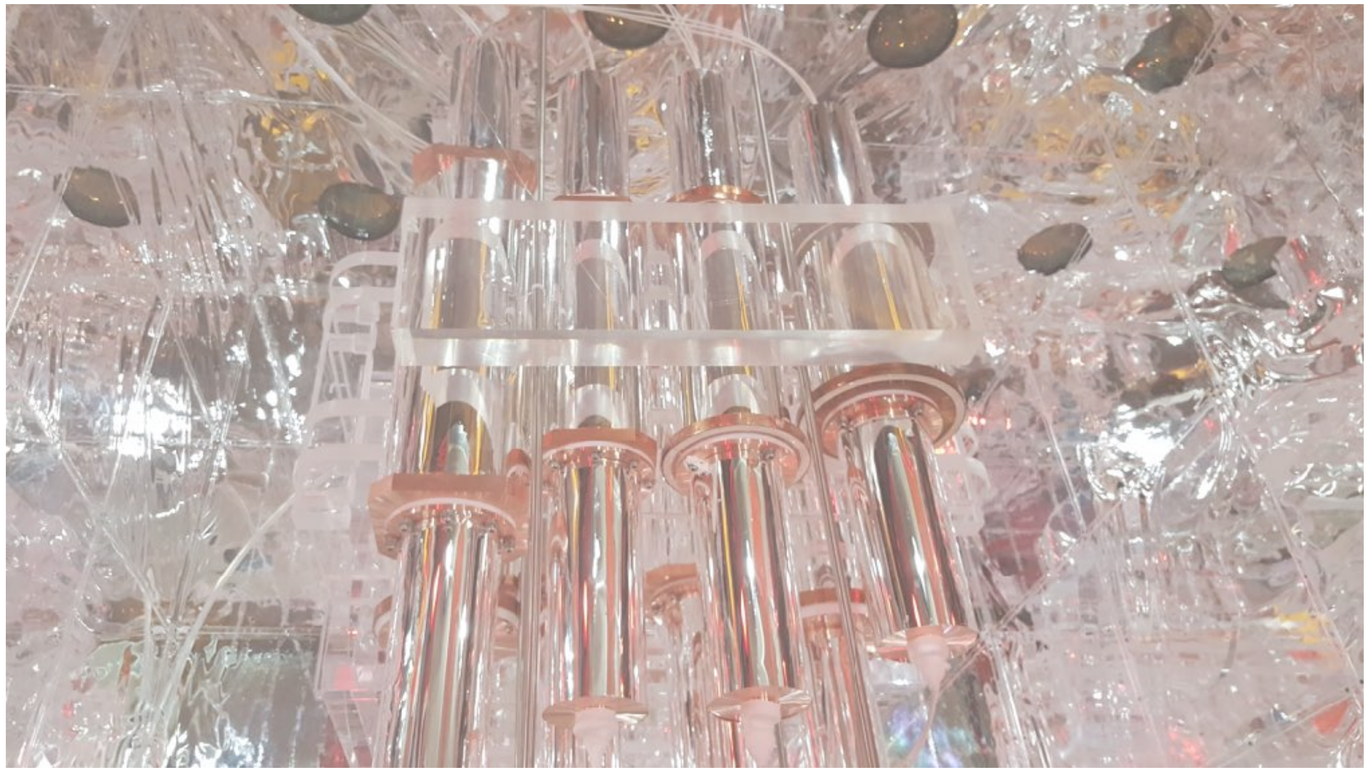
Dark Matter Experiments (Why do we dig?)



