Why detector is so important?

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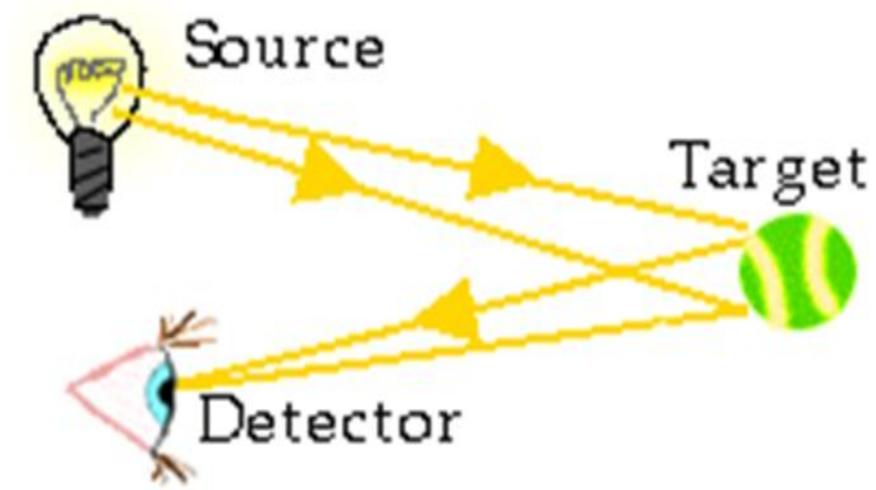
hongjooknu@gmail.com
제1회 고에너지 검출기학교, 2019년 1월 9-11일

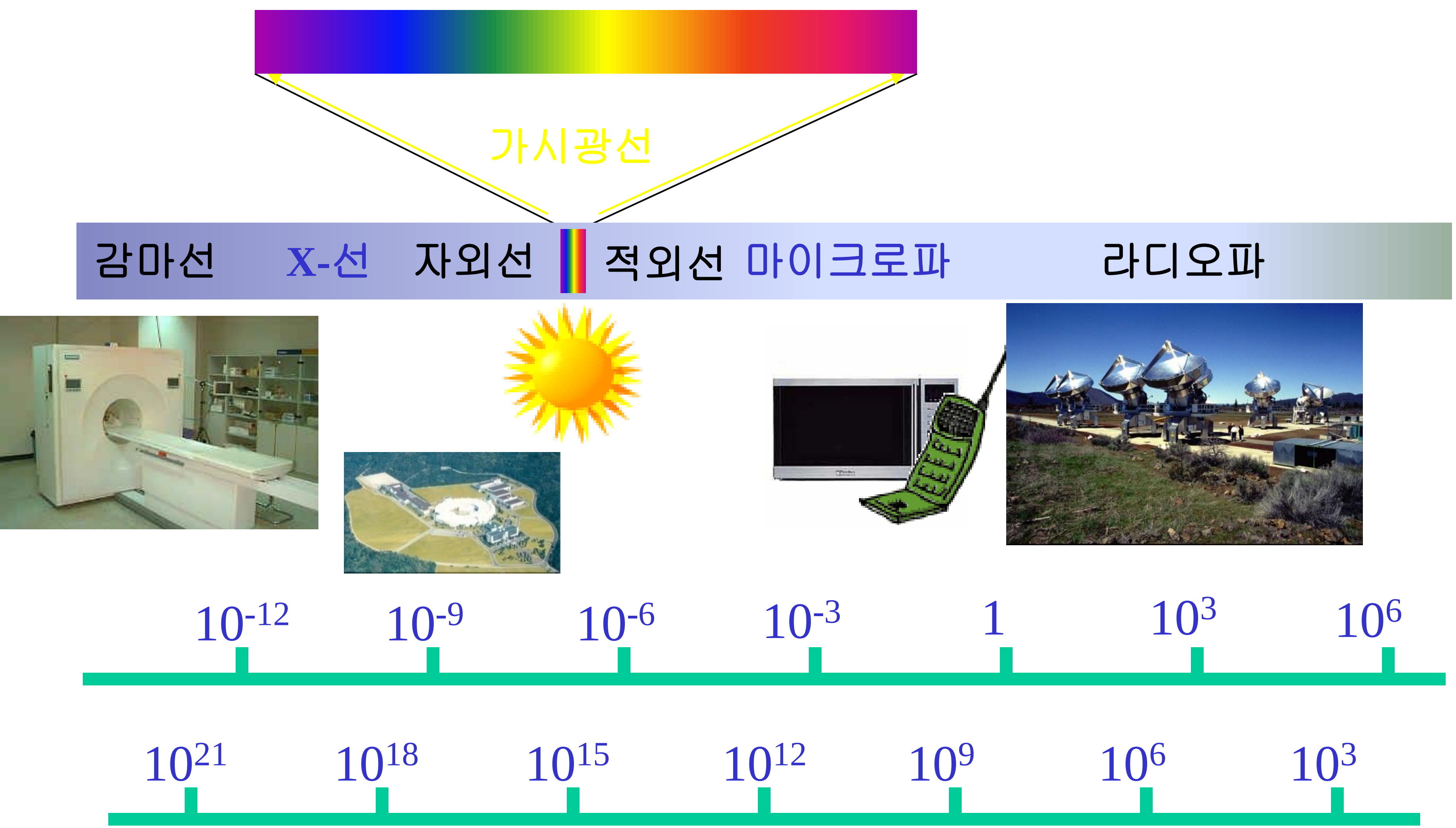
- What is the World (Universe) Made of ?
- How small we can break a matter?
- What is the fundamental interaction?

- Experiment to find it out!

How do you observe matter even if it can't be seen by eye?



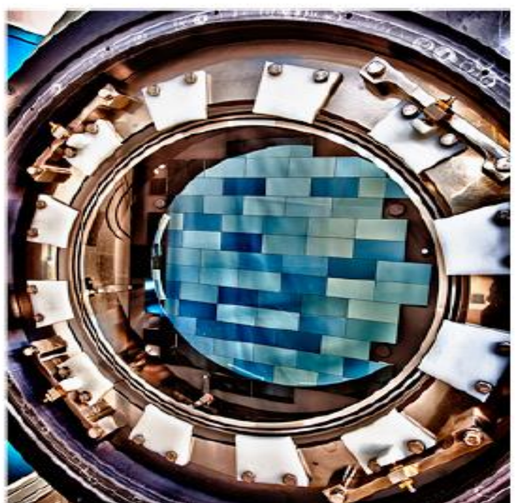
Electromagnetic Radiation



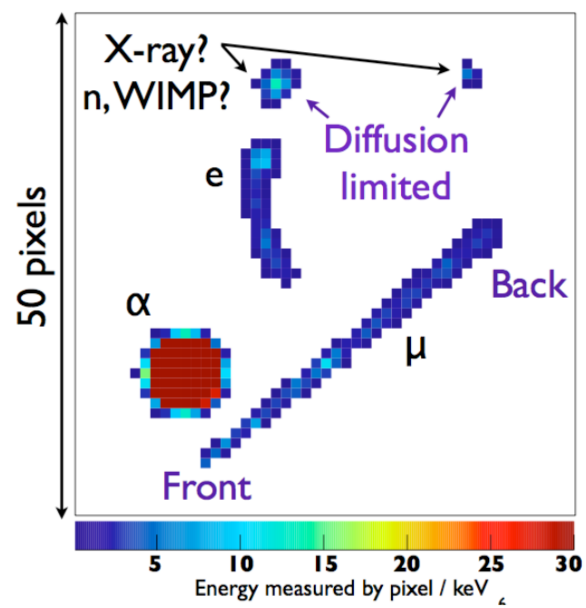
Why sensitivity is extremely important?

- Ultra-low-noise readout down to 2 e-
- Back-illuminated CCDs deliver >95% peak QE

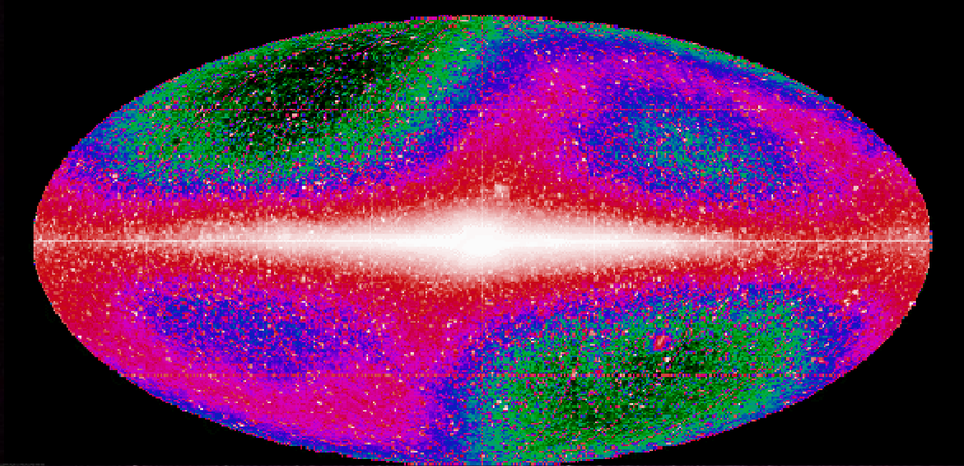
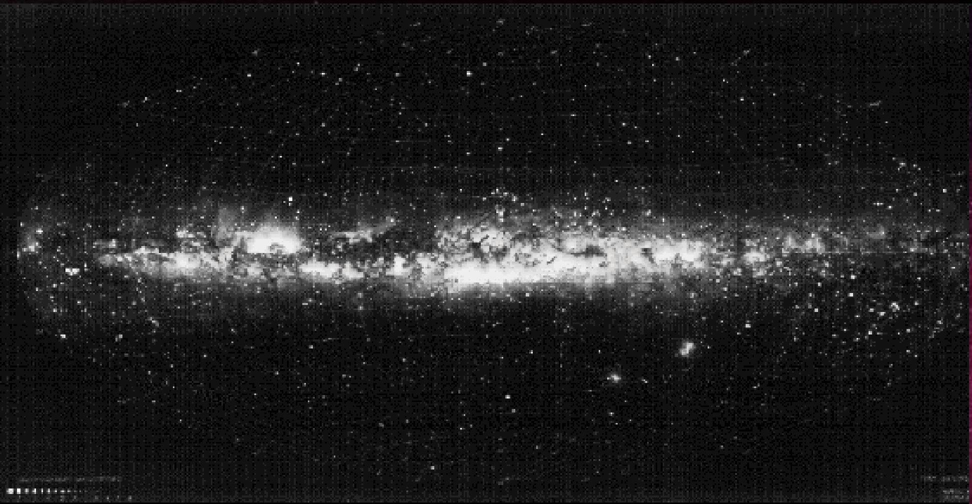
Dark Energy Survey Camera

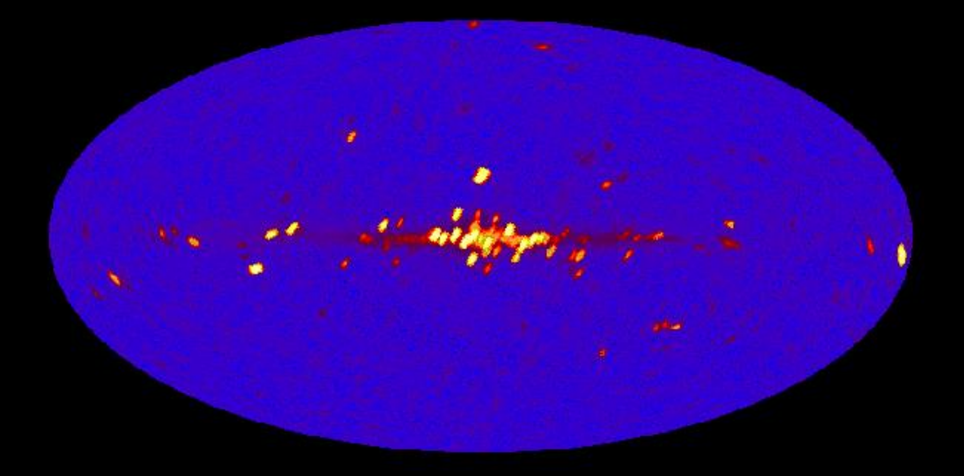
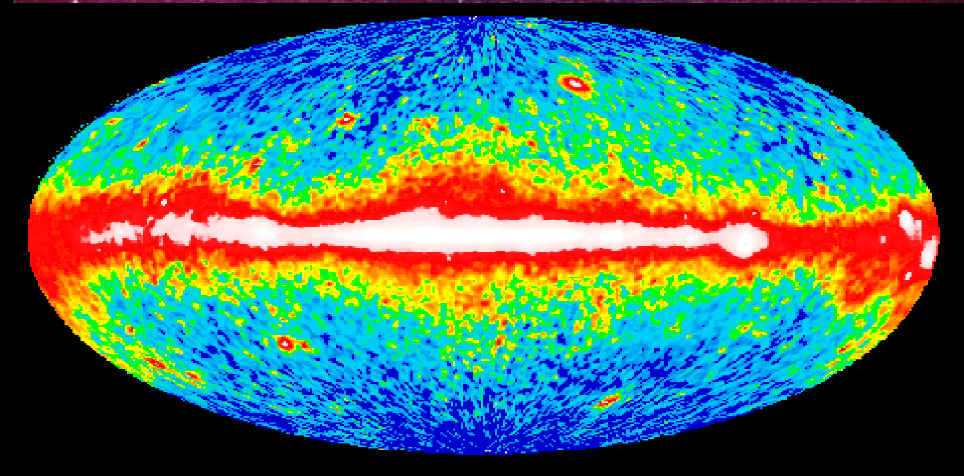


250 μm thick CCDs with enhanced IR sensitivity developed at LBNL

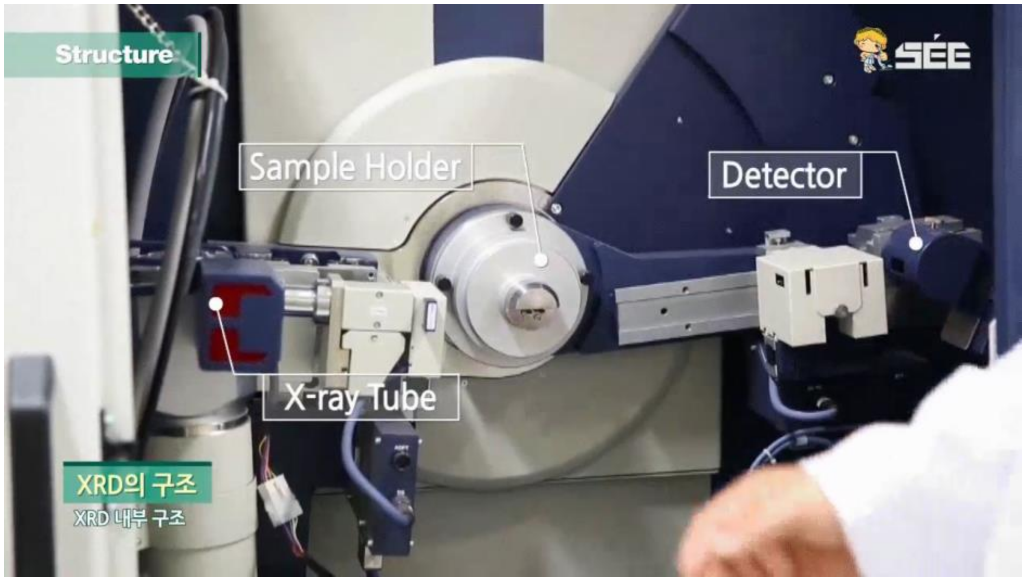


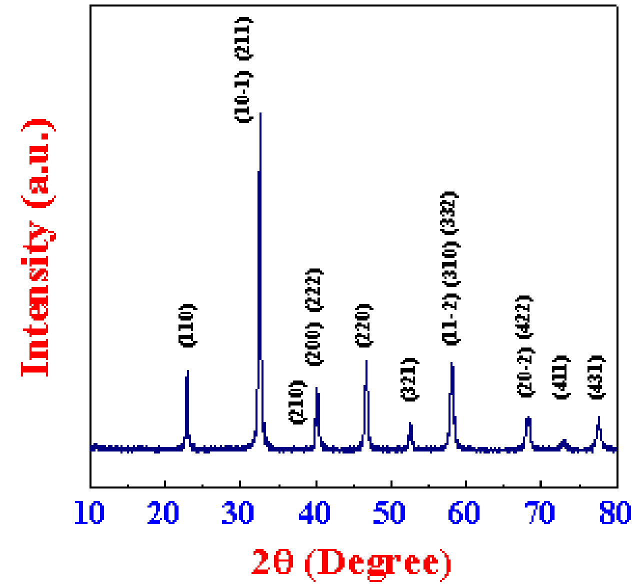
Dark matter search with CCD (DAMIC)

