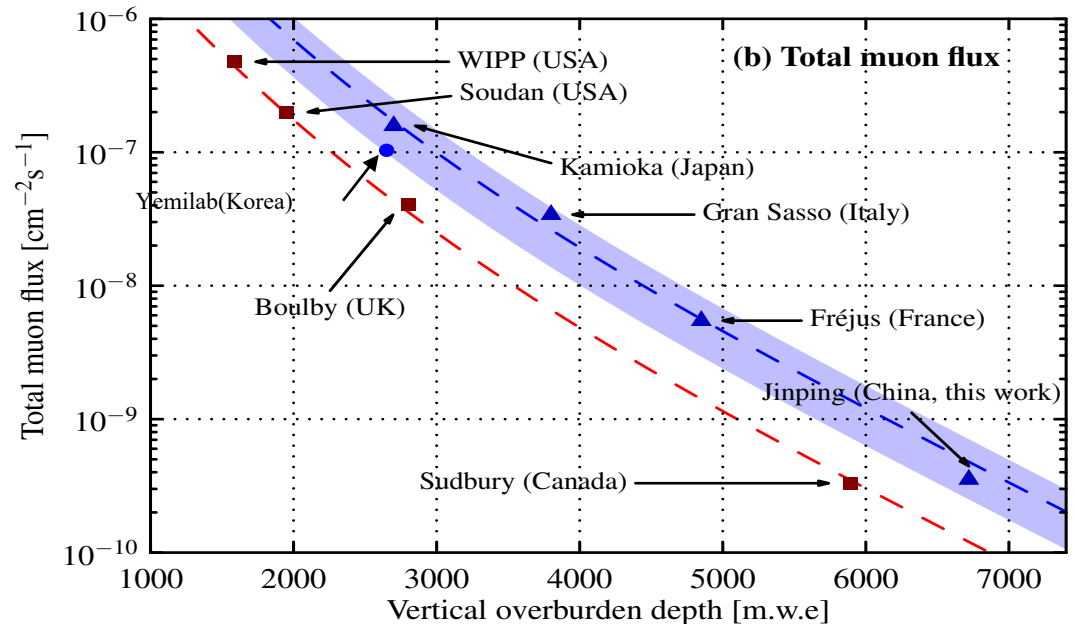
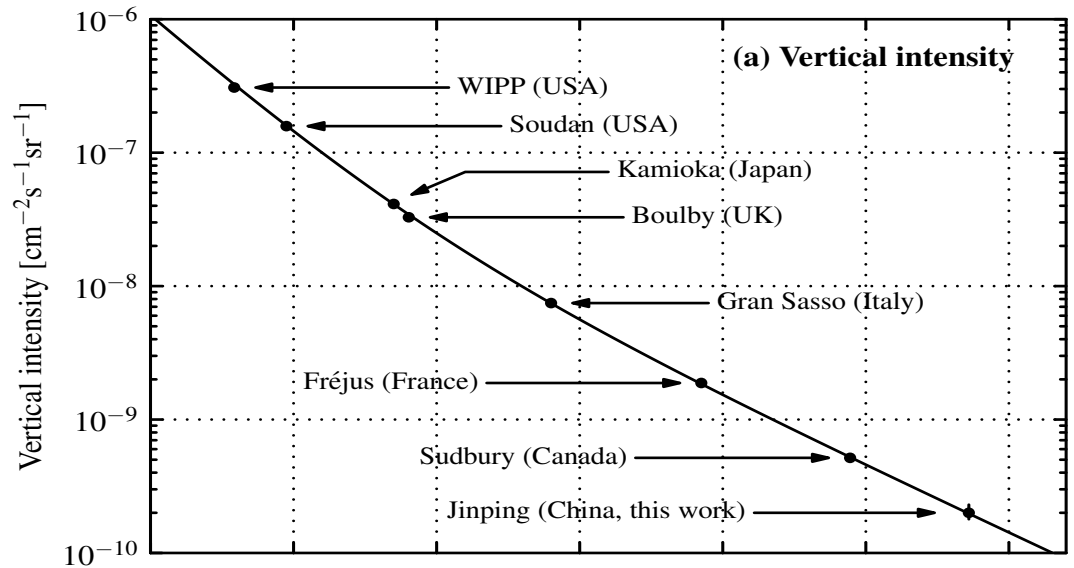
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- 2015. 8 AMoRE-Pilot began
- 2016. 1 NEOS began.
- 2016. 9 COSINE-100 began.
- 2016. 7 Handuk Mine selected for New Underground Lab.
- 2018. 3 Moved to IBS HQ lab
- 2018. 7. 5th year Evaluation
- 2019. 4. 12 Yemilab Construction kick-off
- 2021. 7. 8th year Evaluation
- 2022. 9. Yemilab Construction finished.
- 2023. 5 AMoRE-I finished.