중앙대학교
CHUNG-ANG UNIVERSITY
RESL
RARE EVENT SEARCH LABORATORY

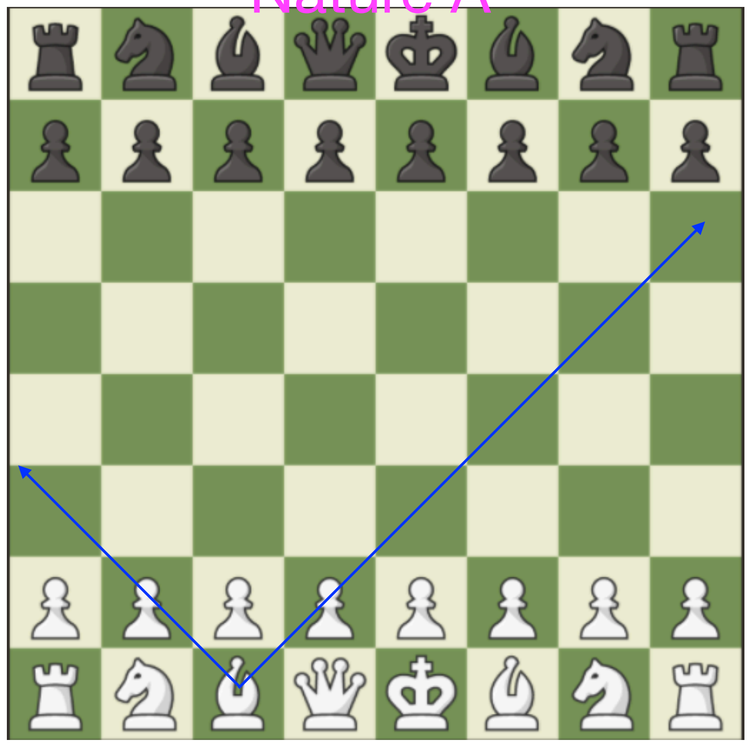
암흑물질 실험

KIAS Particle Physics Summer Camp 2022
중앙대학교 물리학과 하창현
8월 24일

Progress in Physics

Competition and Collaboration between experiment and theory

Nature A



Nature B

We look the game for a long time and figure out the rules of the chess game. For example, a Bishop moves only diagonally.

Natures play as they want and do not tell us the rule



However, we sometimes find an unexpected phenomenon. It looks like there seems to be a new rule. We look at it more carefully and figure out that a Pawn is missing.