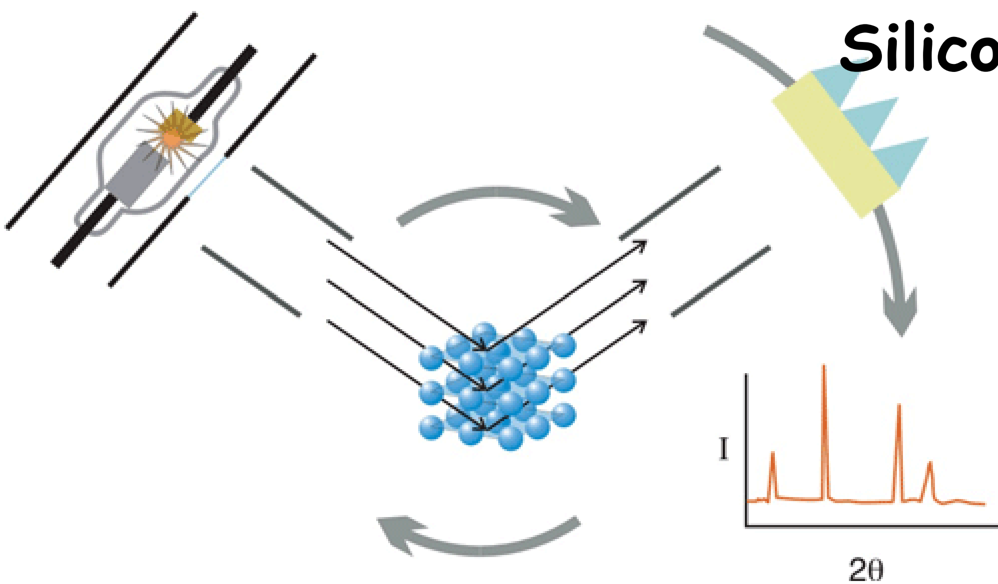




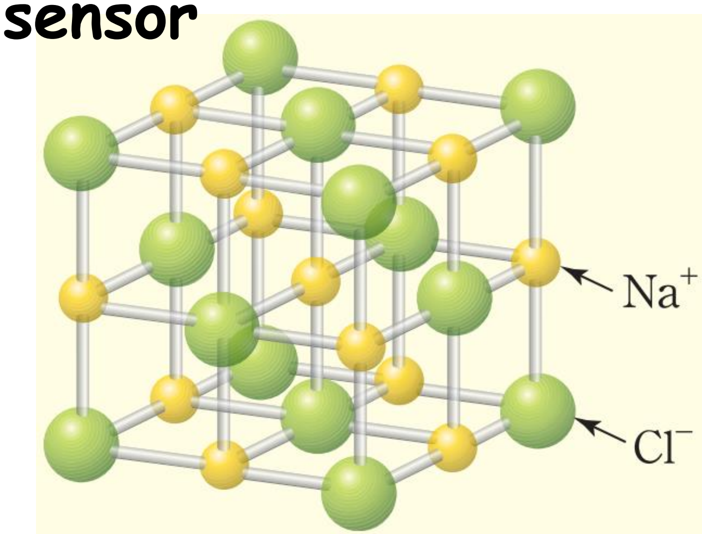
XRD (X-Ray Diffraction)





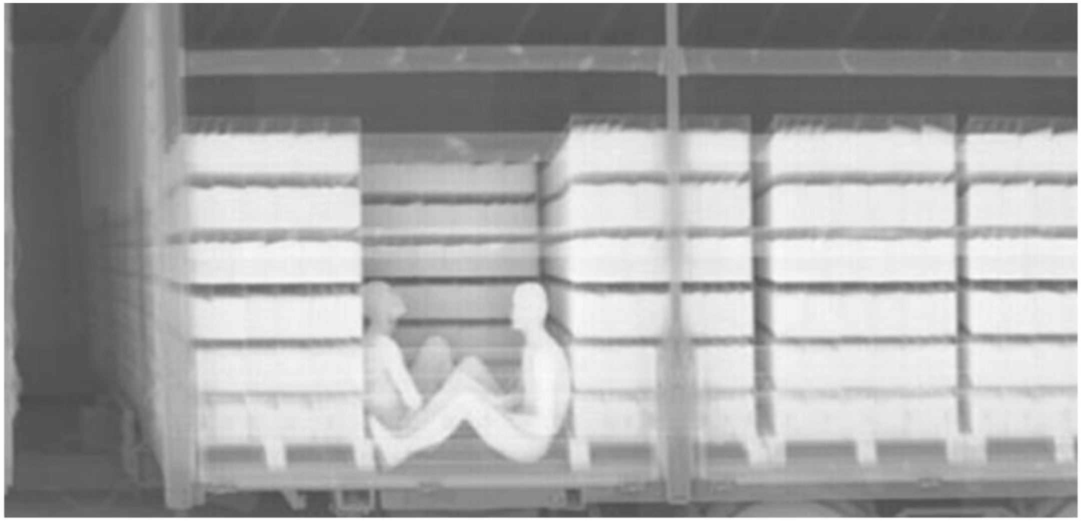


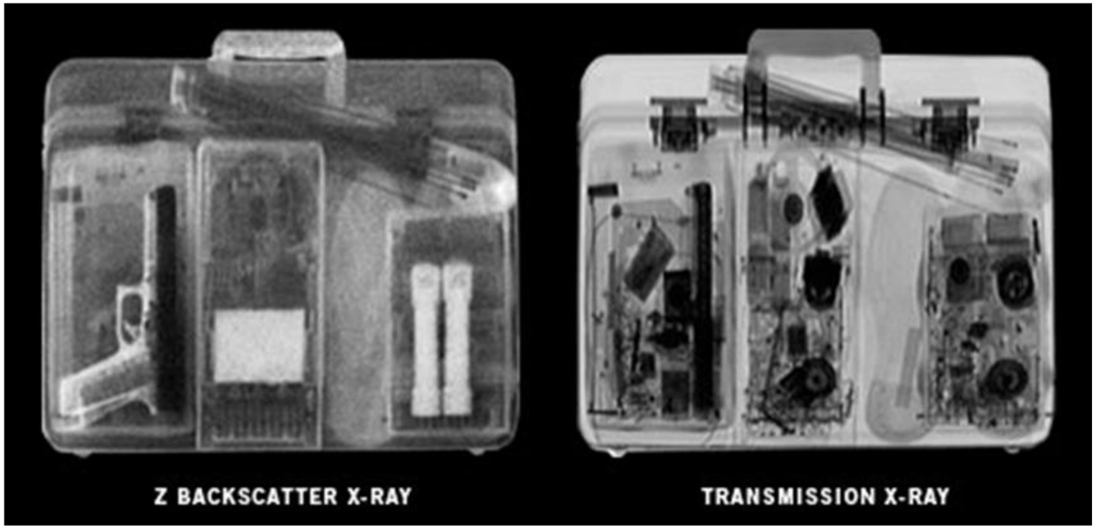
Silicon sensor



How do you observe matter

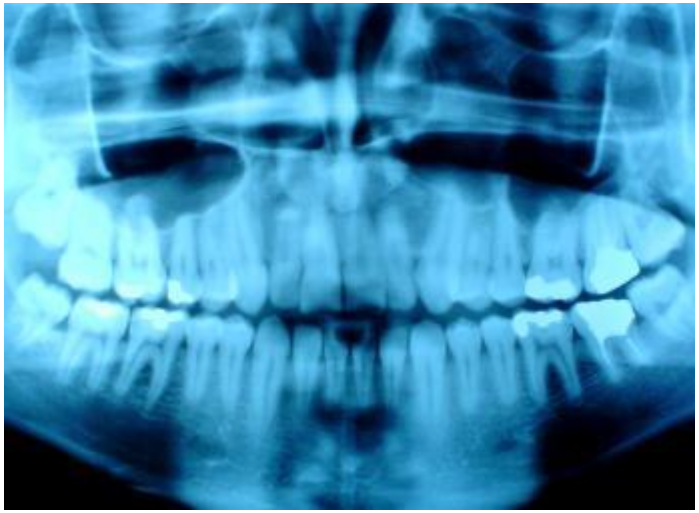
Scintillator
+ photosensor





AS&E Corporation

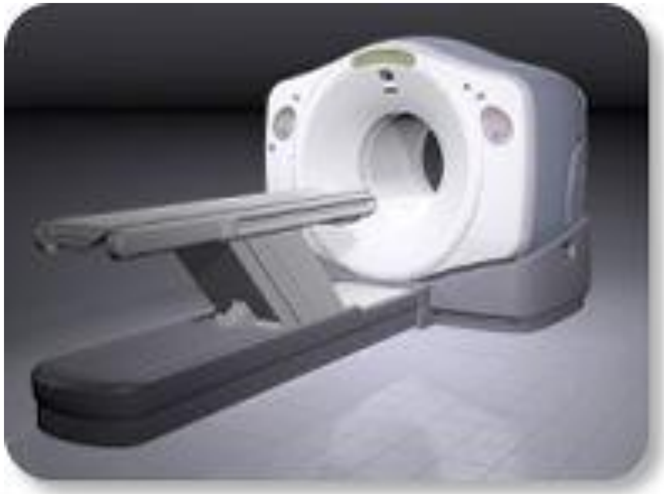
How do you observe matter

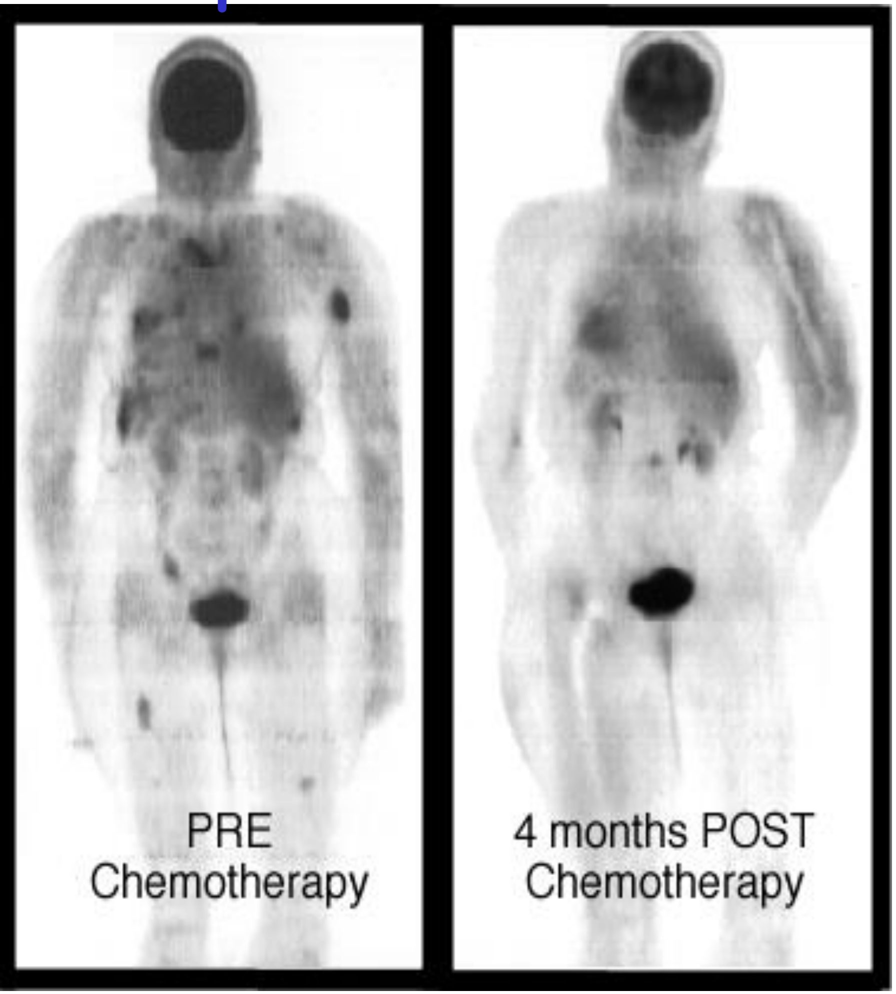


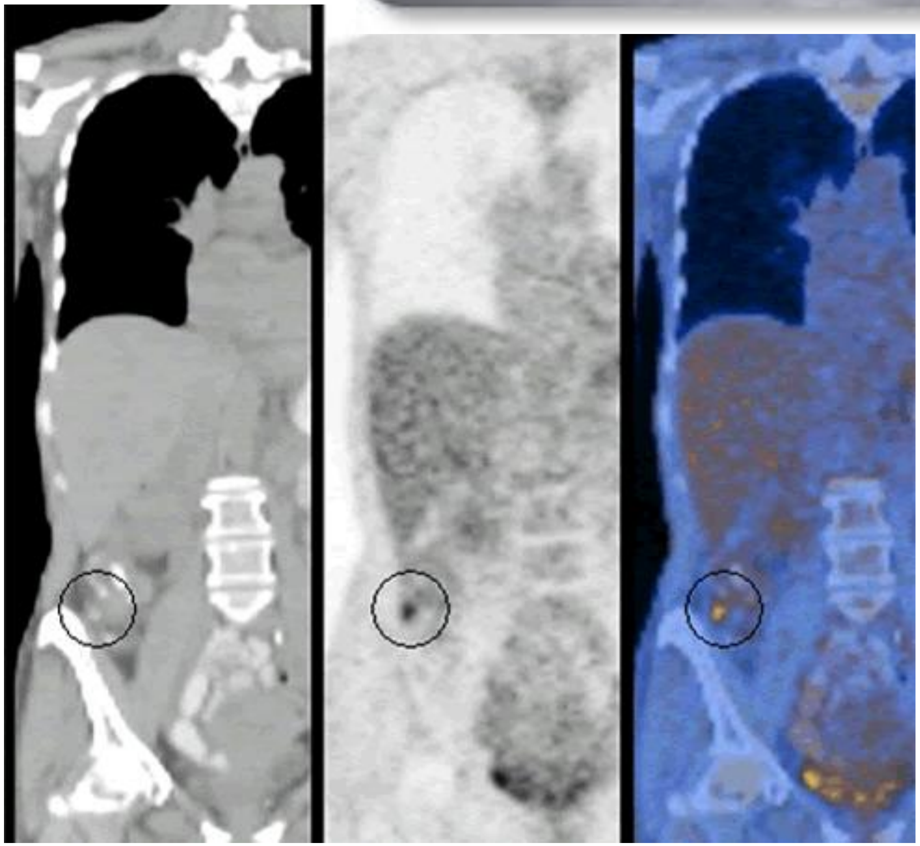
Pixeleted CsI:Tl
+ CMOS pixel sensor

PET/CT Scanners

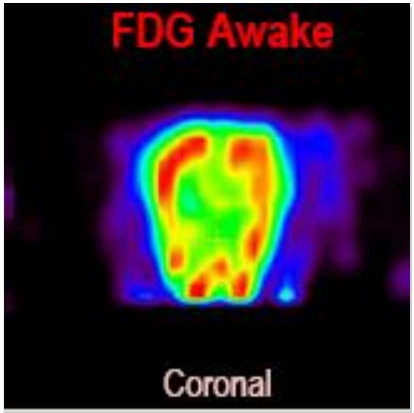
Crystal Scintillator
+ photosensor



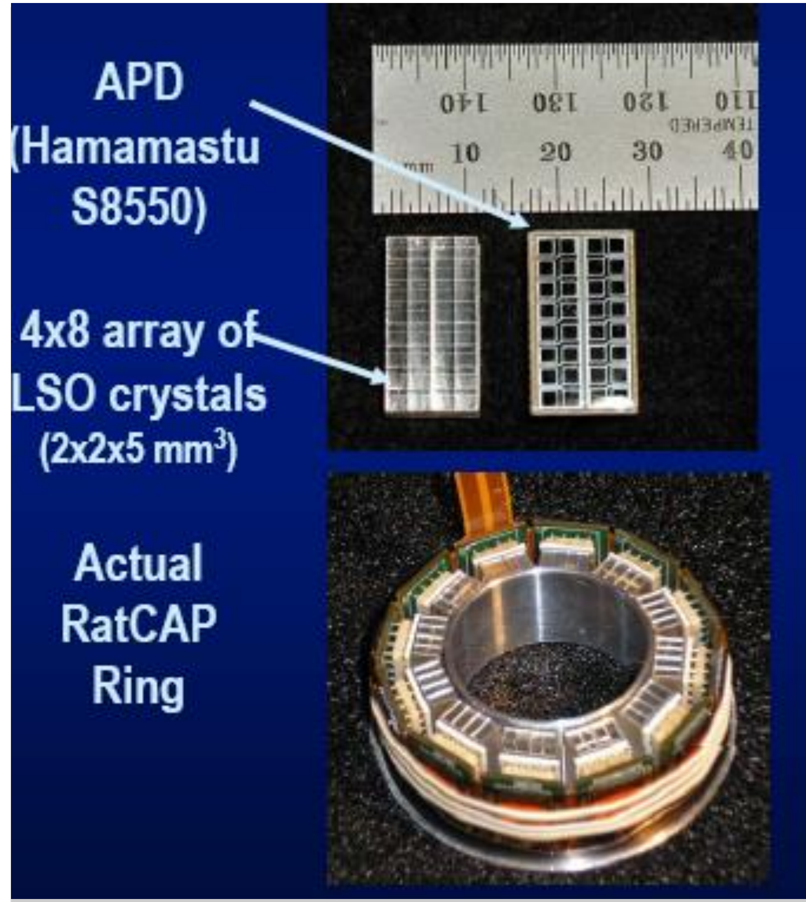




RatCAP: Rat Conscious Animal PET



C.Woody, SCINT 07, 6/7/07

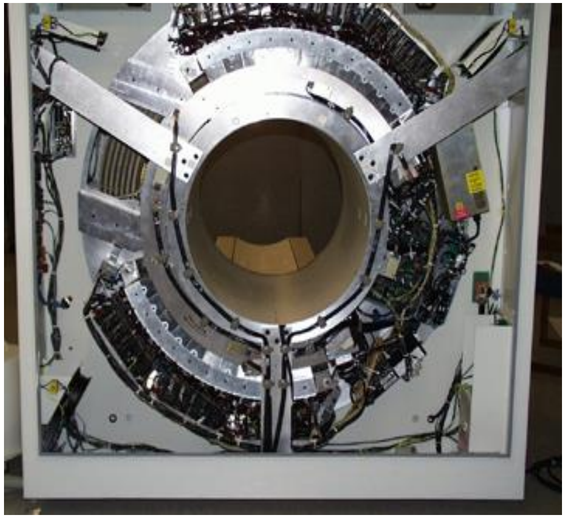


- Good energy resolution
- Fast decay time
- Reasonable cost

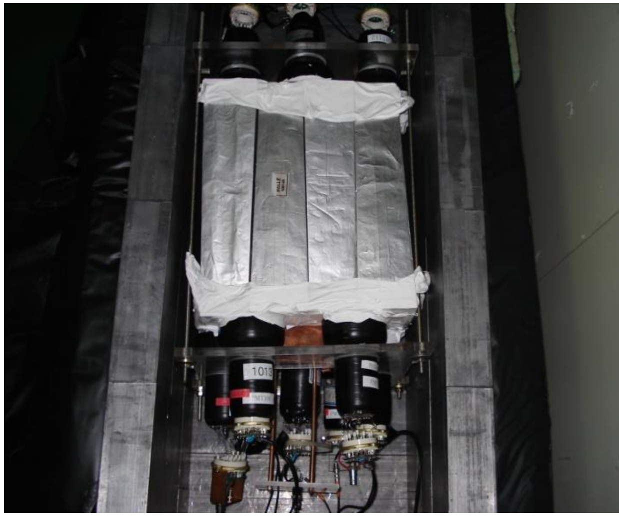
Calorimeters , PET and EC/β+ double beta decay