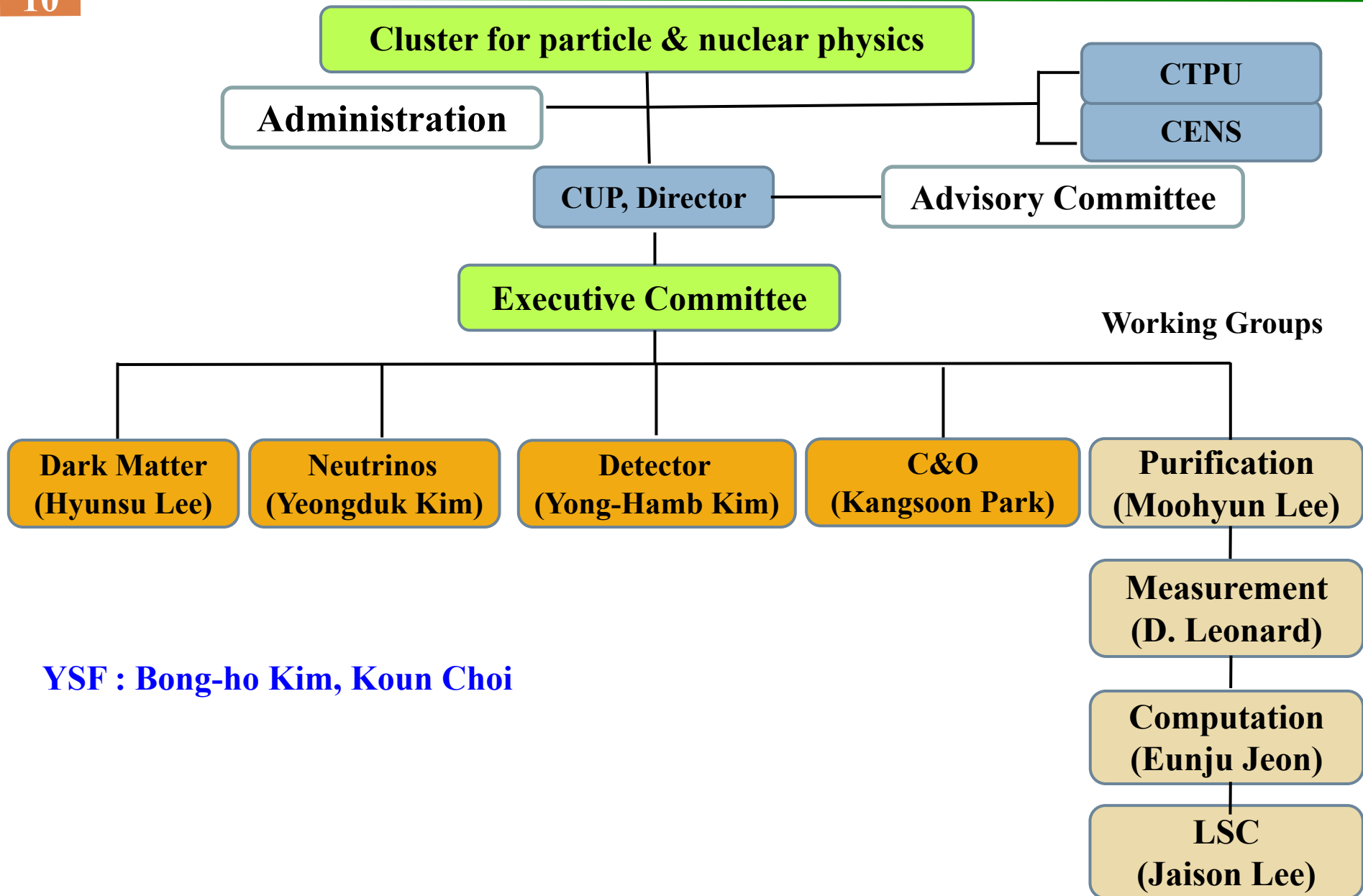
Muon flux

- Vertical flux is in linear with vertical depth.
- Total muon flux depends on geological profile.
- Updated from [arXiv:2007.15925](https://arxiv.org/abs/2007.15925)