Progress in Physics

Competition and Collaboration between experiment and theory

Pawn-Decay Theory



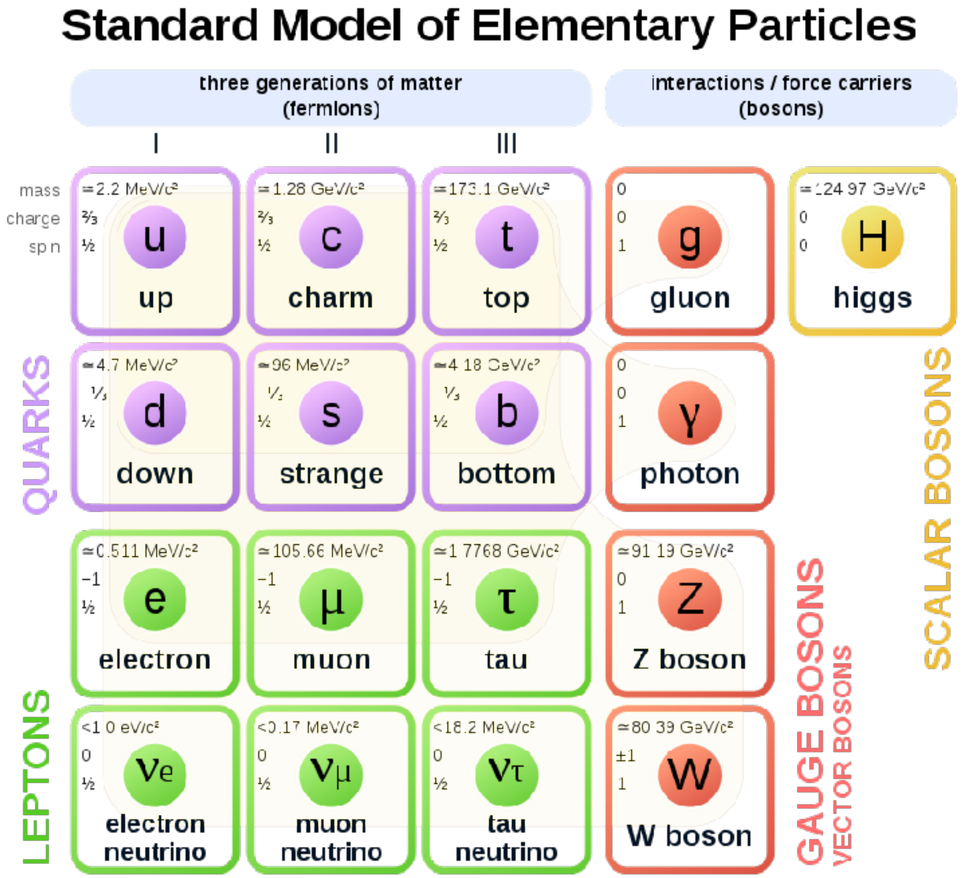
Nine Queen



Theorists make “Pawn Decay Theory” and Experimenters try to find it. They eventually find that a Pawn moves up to the board and transformed into a Bishop. Now, this theory predicts another phenomenon called “Nine Queens”

Finally, experimenters find the “Nine Queen” phenomenon. Then, they also find “Eight Queen + Upsidedown Rook”. Again, the theory is further modified and advances into more robust “Pawn Decay Theory”

Beyond the Standard Model?



More Exotic Particles?



Maybe, what we've found so far was at the corner of the chess board.
Quest for a new particle leads us to a new rule that Nature hides.

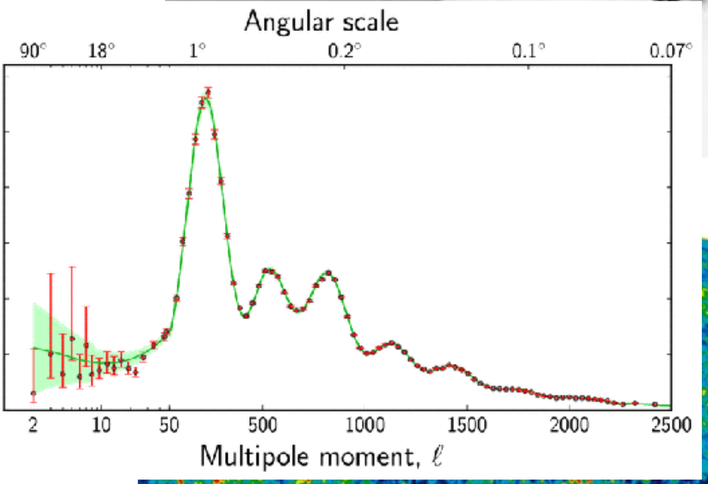
Big Question : What is Universe made of?
Universe is full of Dark Matter!

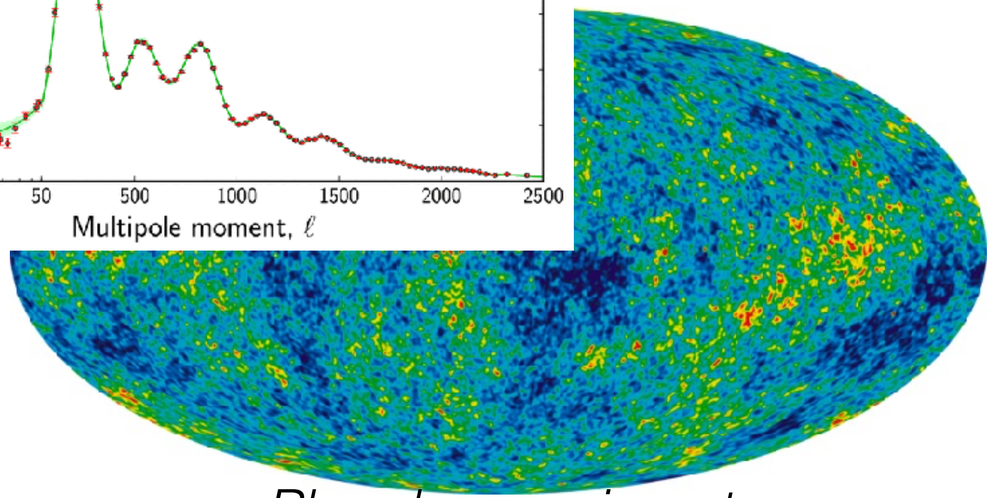


Zwicky (1933)
Dunkle Materie”