Calorimeter

PET Camera



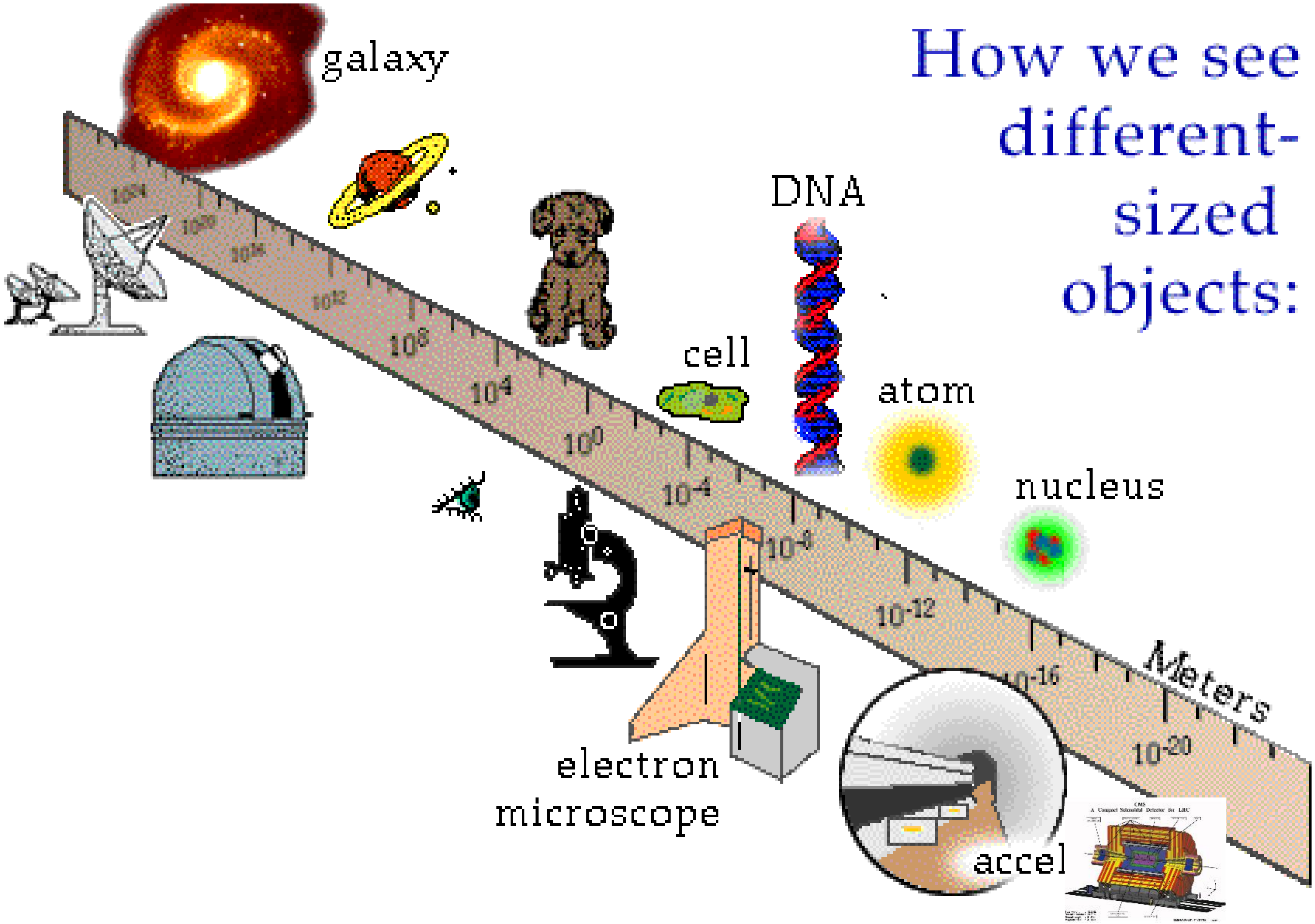
0ν EC/β+



- Cylindrical Gamma Ray Detectors
- High Efficiency, Hermetic
- Segmented, High Density Scintillator Crystals
- High Performance Photodetectors
- High Rate, Parallel Readout Electronics

Principle of Particle Detection

Quarks to Cosmos



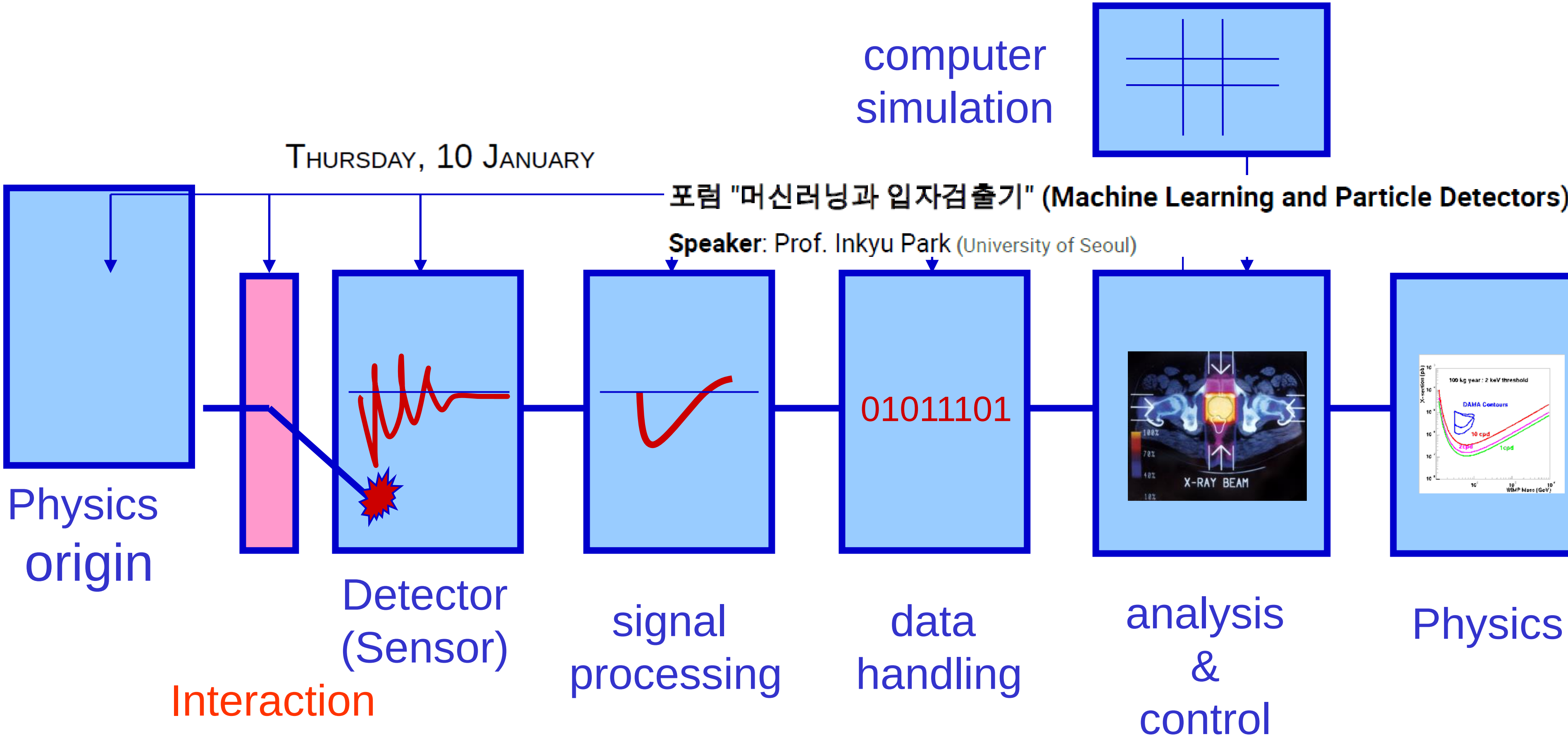
How we see different-sized objects:

Cosmos

-궁즉통-

Quark

Experiment



THURSDAY, 10 JANUARY

포럼 "머신러닝과 입자검출기" (Machine Learning and Particle Detectors)

Speaker: Prof. Inkyu Park (University of Seoul)

입자검출기 개론 (Introduction to Particle Detector) I - particle interactions with matter

Speaker: Prof. Hong-Joo Kim (경북대학교)

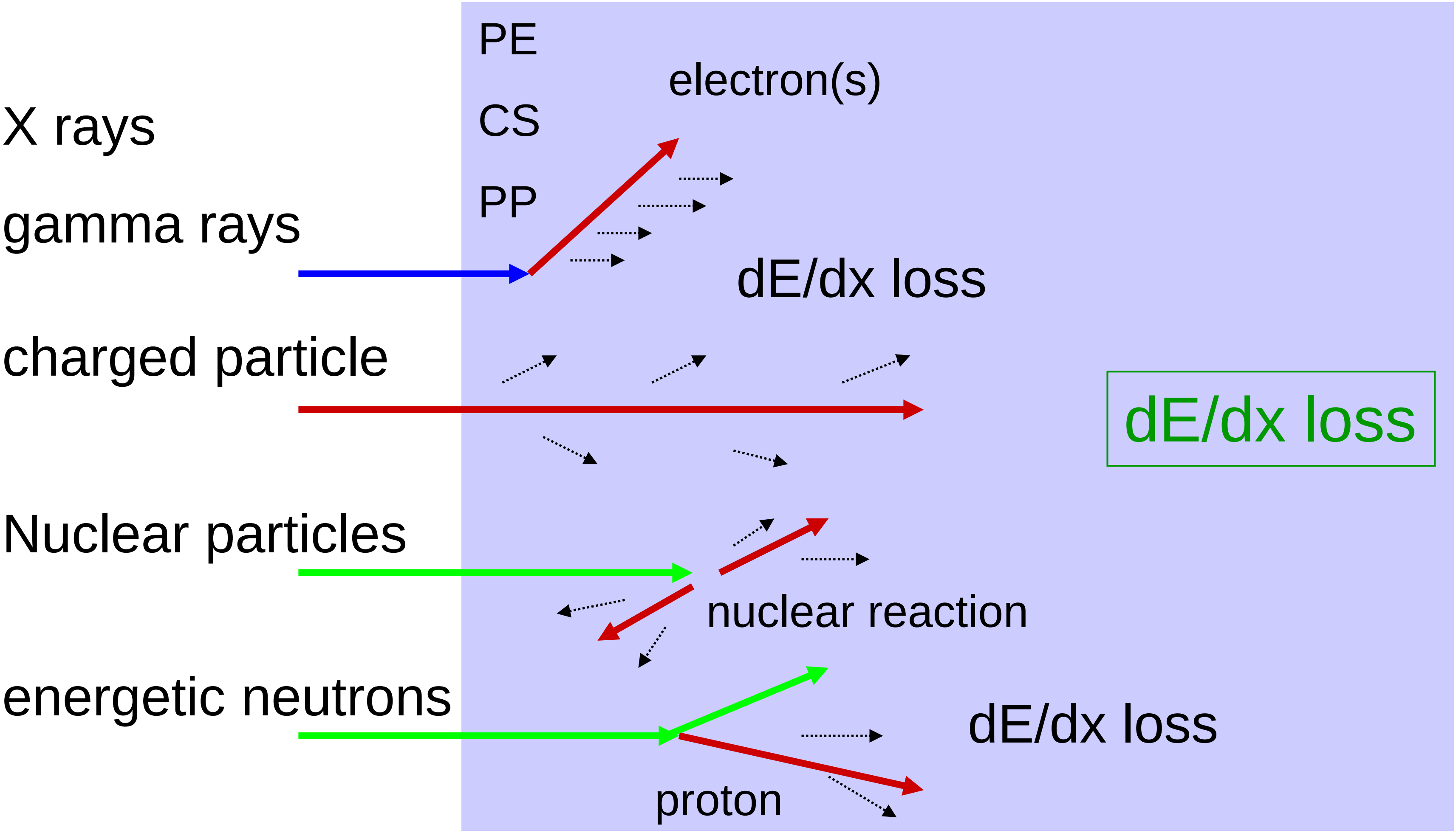
10:20 **물리학도를 위한 전자학 강의 (Electronics for Physicists)**

Speaker: Prof. Il Hung Park (성균관대학교)

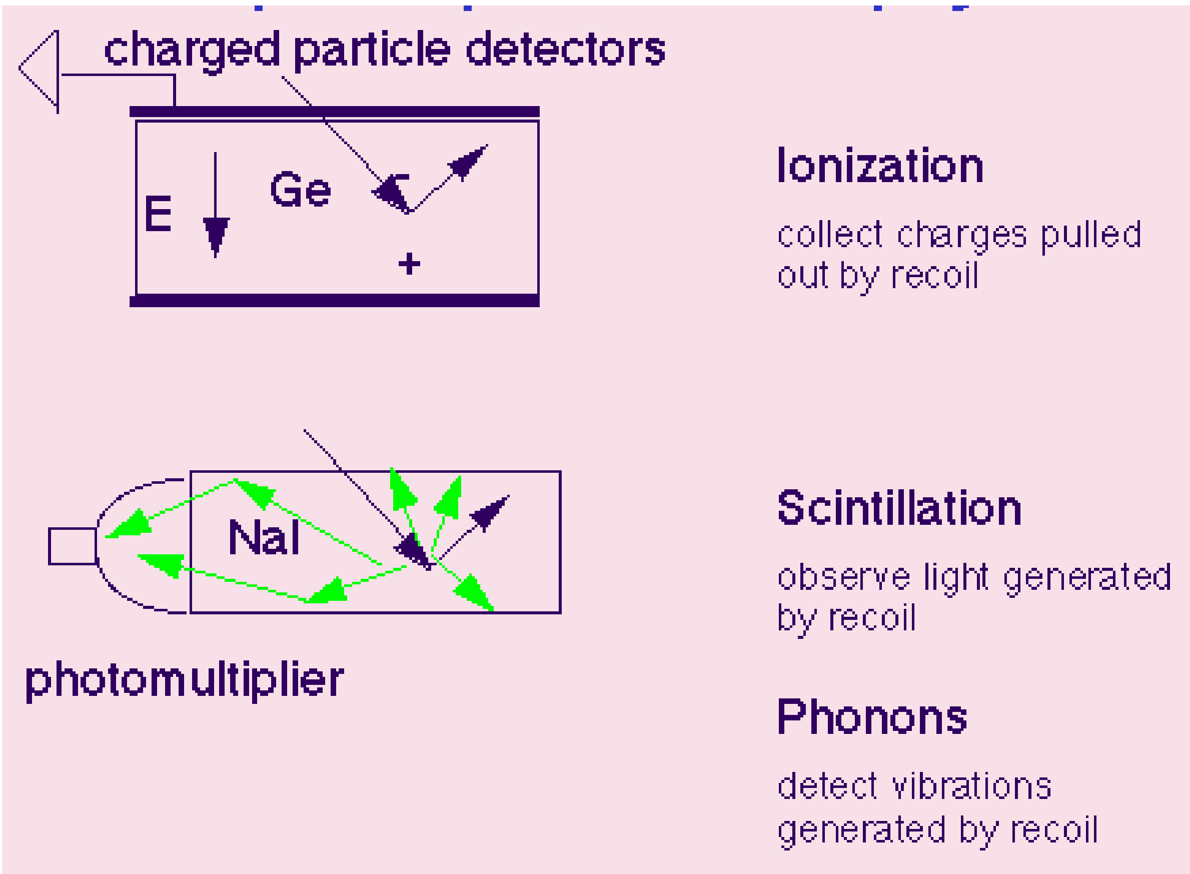
신호처리, 방아쇠 그리고 DAQ의 기초 (Basics of signal processing, trigger and DAQ)

Speaker: Hyupwoo Lee (서울시립대학교)

Particle energy loss in matter



Particle Detection Principle



1) Gas Detector
2) Liquid ionization
3) Semiconductor

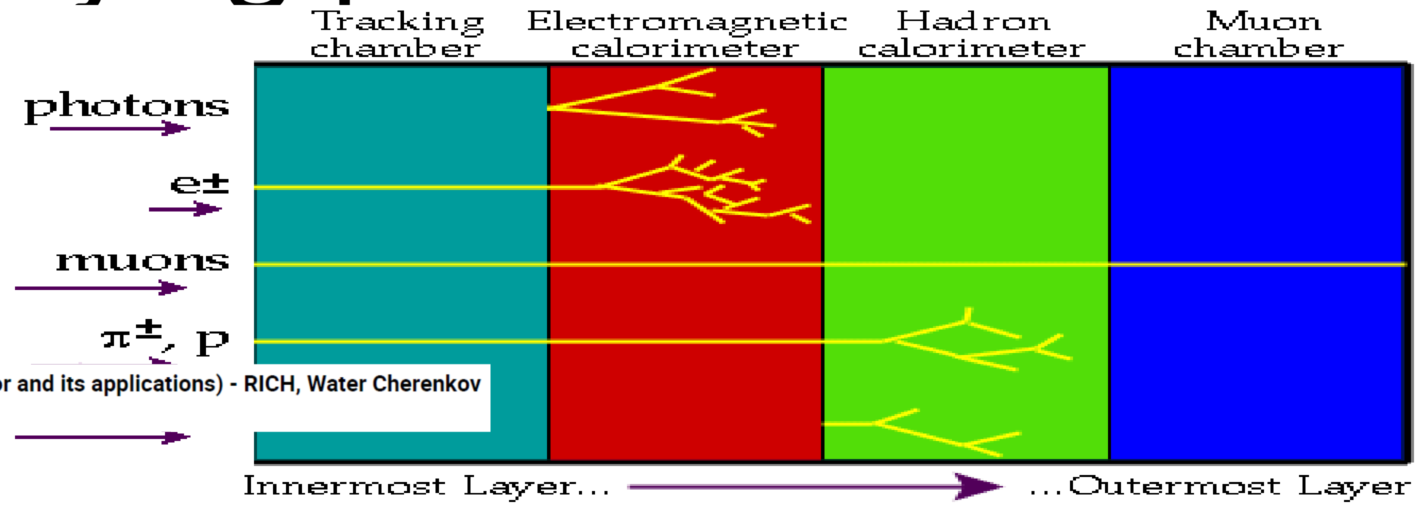
1) Inorganic
2) Organic
(Solid, Liquid, gas)

1) Cryogenic detector

Cerencov radiation Cerencov light 1) Cerencov det.

Transition radiation Transition x–ray 1) Transition det.