Organization of CUP

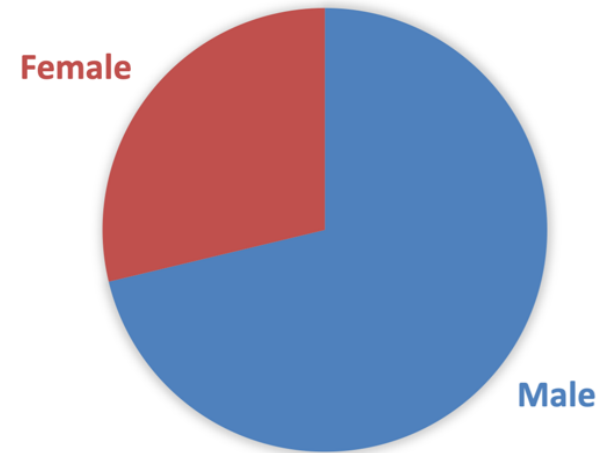
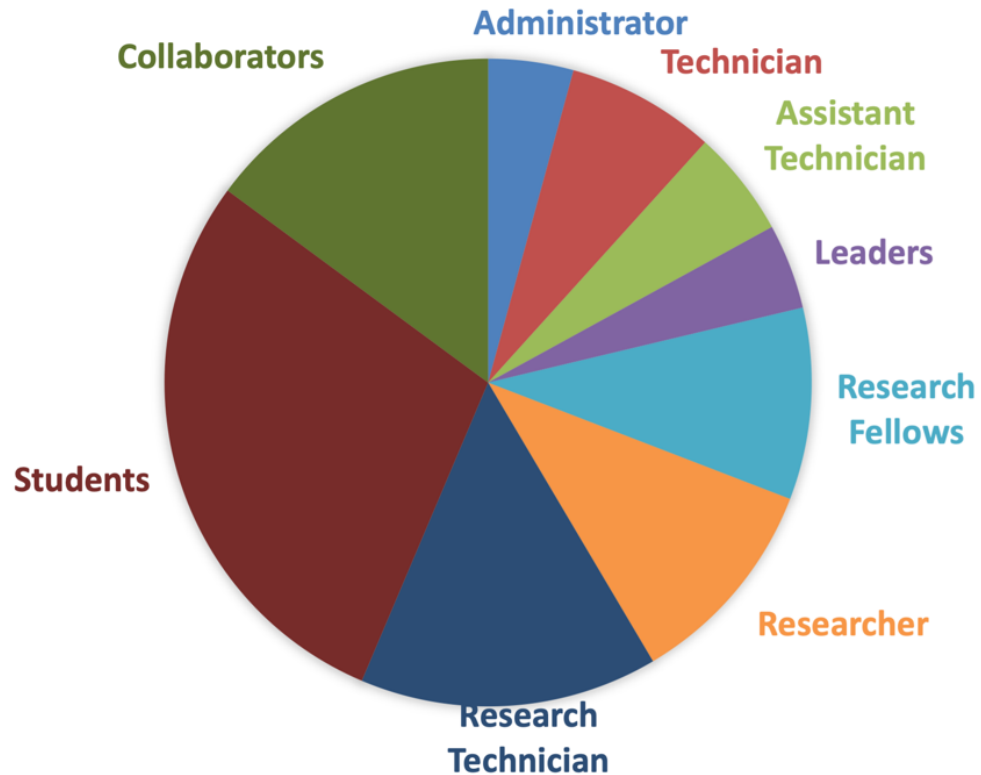
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YSF : Bong-ho Kim, Koun Choi

Human resources

CUP personnel (80+14)