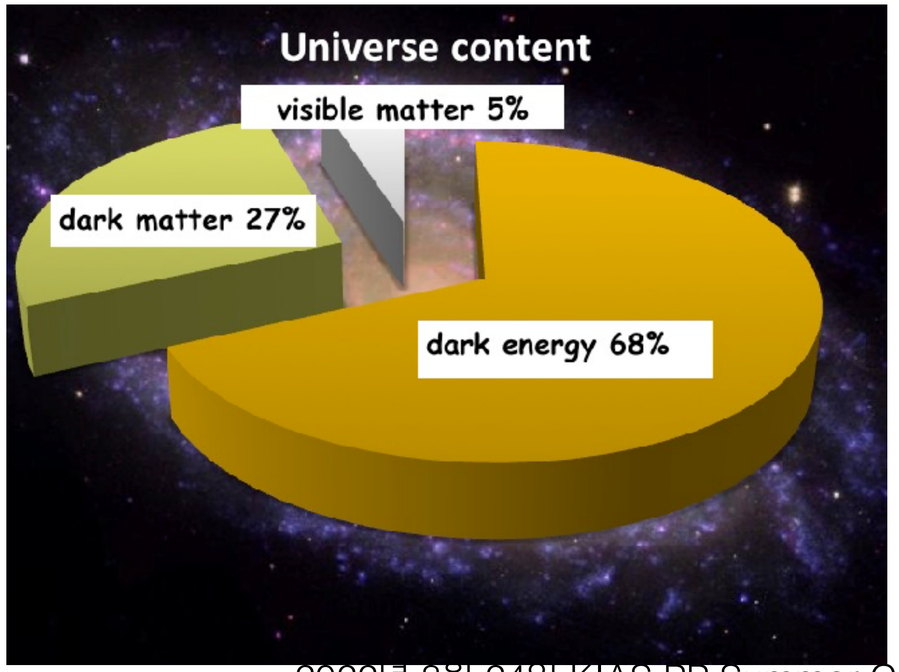
mysterious matter that
holds galaxies together with no light (Coma Cluster)

galaxy velocity curve,
gravitational lensing and
cosmic microwave background





Planck experiment



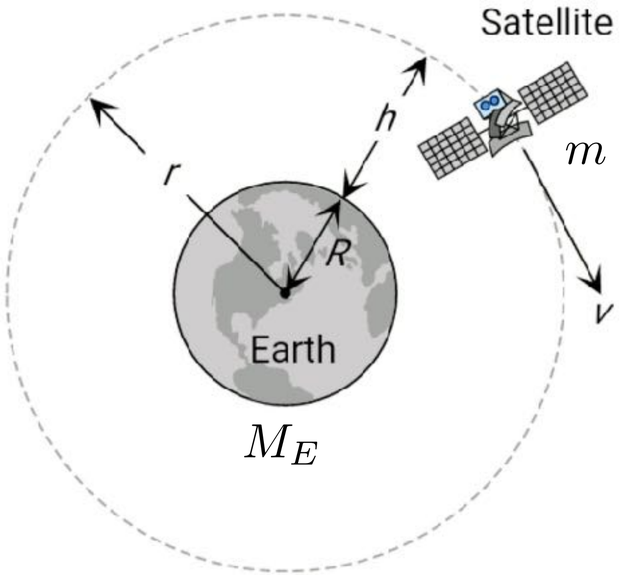
Universal Gravitation

With an apple drop, you can predict when the Halley's comet comes back.