Identifying particles



A detector cross-section, showing particle paths

체렌코프 검출기와 활용 (Cherenkov detector and its applications) - RICH, Water Cherenkov
Speaker: Prof. Youngjoon Kwon (연세대학교)

실리콘검출기 (Semiconductor detector) - Vertex & Track measurements
Speaker: Prof. Inkwon Yoo (부산대학교)

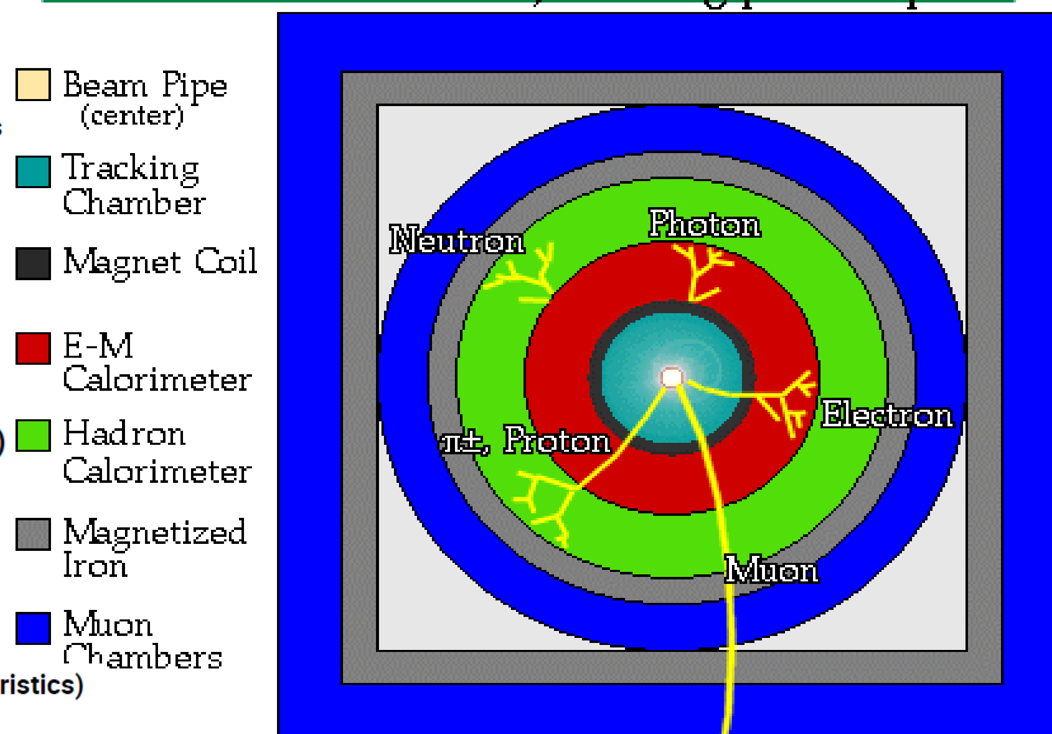
에멀젼, 액체아르곤 (Emulsion & Liquid Argon Precision Detectors)

섬광검출기와 PMT (Scintillation detector & PMT)
Speaker: Dr Jongwon Lee (고려대학교)

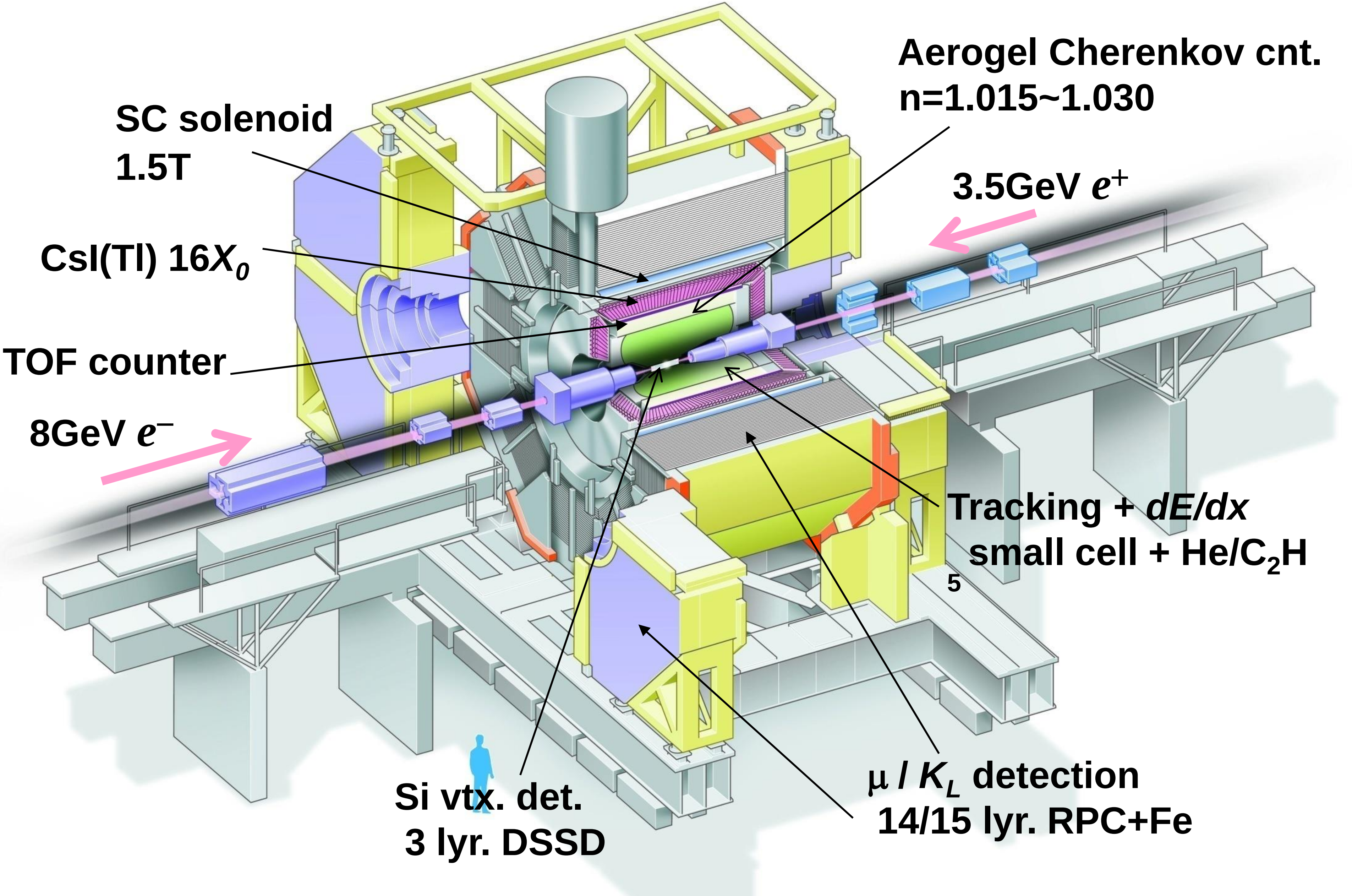
전자기열량계와 하드론열량계 (EM & Hadron Calorimeters)
Speaker: Prof. Sehwook Lee (경북대학교)

뮤온검출기의 세계 (World of muon detectors) - RPC, Drift Tube, CSC
Speaker: Dr Kyonsei Lee (고려대학교)

젬검출기의 원리와 특성 (Principles of the GEM detector & its characteristics)
Speaker: Dr Inseok Yoon (서울대학교)

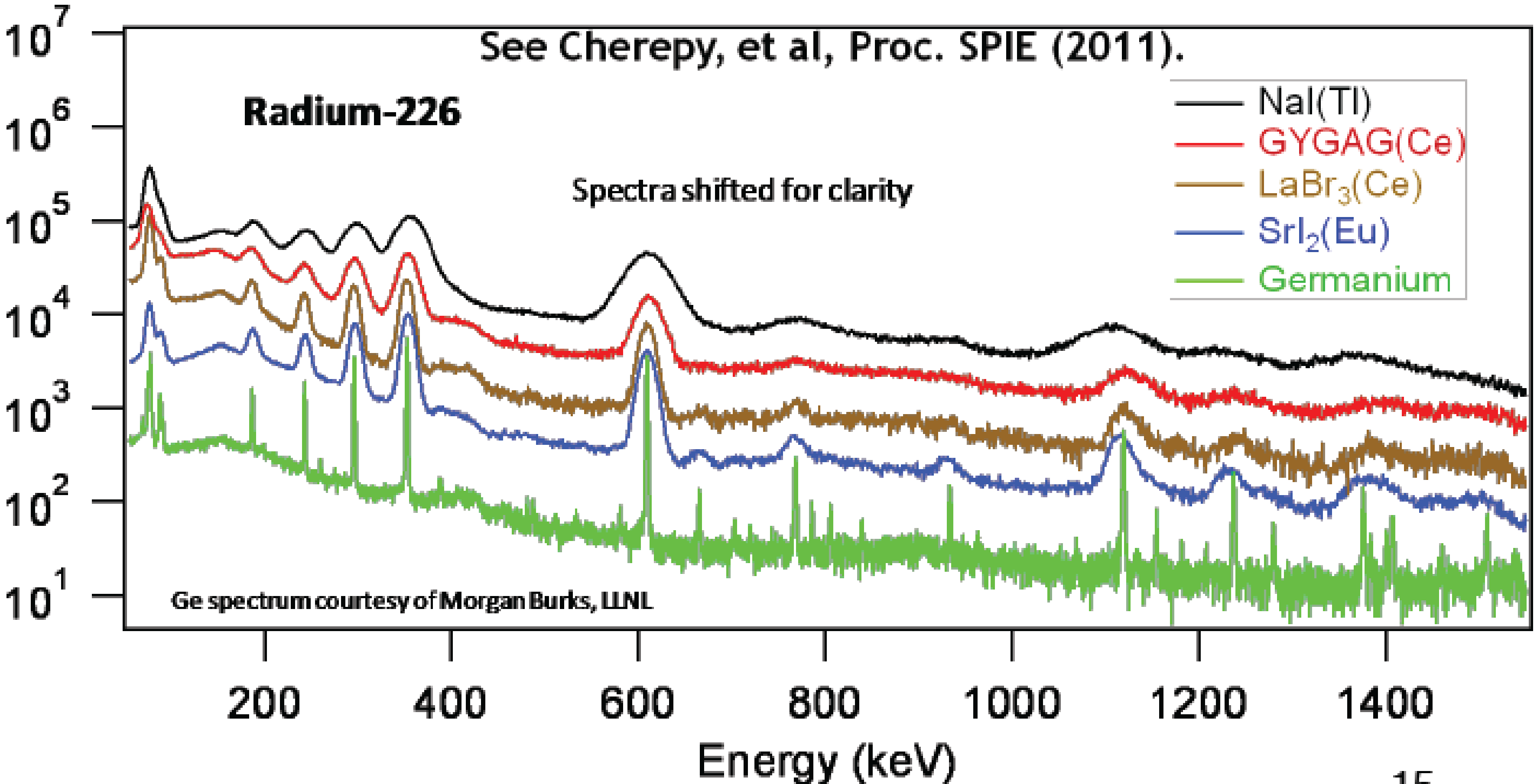


Belle Detector



Why good energy resolution for γ-ray spectroscopy?

Background rejection from signal is important and you need to have a detector which perform it!



The best detector performance

- Energy resolution
  HPGe : 1-2keV at 1MeV (0.1%)

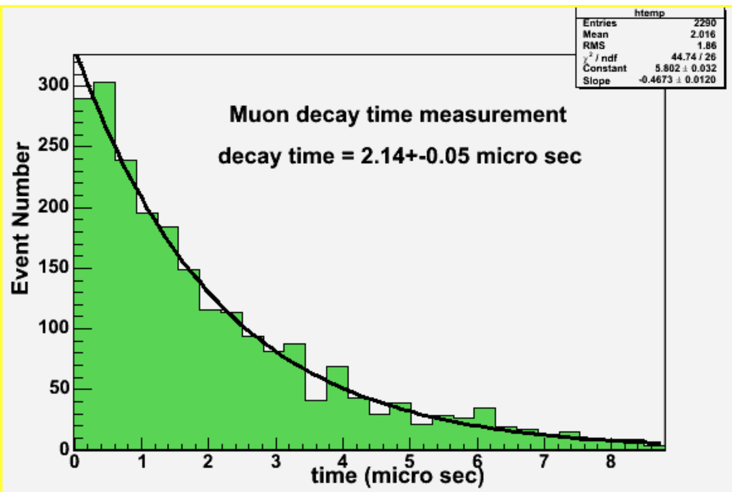
- Low energy detection :
  EMCCD (6eV RMS), Bolometer (<10eV)

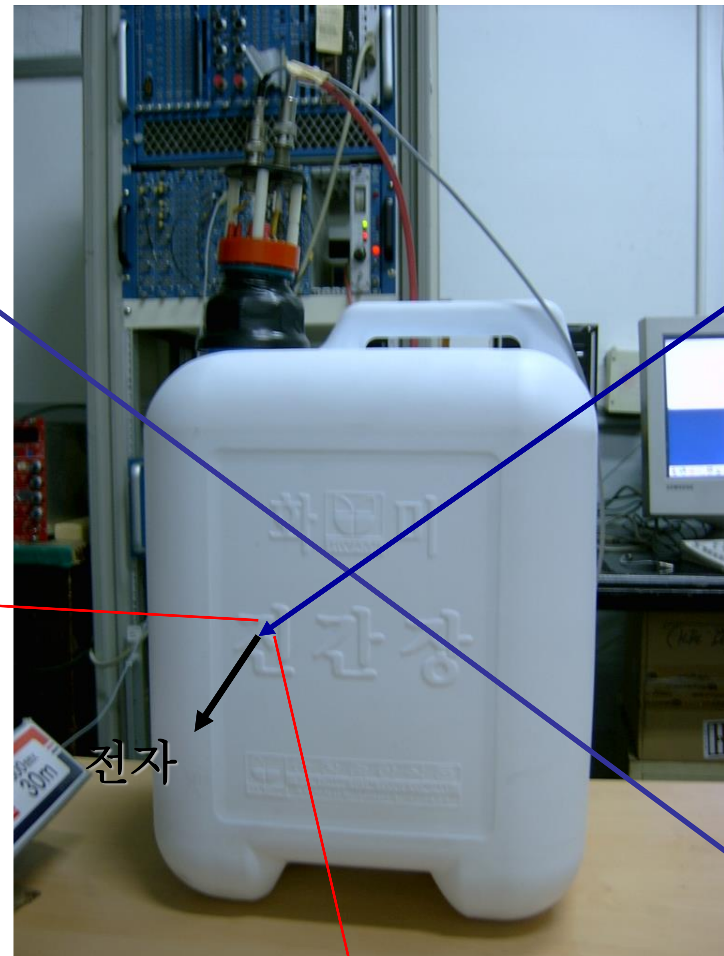
- Timing resolution
  50 ps with scintillator

- Position resolution
  1μm with Emulsion (5 μm with silicon pixel)

- Maximum Size
  $1km^3$ (Giga Ton) with IceCube Cerencov detector

간장 을 이용한 뮤온 검출용 액체 섬광 검출기





정지뮤온

2.2μs
붕괴시간

중성미자

전자

통과 뮤온

섬광검출기와 PMT (Scintillation detector & PMT)

Speaker: Dr Jongwon Lee (고려대학교)

Development of new physics is closely related how to invent new detection method !

Examples in Nobel Prize in Physics

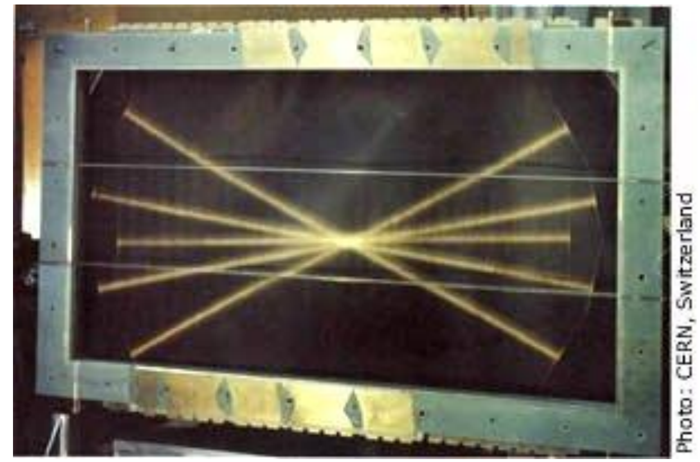
http://en.wikipedia.org/wiki/List_of_Nobel_laureates_in_Physics

특강: "가속기, 컴퓨팅, 검출기 그리고 입자물리학의 미래" (Accelerators, Computing, Detectors and the future of Particle Physics.)
50m

Speaker: Prof. Jaehoon Yu

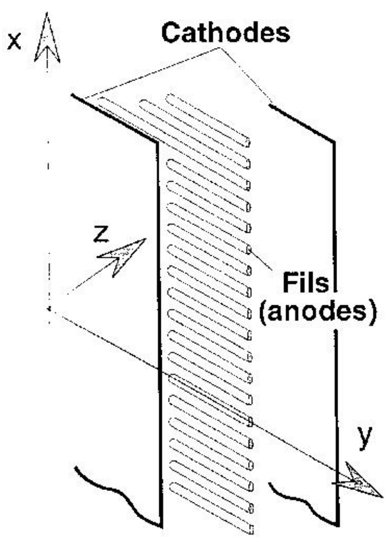
Multiwire Proportional Chambers

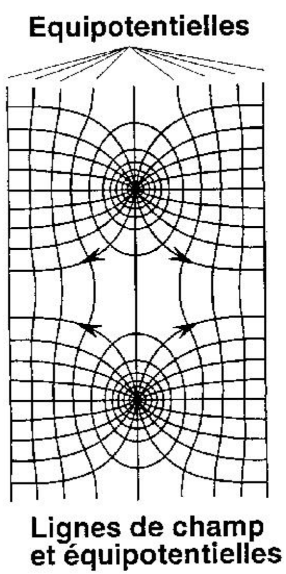
The MWPC was invented by Charpak at CERN. Principle of proportional counter is extended to large areas.