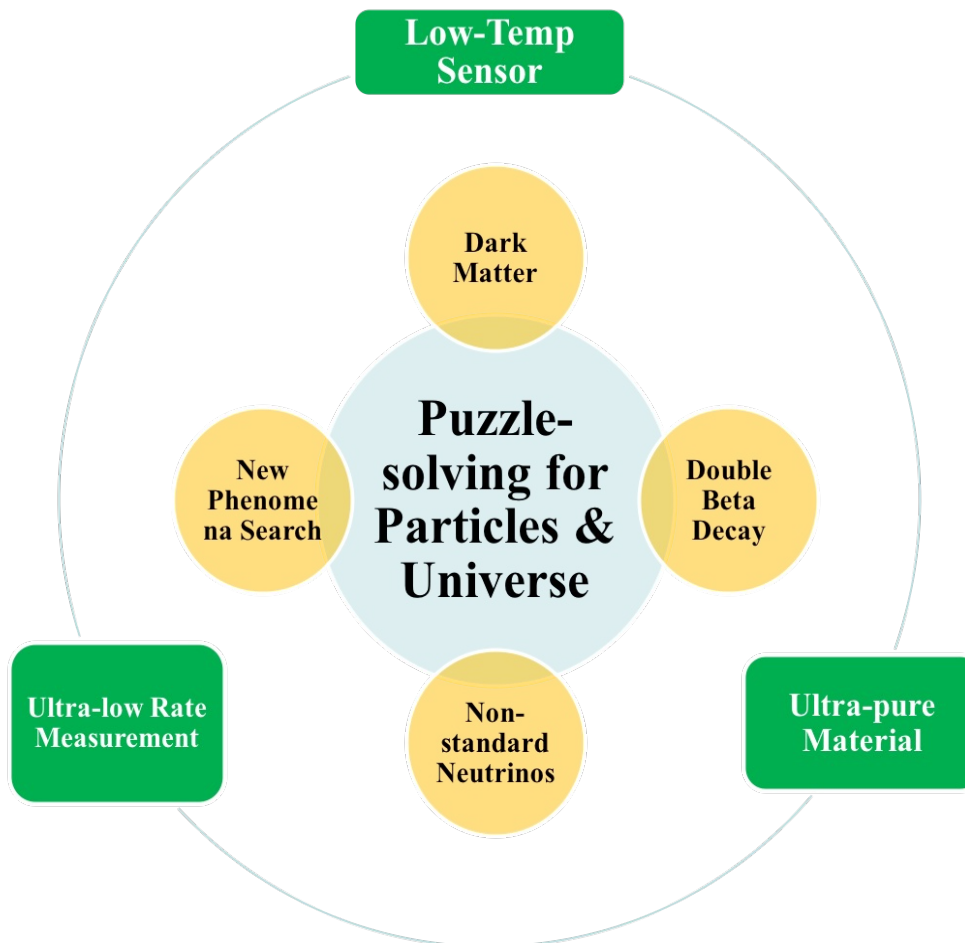


Domestic & International Collaborators ~ 200

Overall Concept of CUP

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- **CUP is a center with definite scientific goals.**
- **These goals are pursued by cooperation between strong technical working groups and experimental groups.**



Achievements of CUP

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Goal 1 : Discovery in dark matter and neutrino physics

Constraining DAMA/LIBRA modulation signals – COSINE-100 experiment

“An experiment to search for dark-matter interactions using”, Nature (2018)

“First Direct Search for Inelastic Boosted Dark Matter with ...”, Phys. Rev. Lett. (2019)

“Search for a Dark Matter-Induced Annual Modulation Signal in”, Phys. Rev. Lett. (2019)

“Strong constraints from COSINE-100 on the DAMA dark matter results using the same sodium iodide target,” Sci. Adv. (2021)

→ **COSINE has rejected DAMA/LIBRA interpretation of WIMPs with standard halo model. Constrained the modulation signal. Demonstrated new experiment feasibility.**

Progresses towards AMoRE-II experiment

“First Results from the AMoRE-Pilot neutrinoless double beta decay...”, Eur. Phys. J. C (2019)

“Alpha backgrounds in the AMoRE-Pilot experiment,” Eur. Phys. J. C (2022)

“AMoRE-I results”, TAUP 2023 presentation. (2023)

→ **AMoRE demonstrated detector performance and background reduction. Best limit for Mo-100. Rapid progresses toward AMoRE-II at Yemilab !**

Searching the sterile neutrinos and new physics

“Sterile Neutrino Search at the NEOS Experiment,” Phys. Rev. Lett. (2017)

“Dark Photon Sensitivity at Yemilab, Korea”, JHEP (2021)

→ **NEOS gave most stringent limit for reactor neutrino anomaly. NEOS-II finished. LSC feasibility studies.**

Goal 2 : Constructed world class underground laboratory

→ Yemilab, a world class underground Lab completed in 2022.

Goal 3 : Fostering young astroparticle physicists.

- 20s and 30s are about 60% of all researchers.**
- 2 YSFs working DM and antimatter joined CUP.**
- 25 graduate students and 8 post-doctors.**
- 9 graduated and 5 got positions at internationally renowned labs.**

Goal 4 : Construct world class research facility for ultra-rare event search

Developing low temperature detectors for underground physics

“ Li_2MoO_4 Phonon–Scintillation Detection Systems with MMC Readout”, Low Temp. Phys. (2020)

“Low temperature property study of MMCs used for ... ”, IEEE T. Appl. Supercon. (2021)

“An MMC-based cryogenic calorimeter with a massive sodium molybdate” JINST (2022)

→ Novel techniques in cryogenic detectors !