Apple-Earth ⟶ Halley's comet - Sun

$$F_g = G\frac{m_1 m_2}{r^2}$$

$$G = 6.67 \times 10^{-11} N\ m^2/kg^2$$



$$F_g = G\frac{M_E m}{(R+h)^2} = ma(h)$$

$$a(h) = G\frac{M_E}{(R+h)^2}$$

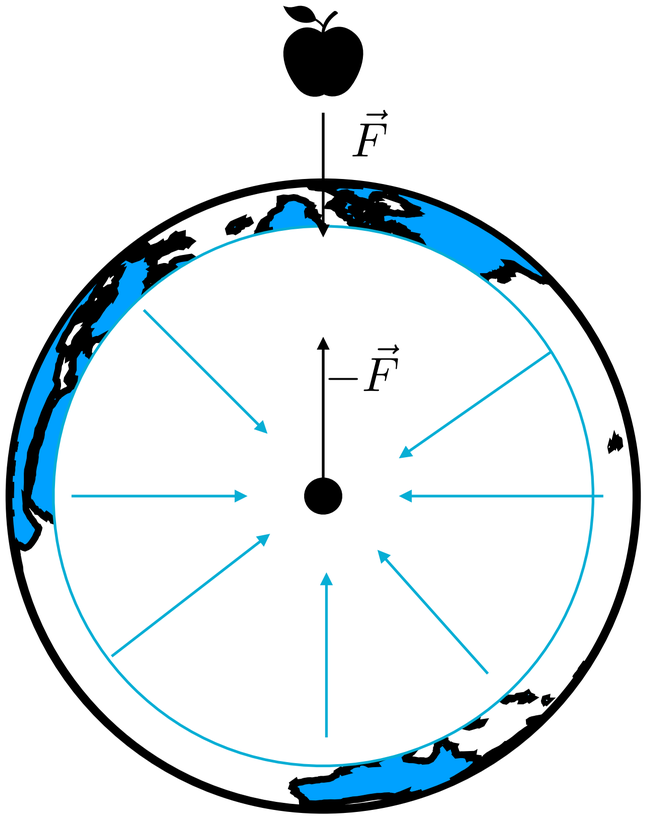
h becomes larger and $a(h)$ becomes small.

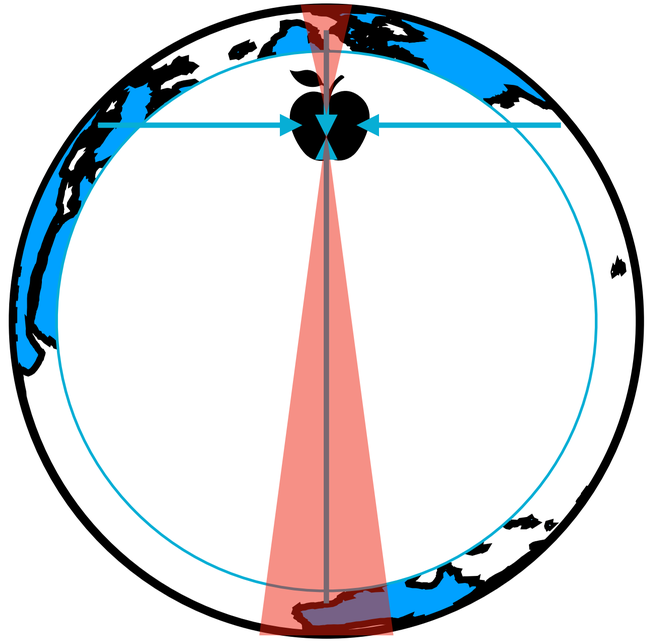
How about you go underground of Earth?

Or with a small R how does a become?

Universal Gravitation

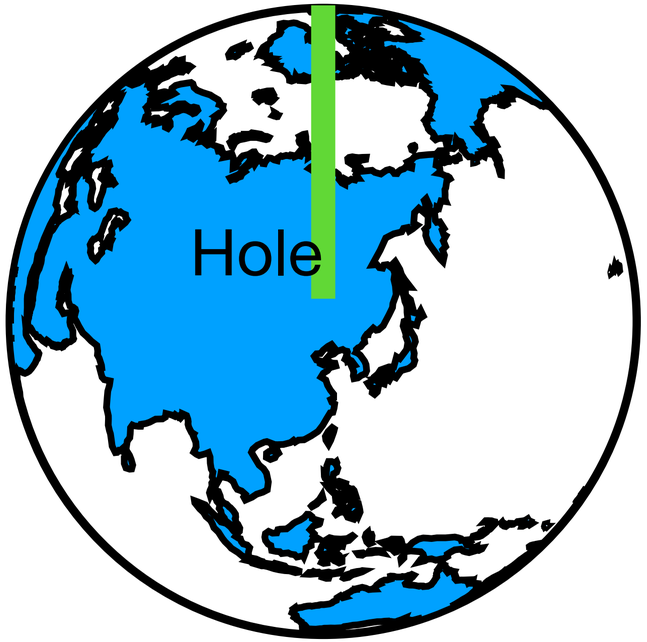
Newton's Shell Theorem I : An object outside of the uniform spherical shell feels the gravitational force due to the mass that is concentrated at the center of the sphere.