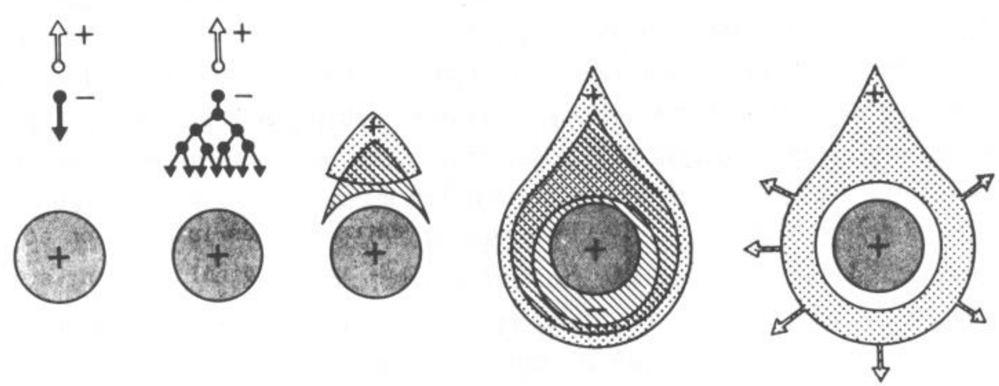


Stack several wire planes up in different direction to get position location.

1992 Prize

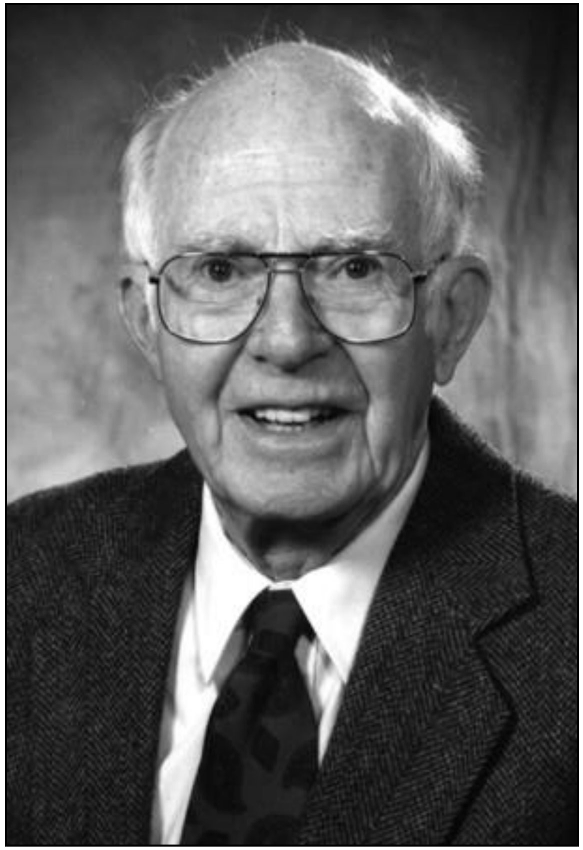






Avalanche developing

2002 Physics Nobel Prize for Neutrino Astronomy



Ray Davis Jr.
(1914–2006)

Masatoshi Koshiba
(*1926)

“for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos”

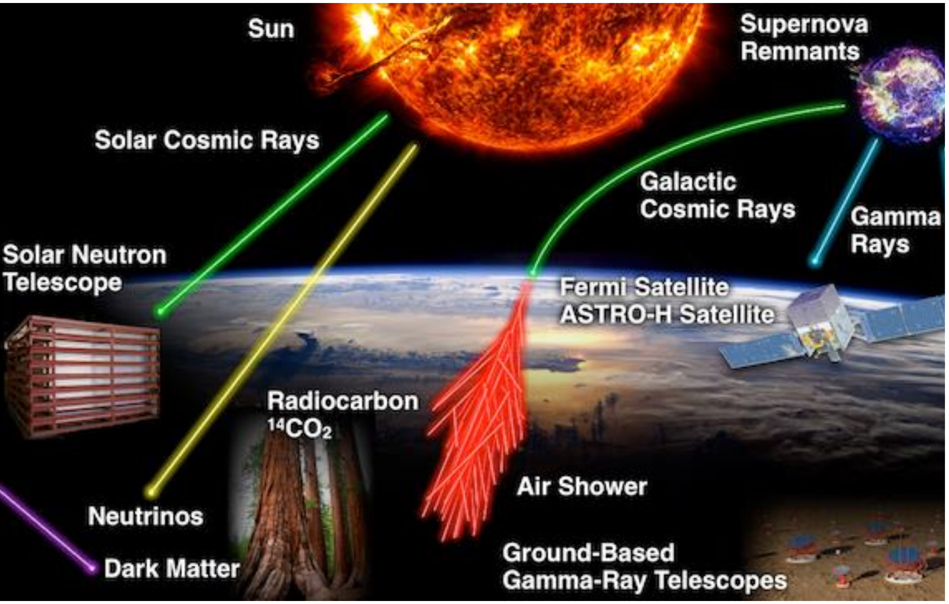
Over sky

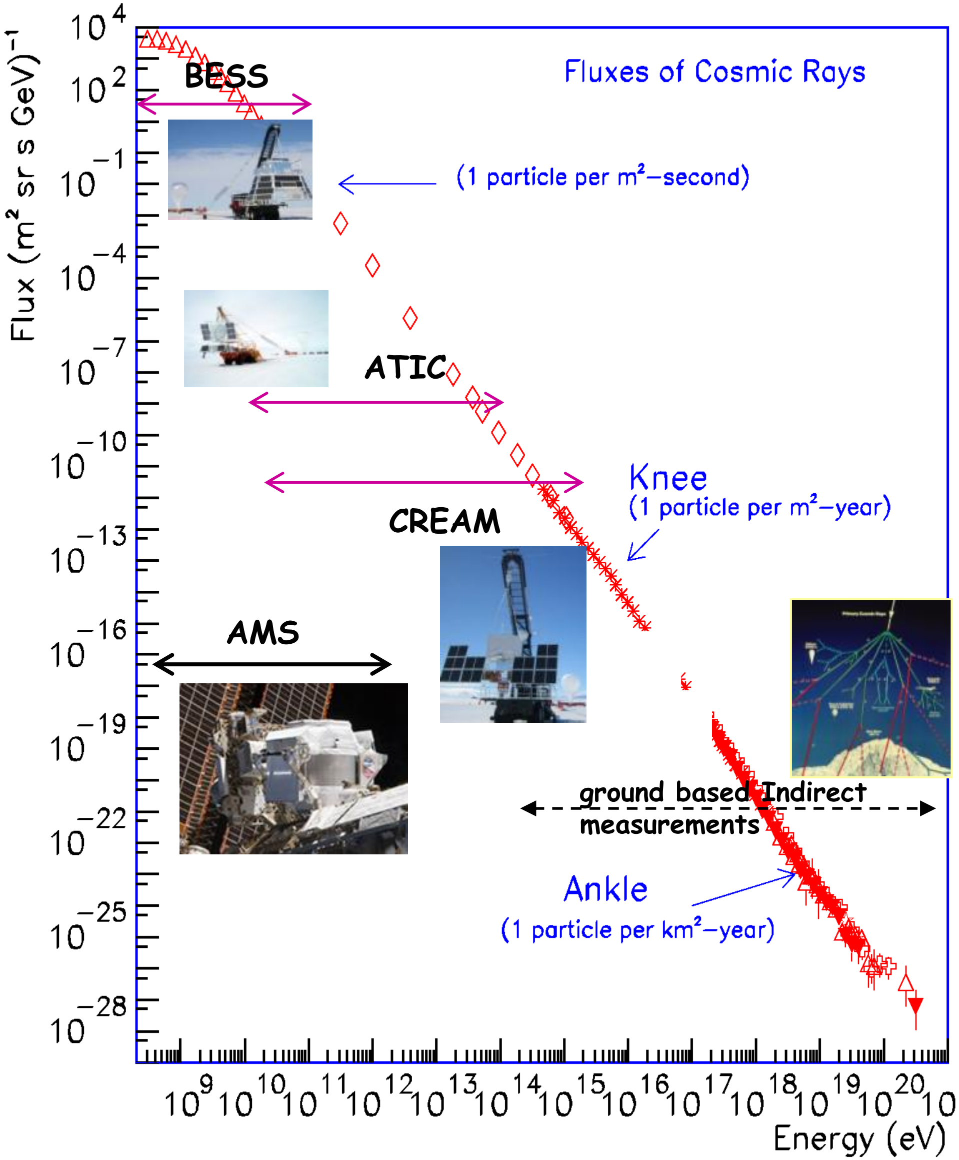
How do cosmic accelerators work?

Fundamental questions of CRs physics

Where do CRs come from?

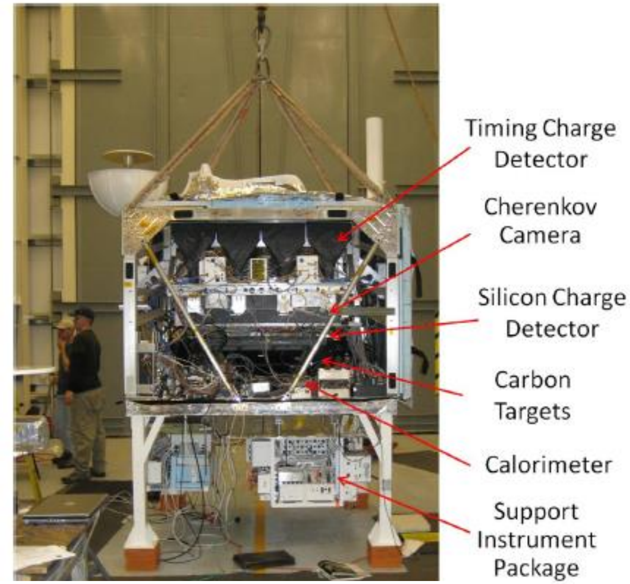
How are they accelerated to such HE?



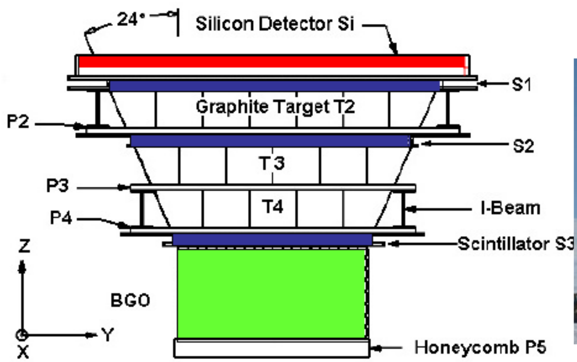


Astro-physics

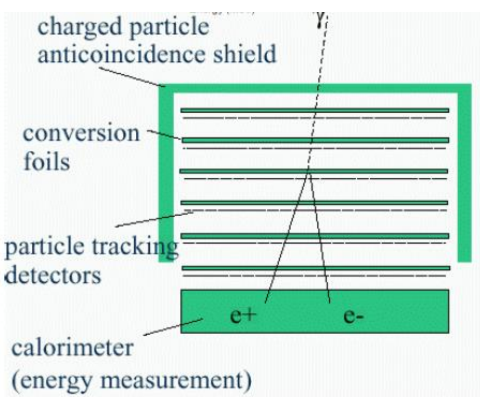
CREAM(W+plastic)

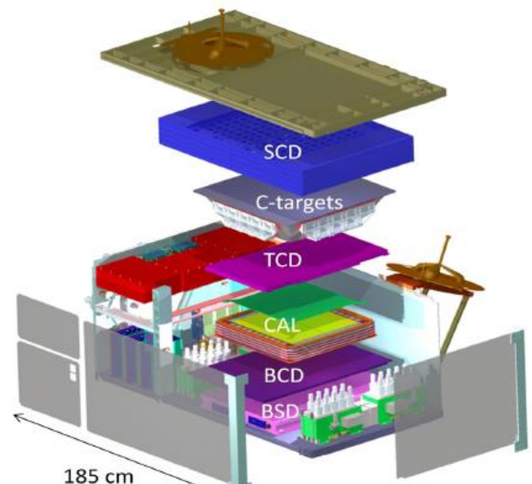


ATIC (BGO, 22.4 Xo)



FERMI (CsI:Tl, 8.6Xo)





ISS-CREAM(W+plastic)

Science
AAAS

ASTROPHYSICS

Catching cosmic rays where they live

The International Space Station gears up to study high-energy particles in space

By **Emily Conover**

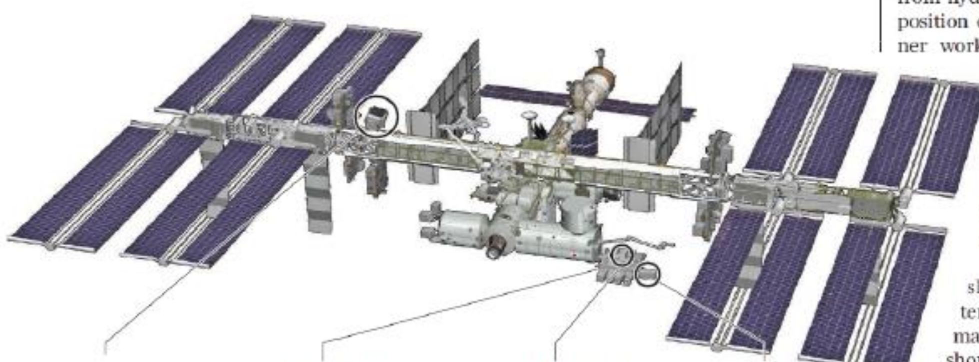
The International Space Station (ISS), which has sometimes struggled to find its scientific purpose, is broadening its role as a cosmic ray observatory. Within a year, two new instruments are slated to join a massive detector, the Alpha Magnetic Spectrometer (AMS), which the station has hosted since 2011. The ISS's perch above Earth's atmosphere is ideal for detecting high-energy particles from space, says astrophysicist Eun-Suk Seo of the University of Maryland, College Park, principal investigator of the Cosmic Ray Energetics and Mass for the International Space Station (ISS-CREAM) experiment. What's more, she notes, launch vehicles already go there regularly. "Why not utilize it?"

The AMS was a gargantuan effort costing $1.5 billion and requiring more than a decade of planning (*Science*, 22 April 2011, p. 408). The two smaller experiments—the CALorimetric Electron Telescope (CALET), and ISS-CREAM—will measure cosmic rays at energies many times higher than the AMS can reach, at a much lower price tag.

High-energy cosmic rays are scientists' best chance to glimpse what goes on inside exotic objects thought to accelerate them—such as exploding stars called supernovae. Ground-based detectors spot cosmic rays indirectly, by observing the showers of other particles they give off on striking the atmosphere. Astrophysicists hope direct measurements in space will give them a more straightforward handle on the energies and types of cosmic ray particles reaching Earth.

Cosmic ray detectors on the ISS

New experiments, perched outside Earth's atmosphere, promise to turn the International Space Station into a well-rounded platform for unlocking the secrets of supernovae and even dark matter.



Whereas the AMS is a general-purpose detector, measuring electrons, protons, nuclei, and antimatter at a range of energies, the new experiments have more focused agendas. The $33 million CALET—an international project scheduled for launch from the Japan Aerospace Exploration Agency's Tanegashima Space Center on 16 August—sets its sights on high-energy electrons. These quickly lose energy as they travel through space, so any that are detected must come from less than a few thousand light-years away.

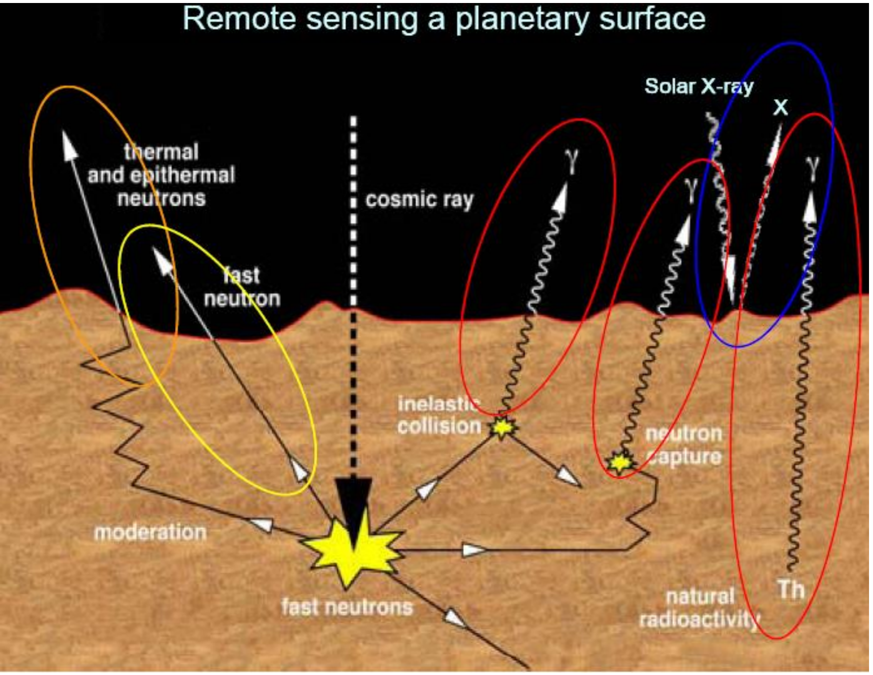
"CALET has the possibility of identifying nearby sources that can accelerate electrons," says Thomas Gaisser, an astrophysicist at University of Delaware, Newark, who is not involved with the project. Those sources could include supernova remnants, the highly magnetized, spinning neutron stars called pulsars, or even clumps of dark matter, the mysterious substance that makes up 85% of the matter in the universe.