Establishing ultra-low radioactivity Techniques for rare event searches

“Measurement of the background activities of a ^{100}Mo -enriched ...”, NIMA (2021)

“Purification and recovery of $^{100}\text{MoO}_3$ in crystal production for AMoRE ...” JINST (2020)

→ Developments in ultra-low radioactivity techniques !

Milestones and Future program

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| Setting Stage (2013-2016) | Developing Stage (2017-2020) | Leaping Stage (2021- 2024) | New Direction (2025-2028) |
|-----------------------------------|----------------------------------|---|--|
| Y2L Expansion | IBS HQ | IBS HQ Yemilab | IBS HQ Yemilab LSC |
| AMoRE-Pilot COSINE-100 NEOS | AMoRE-I COSINE-100 NEOS-II | AMoRE-II COSINE-200 NEON R&D exp. Low mass DM Sterile Nu | AMoRE-II COSINE-200 COSINE-nT DBD ~ ton “LMDM” Sterile Nu |



A thought on future direction...

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- We have constructed a lot of infrastructure for last 10 years. Costly work.
- Most of AMoRE-II has been made, major expenses paid.
- In near future, we will have budget reduction.
- No major hardware construction.
- We have a lot of man power.
- In future, we will concentrate on the research using already existing equipment and facilities.
- Research on R&D for new experiments.
- Research concentrating on data analysis, physics interpretation, feasibility studies with simulation etc.

Summary

- ❑ **Established a unique center for BSM particle astrophysics.**
- ❑ **Achieved world class results in dark matter and neutrino physics .**
- ❑ **With the Yemilab and equipment installed, we expect escalating results from COSINE, AMoRE, low mass DM and sterile neutrino searches.**
- ❑ **CUP will become a world class center for rare phenomena searches.**

Vision of CUP

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Current Paradigm :

Standard Model

3 massive neutrinos

ΛCDM

Vision :

Challenge and Enhance the current paradigm about the structure and the origin of the Universe.

through questions like

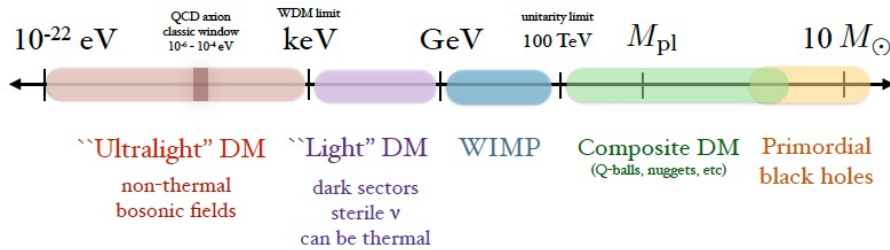
- What is Dark Energy and Dark Matter ?
- How small are neutrino masses and how can we understand neutrino mass ?
- Are there different kind of neutrinos ?

| | | | | | |
|----------------|---|---------------------------------------|--------------------------------------|-------------------------|-------------------------|
| mass → | ≈2.3 MeV/c ² | ≈1.275 GeV/c ² | ≈173.07 GeV/c ² | 0 | ≈126 GeV/c ² |
| charge → | 2/3 | 2/3 | 2/3 | 0 | 0 |
| spin → | 1/2 | 1/2 | 1/2 | 1 | 0 |
| | u up | c charm | t top | g gluon | H Higgs boson |
| QUARKS | ≈4.8 MeV/c ² | ≈95 MeV/c ² | ≈4.18 GeV/c ² | 0 | |
| | -1/3 | -1/3 | -1/3 | 0 | |
| | 1/2 | 1/2 | 1/2 | 1 | |
| | d down | s strange | b bottom | γ photon | |
| | 0.511 MeV/c ² | 105.7 MeV/c ² | 1.777 GeV/c ² | 91.2 GeV/c ² | |
| | -1 | -1 | -1 | 0 | |
| | 1/2 | 1/2 | 1/2 | 1 | |
| | e electron | μ muon | τ tau | Z Z boson | |
| LEPTONS | ≈2.2 eV/c ² | ≈0.17 MeV/c ² | ≈15.5 MeV/c ² | 80.4 GeV/c ² | |
| | 0 | 0 | 0 | ±1 | |
| | 1/2 | 1/2 | 1/2 | 1 | |
| | ν_e electron neutrino | ν_μ muon neutrino | ν_τ tau neutrino | W W boson | |
| | | | | | GAUGE BOSONS |