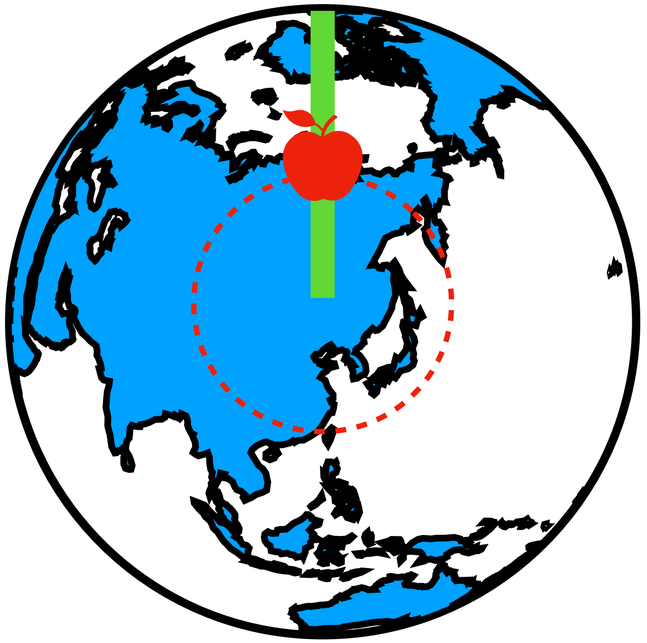




Newton's Shell Theorem II : An object inside of the uniform spherical shell does not feel the gravitational force due to the shell mass.