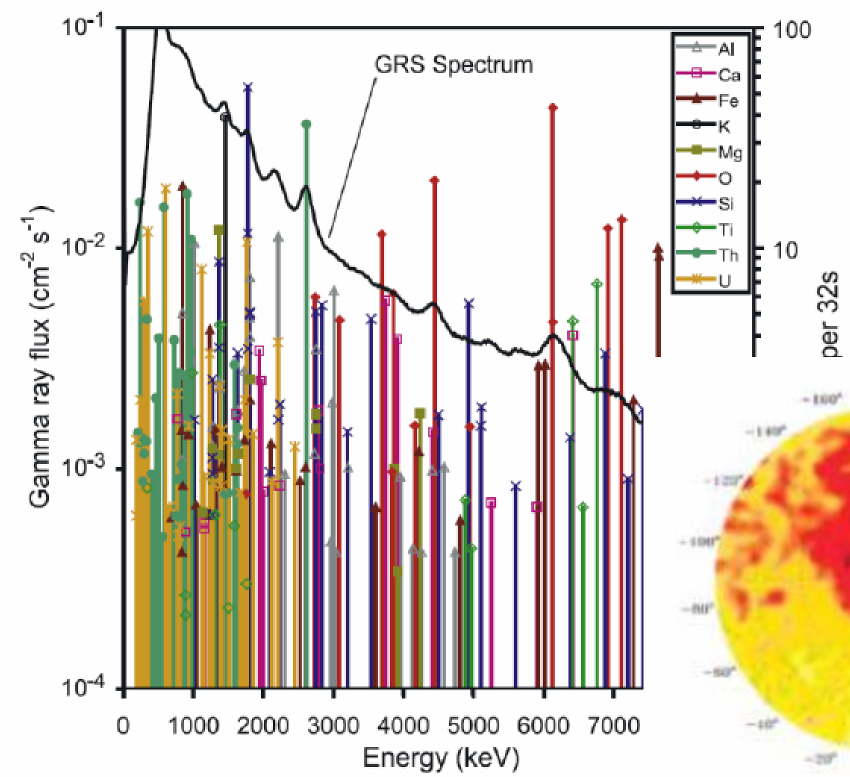
ISS-CREAM (pronounced "ice cream"), slated for launch by SpaceX in June 2016, will focus on high-energy atomic nuclei, from hydrogen up through iron. Their composition could help reveal the unknown inner workings of supernovae. "We cannot even agree why stars explode," says Peter Biermann, a theoretical astrophysicist at the Max Planck Institute for Radio Astronomy in Bonn, Germany, who is not involved with the detector. "The cosmic rays are the best signature of whatever happens there."

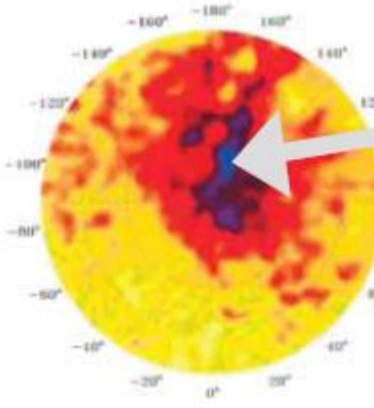
The new experiments could also shed light on the nature of dark matter. Some models predict that dark matter particles colliding in space should annihilate one another, giving off electrons and antielectrons, or positrons. The AMS has already confirmed sightings of unexpectedly high numbers of positrons that could be signs of such reactions; CALET can't tell positrons from electrons, so it will look for a surplus in the total number of both particles at high energies. Detecting dark matter in this way would

(GRAPHIC) A. CUADRA/SCIENCE; (PHOTO) NASA, ESA, AND THE HUBBLE HERITAGE (STSCI/AURA)-ESA/HUBBLE COLLABORATION; ACKNOWLEDGMENT: J. HESTER (ARIZONA STATE UNIVERSITY)

Discovery of water ice in Odyssey





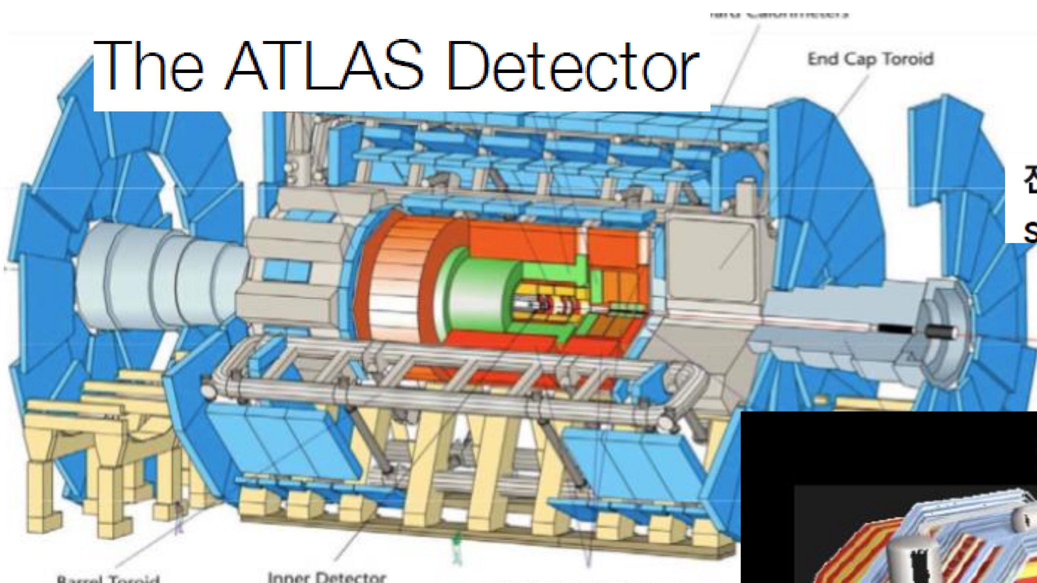


Mars Odyssey/USA	2001-	Mars	HPGe Gamma spectrometer + plastic scintillator as neutron spectormeter + High Energy Neutron Detector (Russia)	Mapping (Altitude ~ 400 km) of elemental composition of major and radioactive elements, Discovery of water ice in the high-latitude regions, observation of mars seasonal CO2 cycle

At ground

LHC(Large Hadron Collider) 7 TeV p + 7 TeV p @CERN

에멀젼, 액체아르곤 (Emulsion & Liquid Argon Precision Detectors)



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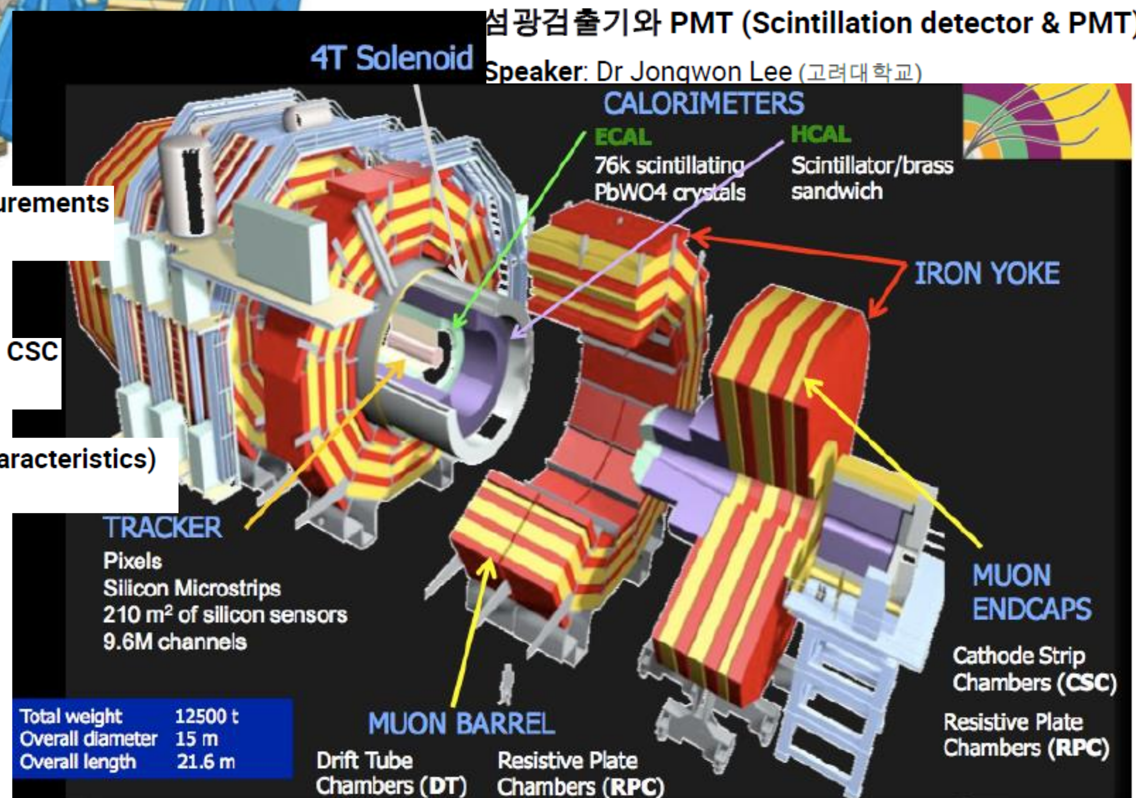
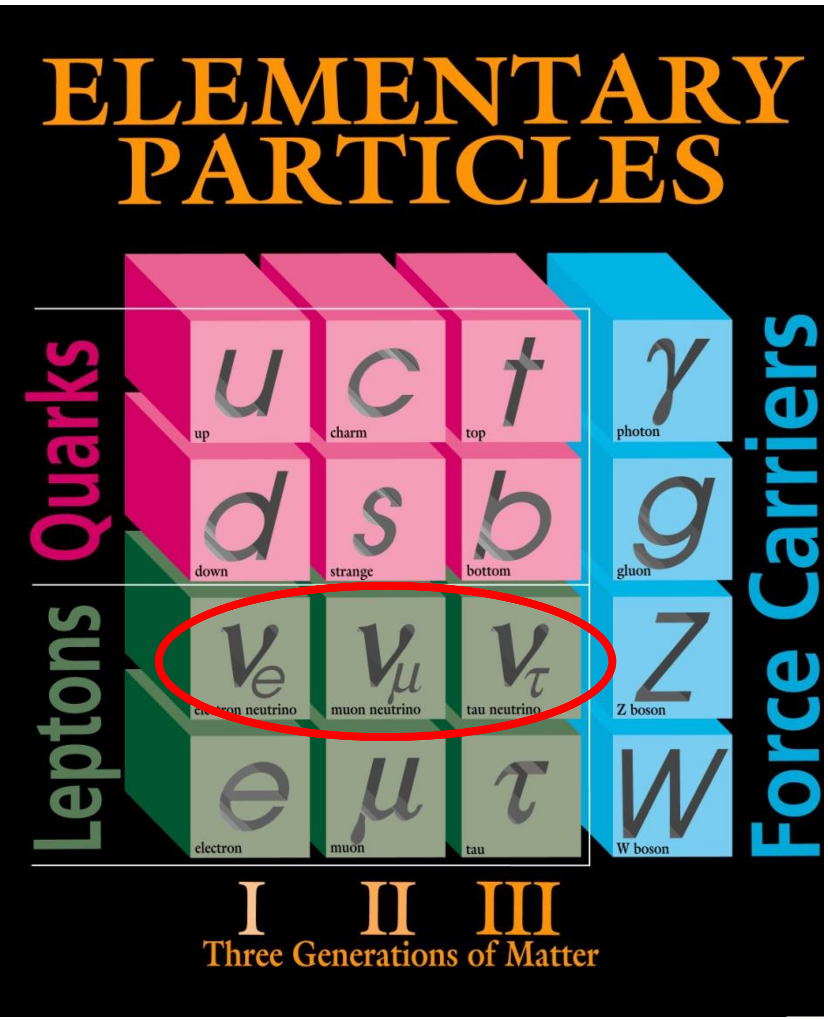
Speaker: Dr Kyonsei Lee (고려대학교)

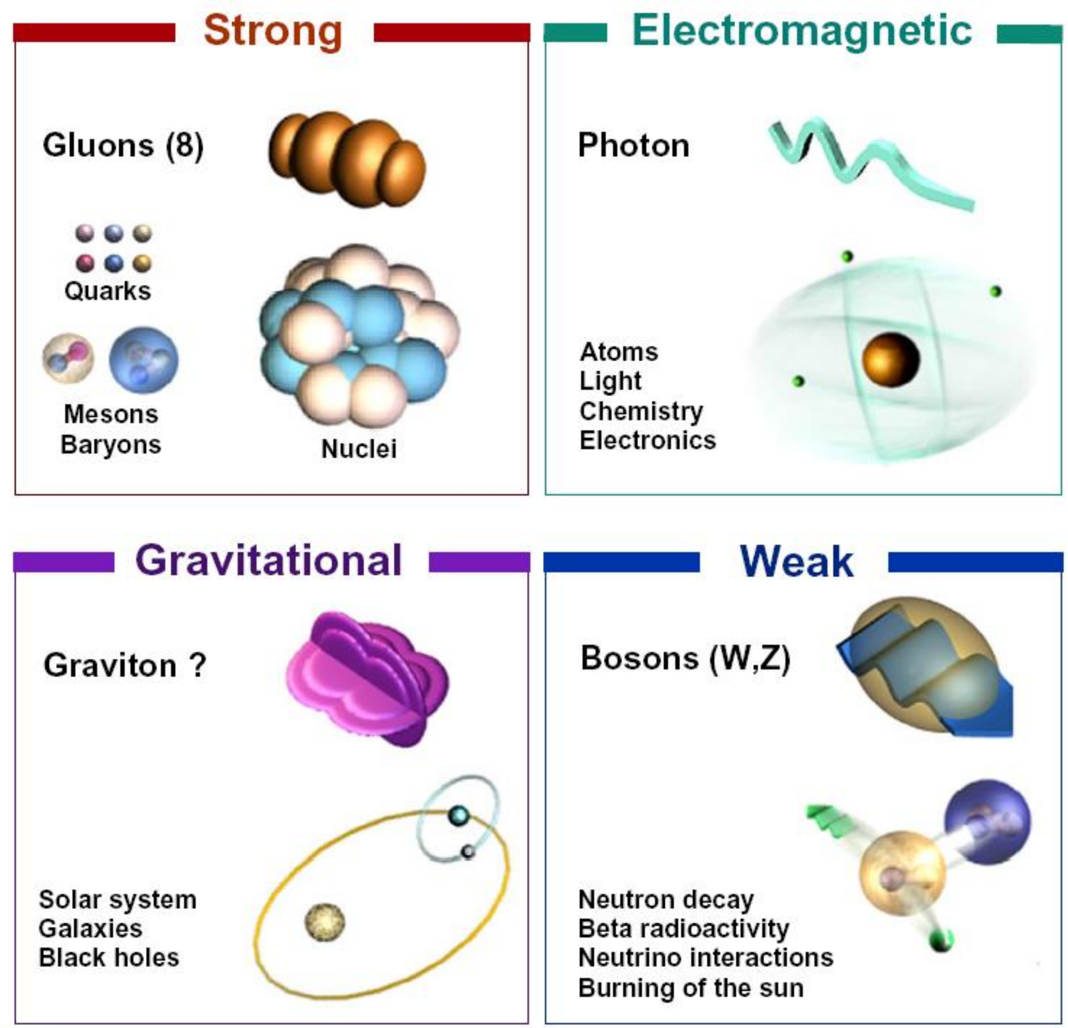
젬검출기의 원리와 특성 (Principles of the GEM detector & its characteristics)

Speaker: Dr Inseok Yoon (서울대학교)



Standard model

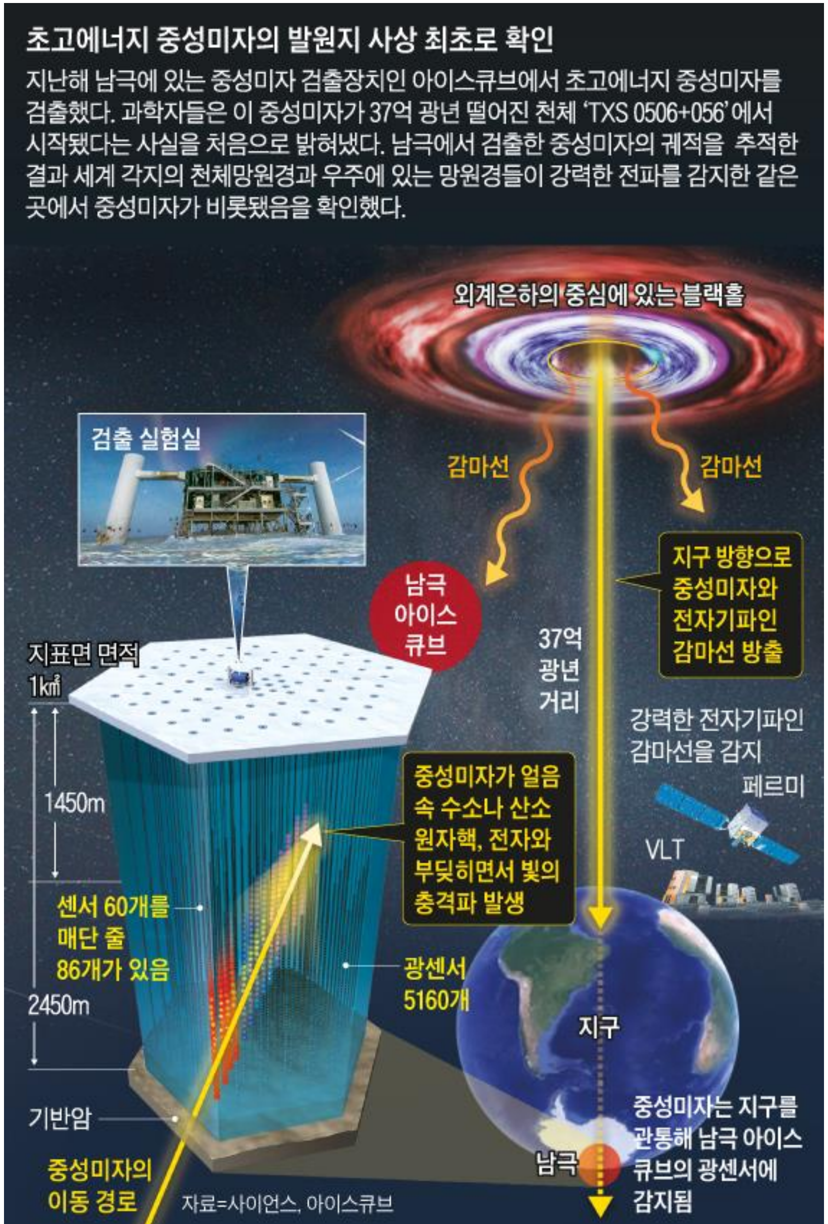




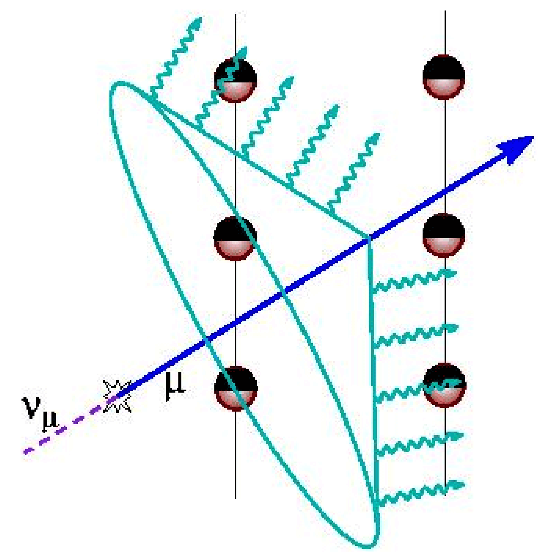
Higgs : 2013

At deep underground

IceCube : Biggest detector; 1km^3



Science 2018



체렌코프 검출기와 활용 (Cherenkov detector and its applications) - RICH, Water Cherenkov

Speaker: Prof. Youngjoon Kwon (연세대학교)