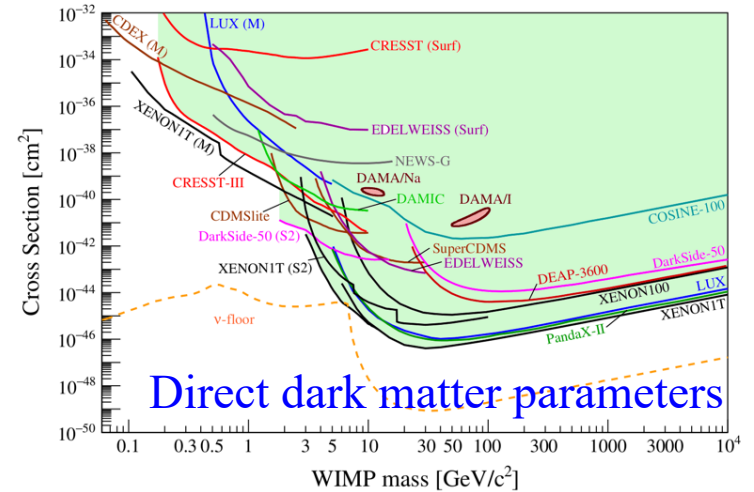
New parameter space to be explored !

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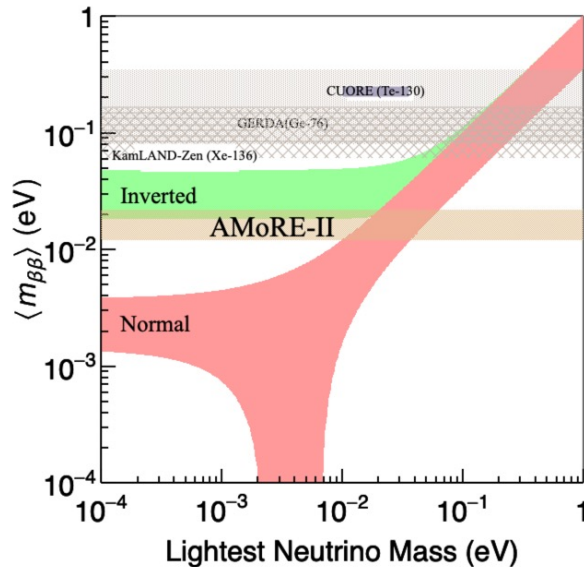
Dark matter mass parameter



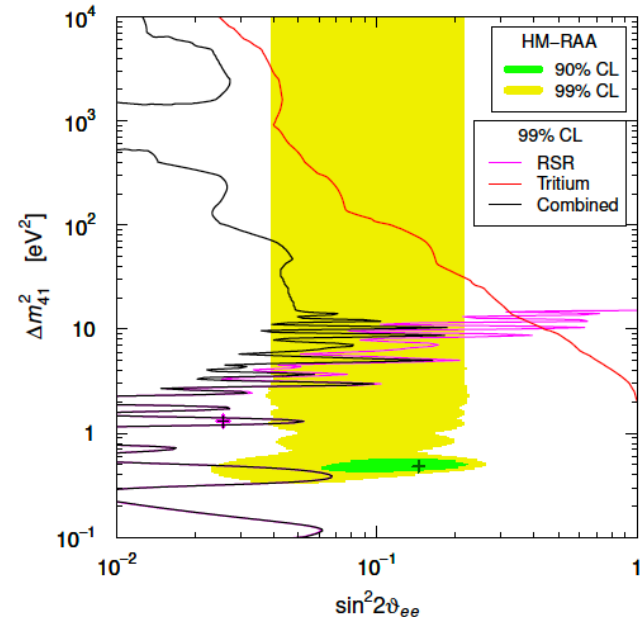
Beyond the standard model (BSM)



Neutrino mass parameters



Sterile neutrino parameters



- KIMS-CsI has given stringent limit for both spin-independent & spin-dependent cross section which challenges DAMA data. KIMS-CMO will be developed.
- Direct confirmation of DAMA with new NaI(Tl) crystals.
- AMoRE-200 : sensitive to $\langle m_{\beta\beta} \rangle \sim 30$ meV
- Both the search experiments at Y2L are the most fundamental studies towards the understanding of the mysteries of our universe.