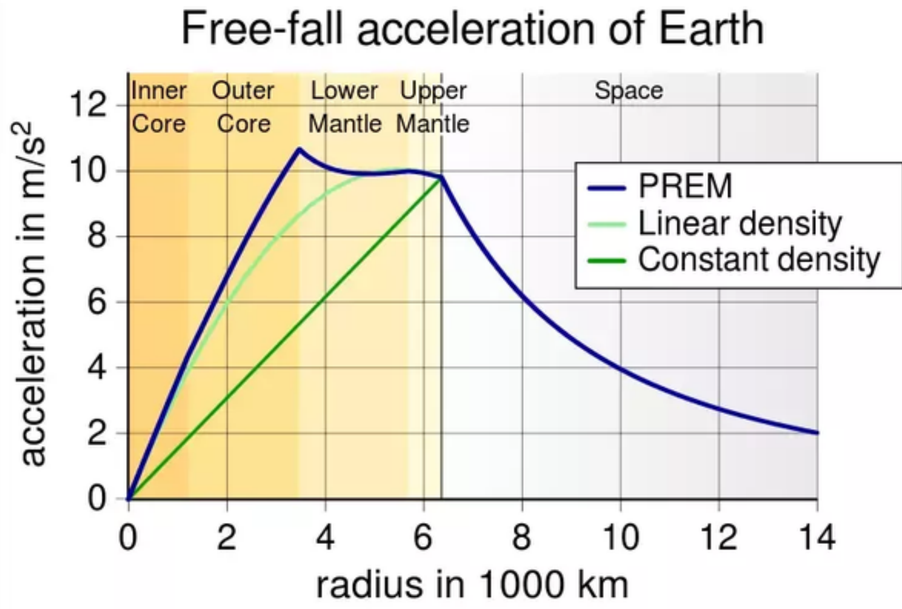
Universal Gravitation





$$a(h) = G\frac{M_E}{R^2} \sim \rho R$$

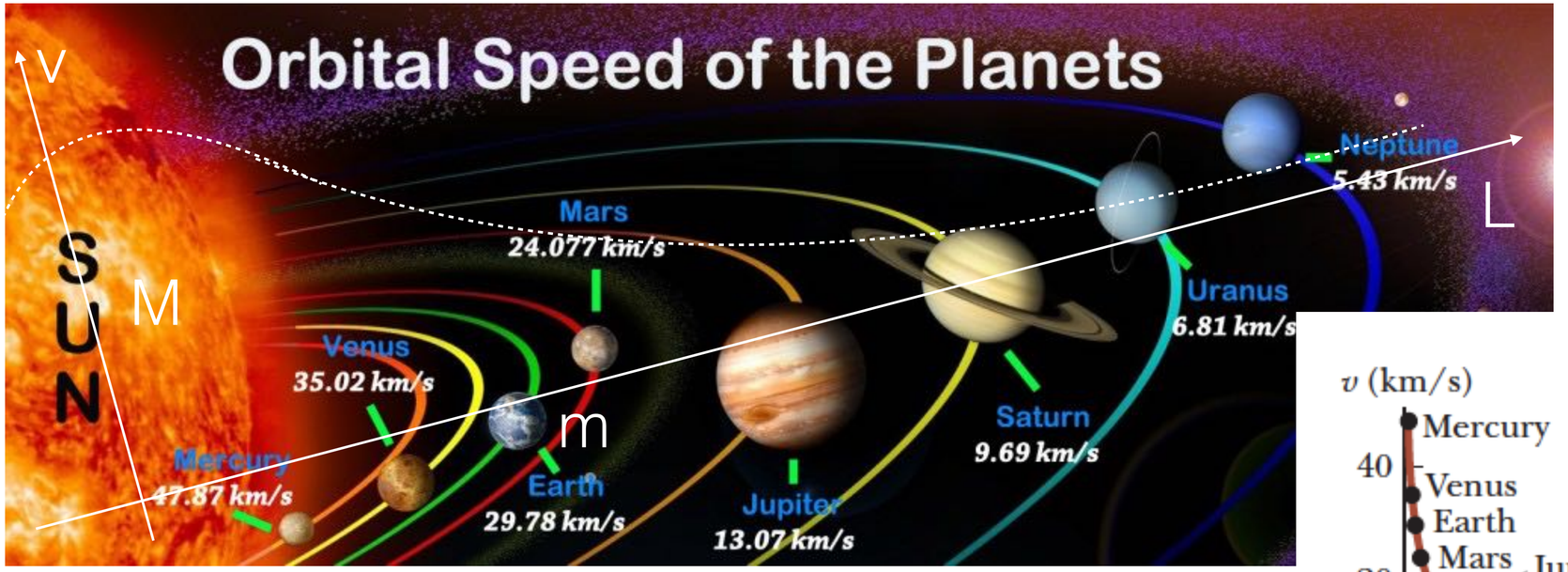
$$M_E = \rho V \sim \rho R^3$$

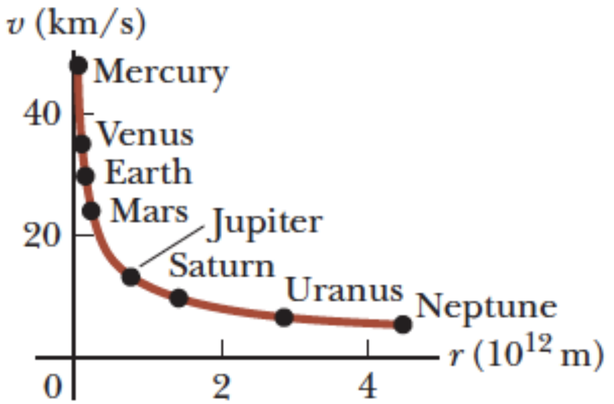


1. Gravitational Acceleration increases?

2. Gravitational Acceleration decrease?

Planetary Velocity Distribution





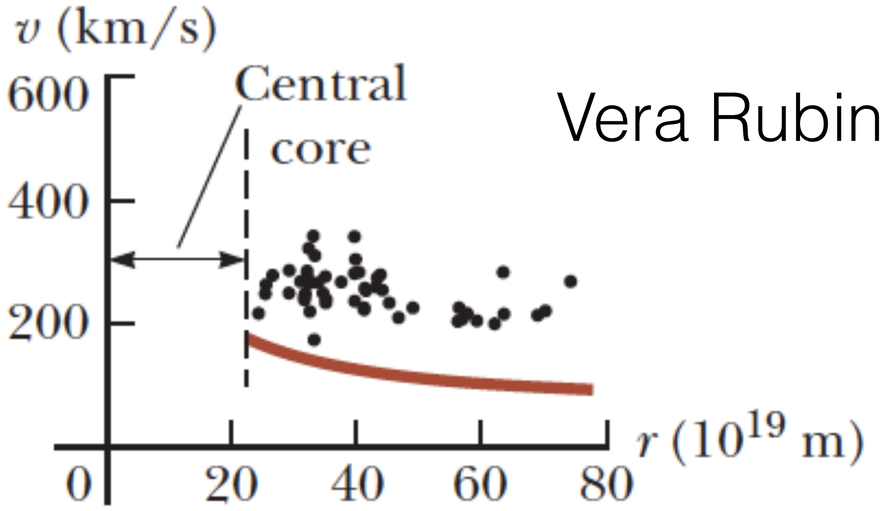