Experiment in KOREA

Past, current and future

KIMS (Korea Invisible Mass Search)

2000 @ CPL, began in the vinyl room

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

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

Darkmatter search in Korea

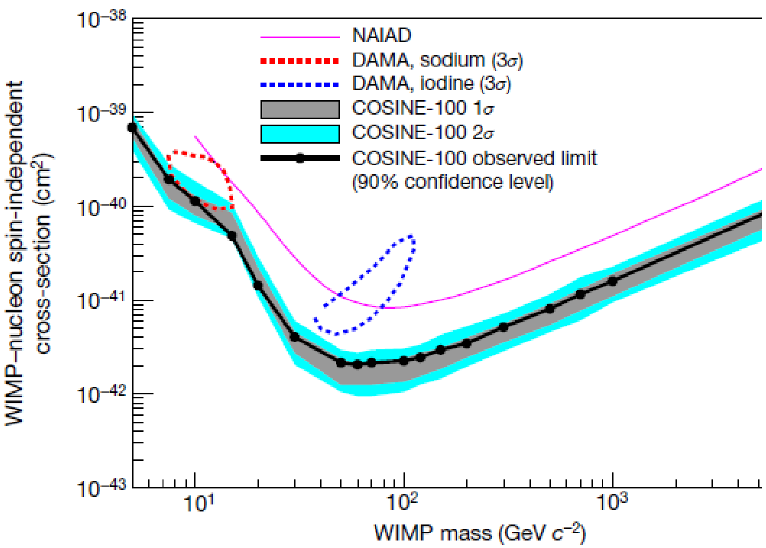
LETTER

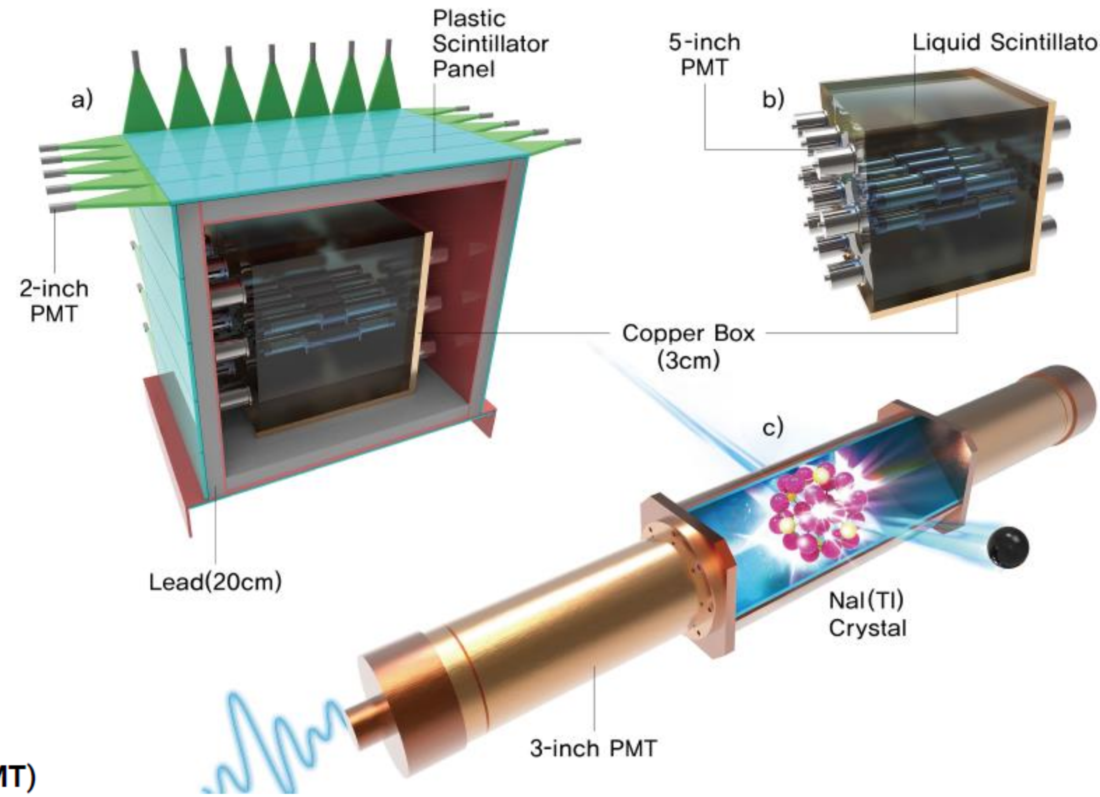
Data taking 2016 : Nature 2018

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*

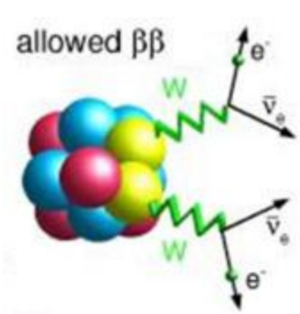


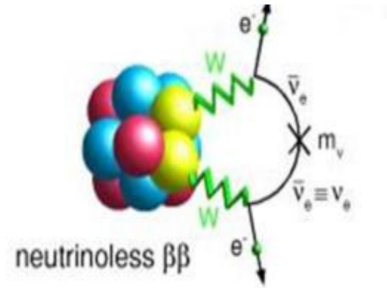


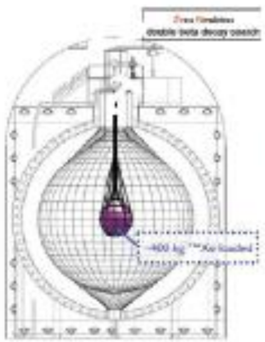
섬광검출기와 PMT (Scintillation detector & PMT)

Speaker: Dr Jongwon Lee (고려대학교)

Current experiments of 0ν ββ search…





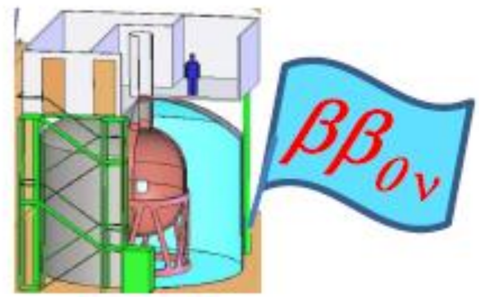


Kamland-Zen

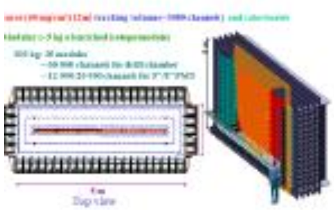
EXO

CUORE

CANDLES



GERDA



Super NEMO

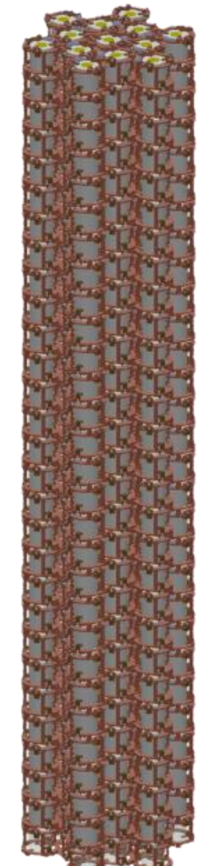
COBRA

NEXT

LUCIFER

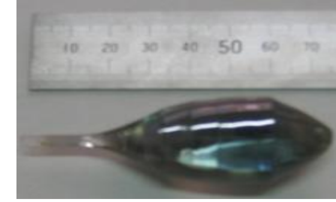
SNO+

MAJORANA

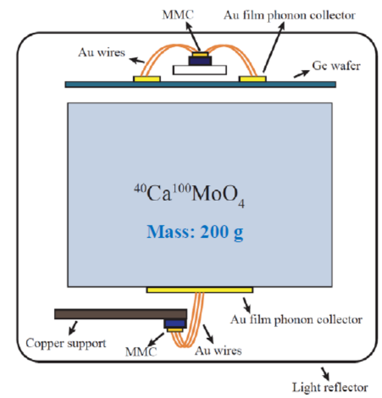


AMoRE

Brief History of AMoRE

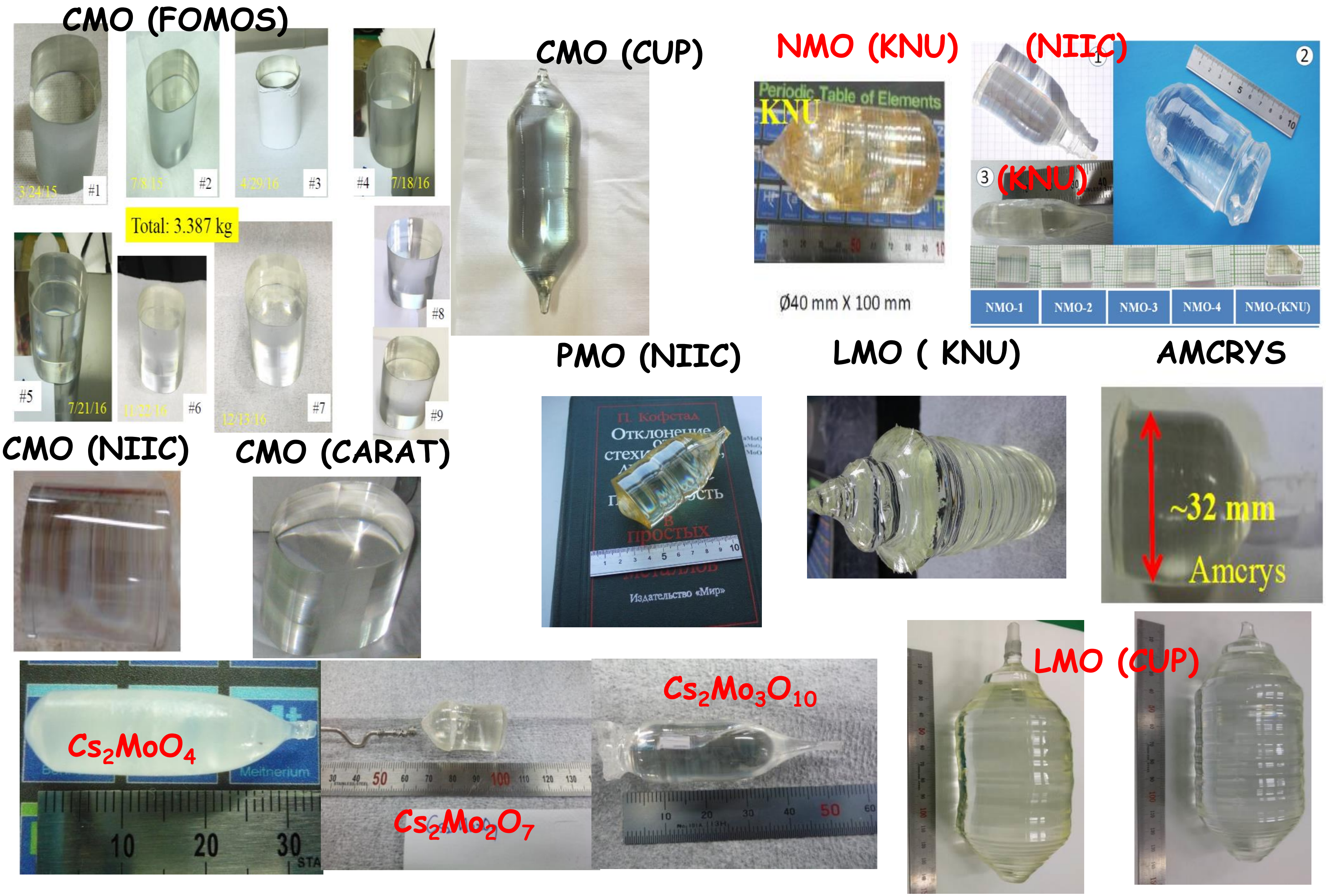


1) 2002 : First idea and try to grow CaMoO4(CMO) in Korea.
2) 2003- 2004 : 1st Conference presentation (VIETNAM2004)
3) 2005-2007 : Large CMO with 1st ISTC project
4) 2007 : CMO R&D in cryogenic temperature started.
5) 2009 : AMORE collaboration formed
6) 2010-12 : $^{48depl}Ca^{100}MoO4$ internal background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



	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-II: Mo crystals grown and tested

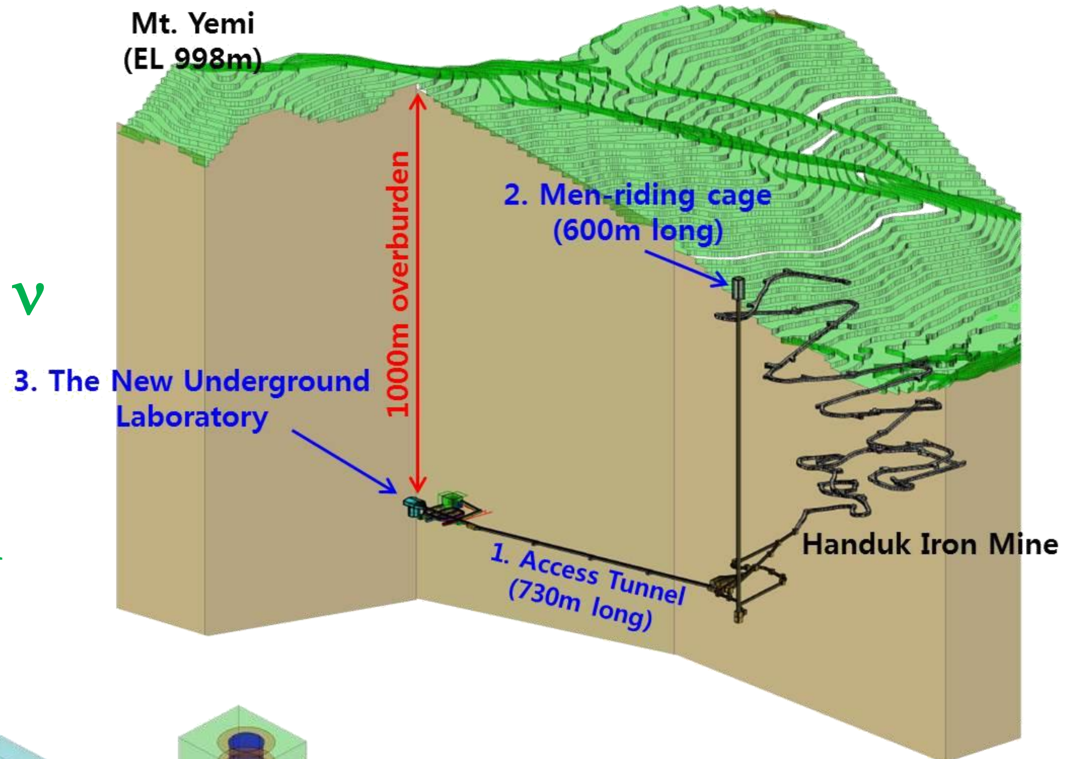


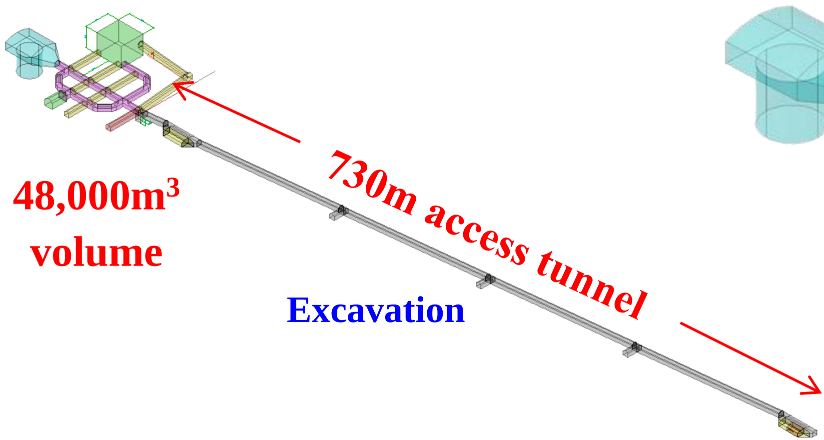
Yemi Underground Laboratory (by 2022)

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

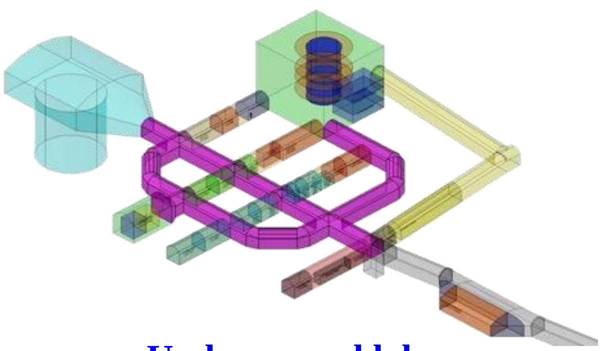
Future possibility

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

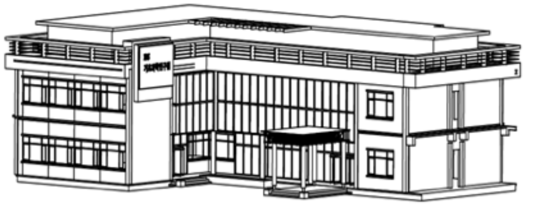




Excavation

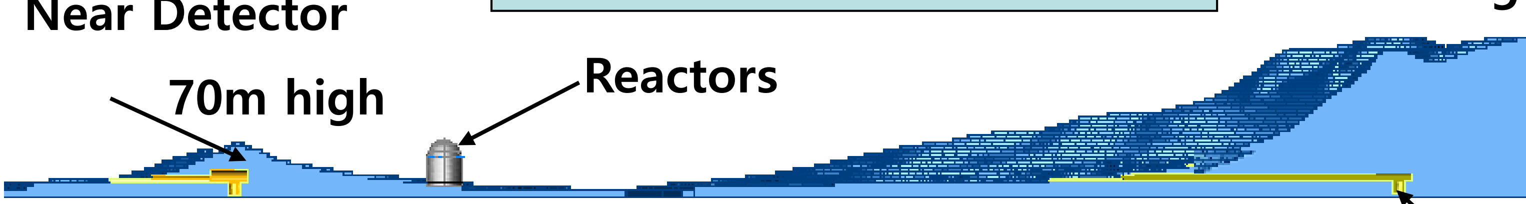


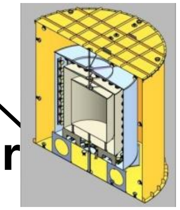
Underground lab

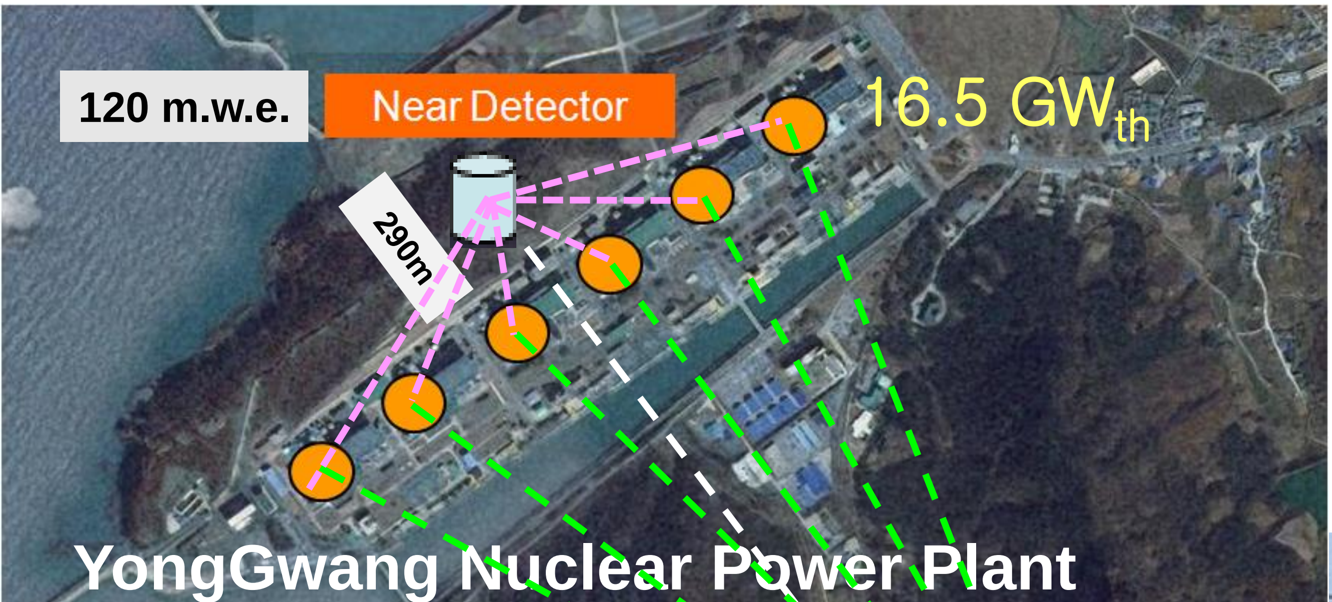


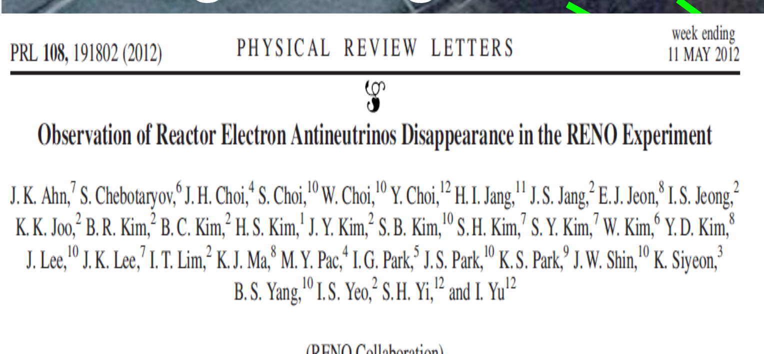
Surface office/lab

Google Satellite View of Experimental Site









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]

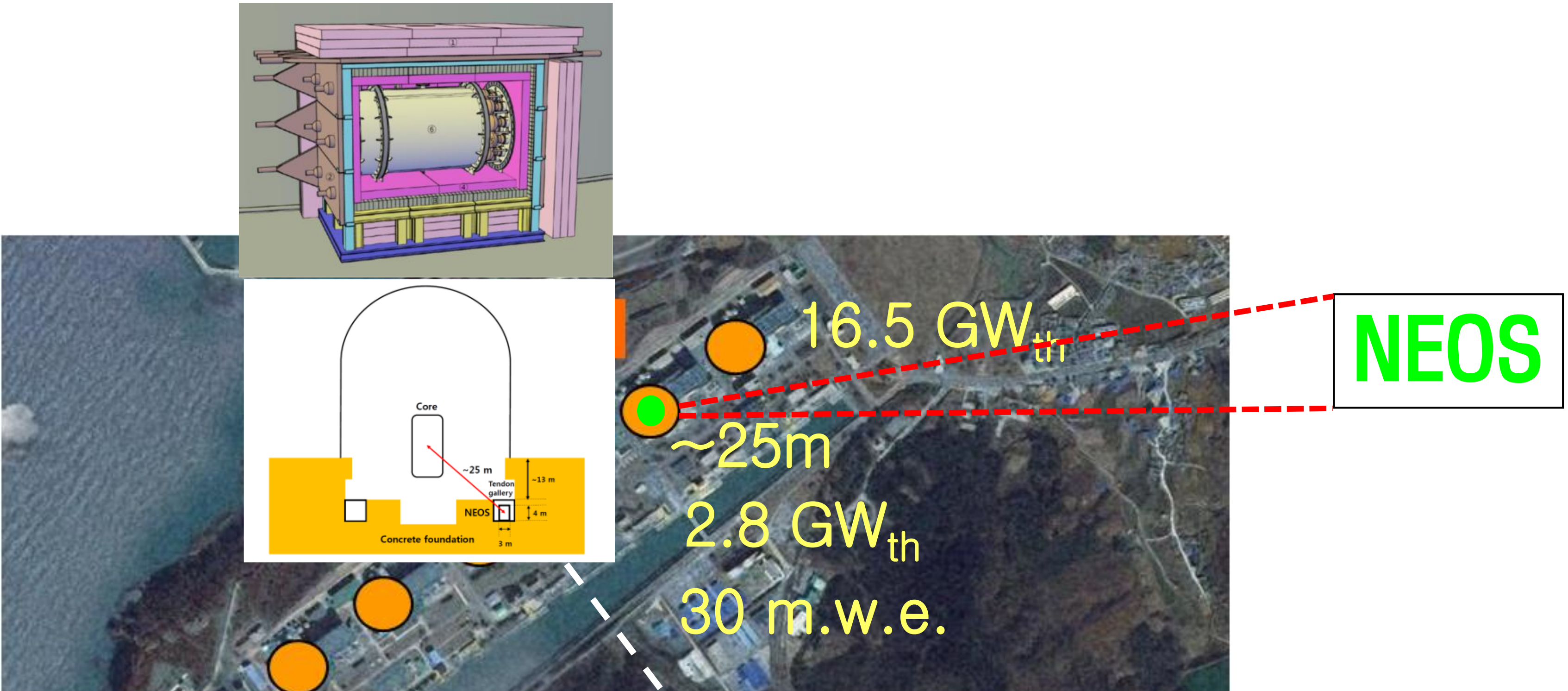
(RENO Collaboration)

RENO

KNRC
Korea Neutrino Research Center

PI : S.B. Kim

NEOS (NEutrino Oscillation at Short-baseline) Experiment



PRL **118,** 121802 (2017) PHYSICAL REVIEW LETTERS 24

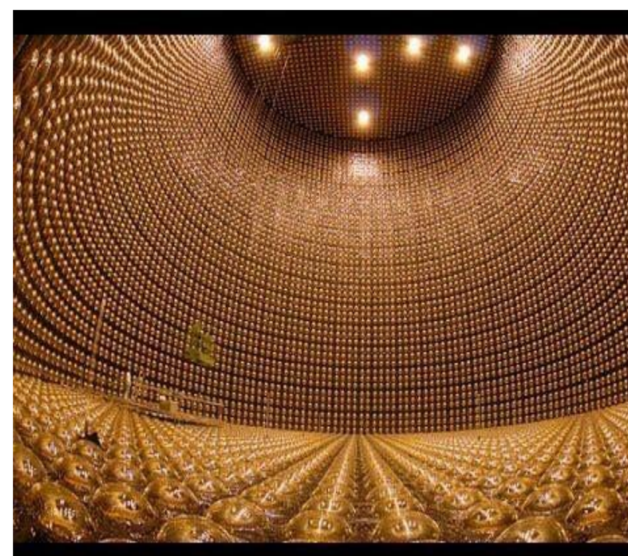
Sterile Neutrino Search at the NEOS Experiment

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]

한국 중성미자 관측소 추진 계획
(Korea Neutrino Observatory : KNO)

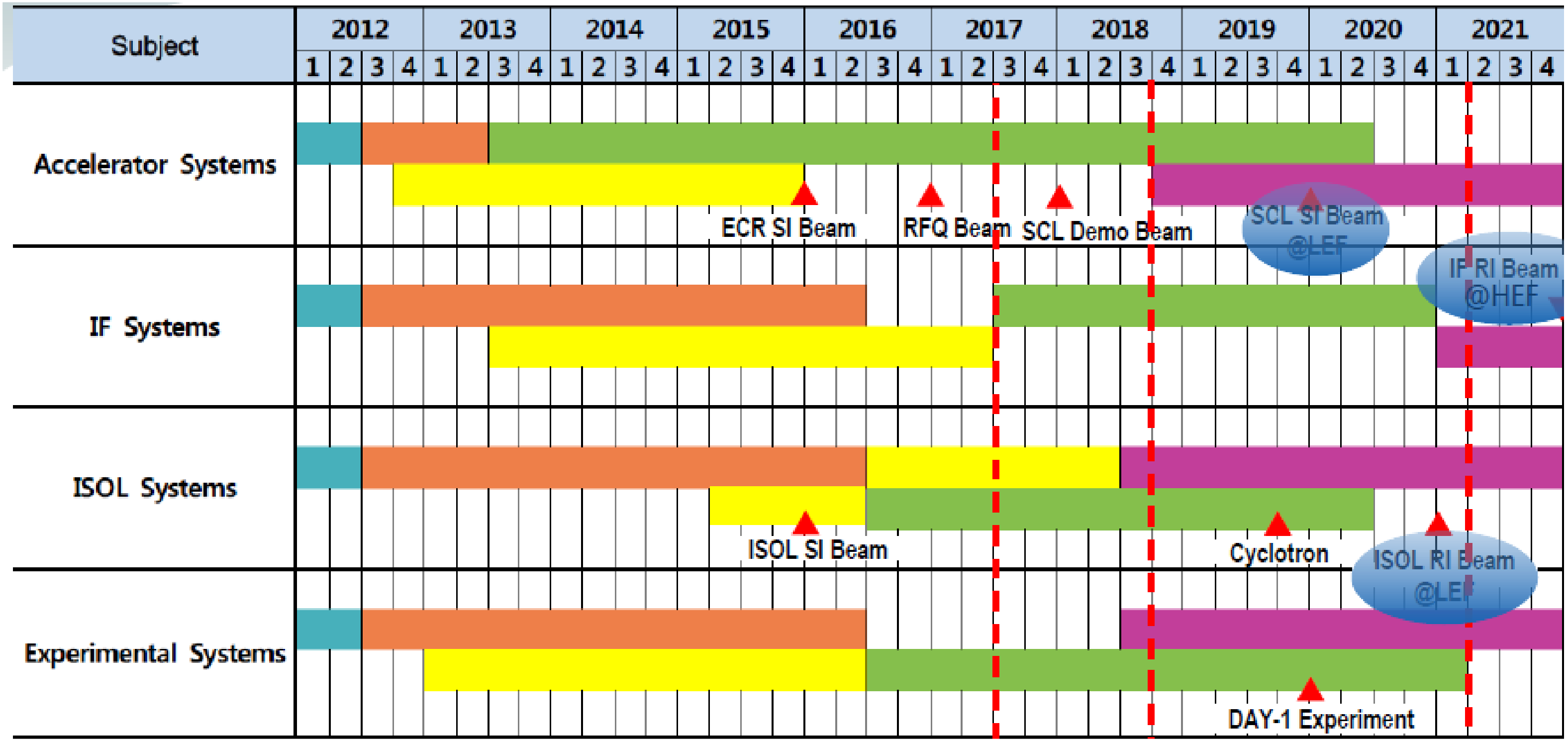
체렌코프 검출기와 활용 (Cherenkov detector and its applications) - RICH, Water Cherenkov
Speaker: Prof. Youngjoon Kwon (연세대학교)

- 구축기간 : 약 7년 소요 (>2025)
- 사업비: 약 3000억 원 예상 (해외 공동연구진 약 500억 공헌 예상)
- 구축내용: 높이 1,000m 이상의 산 (비슬산, 보현산) 지하에 25만 톤의 초순수한 물을 포함하는 검출기인 중성미자 망원경(KNO) 을 비롯한 국제 지하과학 종합 연구시설을 구축
- J-Park 중성미자 빔을 이용한 중성미자 CP, 질량 순서 연구
- 양성자 붕괴 실험
- 중성미자 천문학 : Multi-messenger (supernovae, gamma—ray burst, solar…)



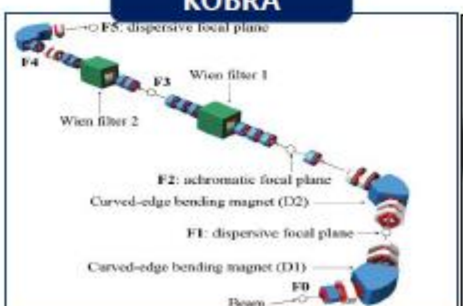
KNO 중성미자 검출기 내부 예상도

RAON : Heavy ion beam @IBS



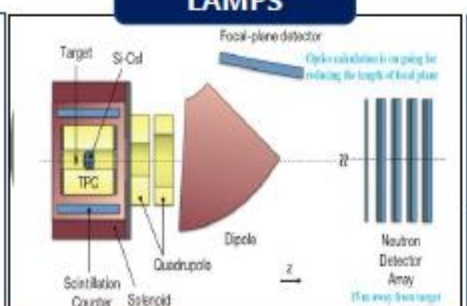
RAON의 주요 실험장치

KOBRA



저에너지(~ 18.5 MeV/u, U 기준)
핵과학 실험 장치

LAMPS



중간에너지(~200MeV/u, U기준)
핵과학 실험 장치

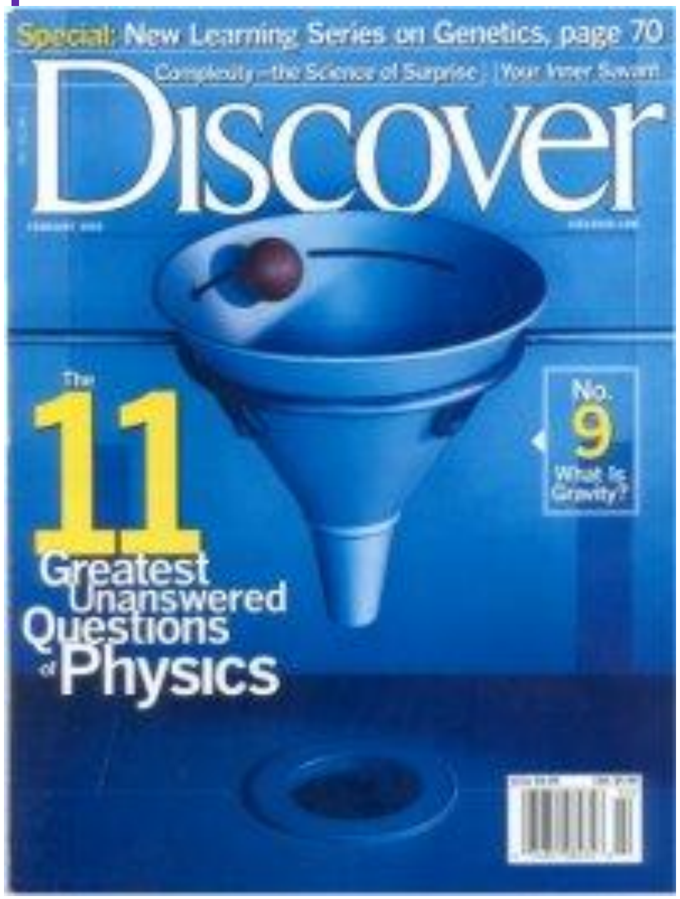
NDPS

고속중성자를 이용한 핵자료
측정장치

MMS

희귀동위원소 핵의 질량 정밀
측정 장치

You need a creative detector to discover one of this !



1. **What is dark matter?**
2. What is dark energy?
3. How were the heavy elements from iron to uranium made?
4. Do neutrinos have mass? Yes!
5. Where do ultrahigh-energy particles come from?
6. Is a new theory of light and matter needed to explain what happens at very high energies and temperatures?
7. Are there new states of matter at ultrahigh temperatures and densities?
8. Are protons unstable?
9. What is gravity?
10. Are there additional dimensions?
11. How did the universe begin?

SPDAK 2019

1st School for Particle Detectors and Applications at KNU

Jan. 13 ~ 17, 2019

Department of Physics, Kyungpook National University, Daegu

Key Topics

1. **Particle Interactions with Materials and Detection Mechanism**
2. **Optics for Light Propagation and Detection**
3. **Detector and Tracking Simulations**
4. **Particle Detectors for HEP and Radiation Detection**
   Silicon, Crystals, Plastic Scintillator, HPGe,
   Liquid Scintillation Counting, Ion Chamber
5. **Introduction to Fast Electronics**

http://spdak2019.knu.ac.kr

Registration deadline: Dec. 19, 2018

Lecturers

Hwanbae Park (KNU)
Hongjoo Kim (KNU)
Jik Lee (KNU)
Junyeob Yeo (KNU)
Chang-Seong Moon (KNU)
Minsang Ryu (RISP)
Sehwook Lee (KNU)

Sponsored and Organized by the ***Center for High Energy Physics*** *and* ***Radiation Science Research Institute***
of Department of Physics, Kyungpook National University

Radiation Science Research Institute
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