$$\frac{mv^2}{L} = \frac{GMm}{L^2}$$

$$v = \sqrt{\frac{GM}{L}}$$

In our Solar system, the speed of the planets is inversely proportional to the distance to the center of the Sun.

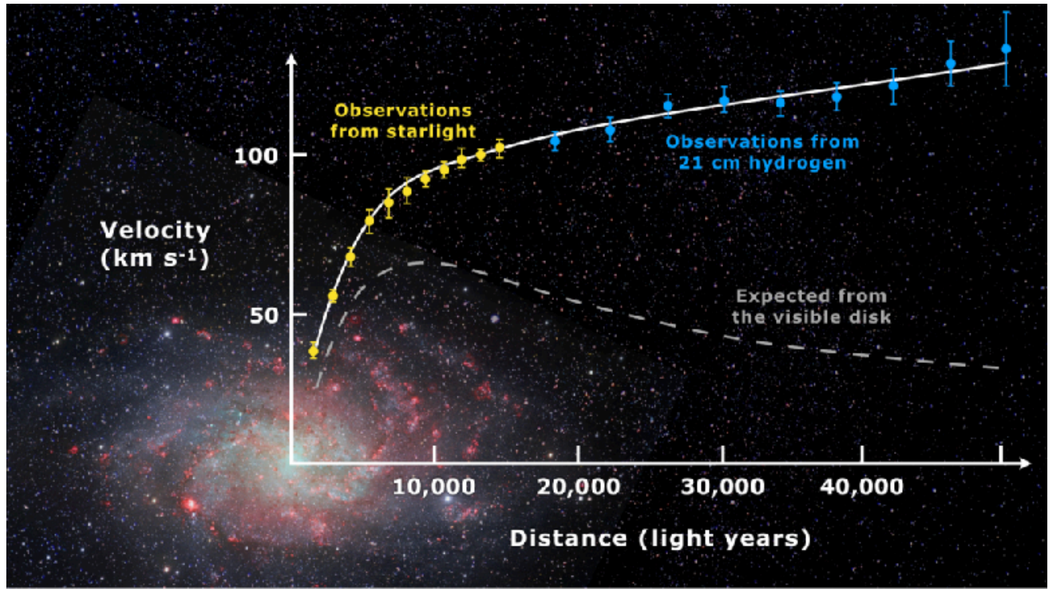
Galaxy(=collection of Suns) Velocity Distribution

Andromeda Galaxy



Vera Rubin

Messier 33 Galaxy



$$v = \sqrt{\frac{GM}{L}}$$

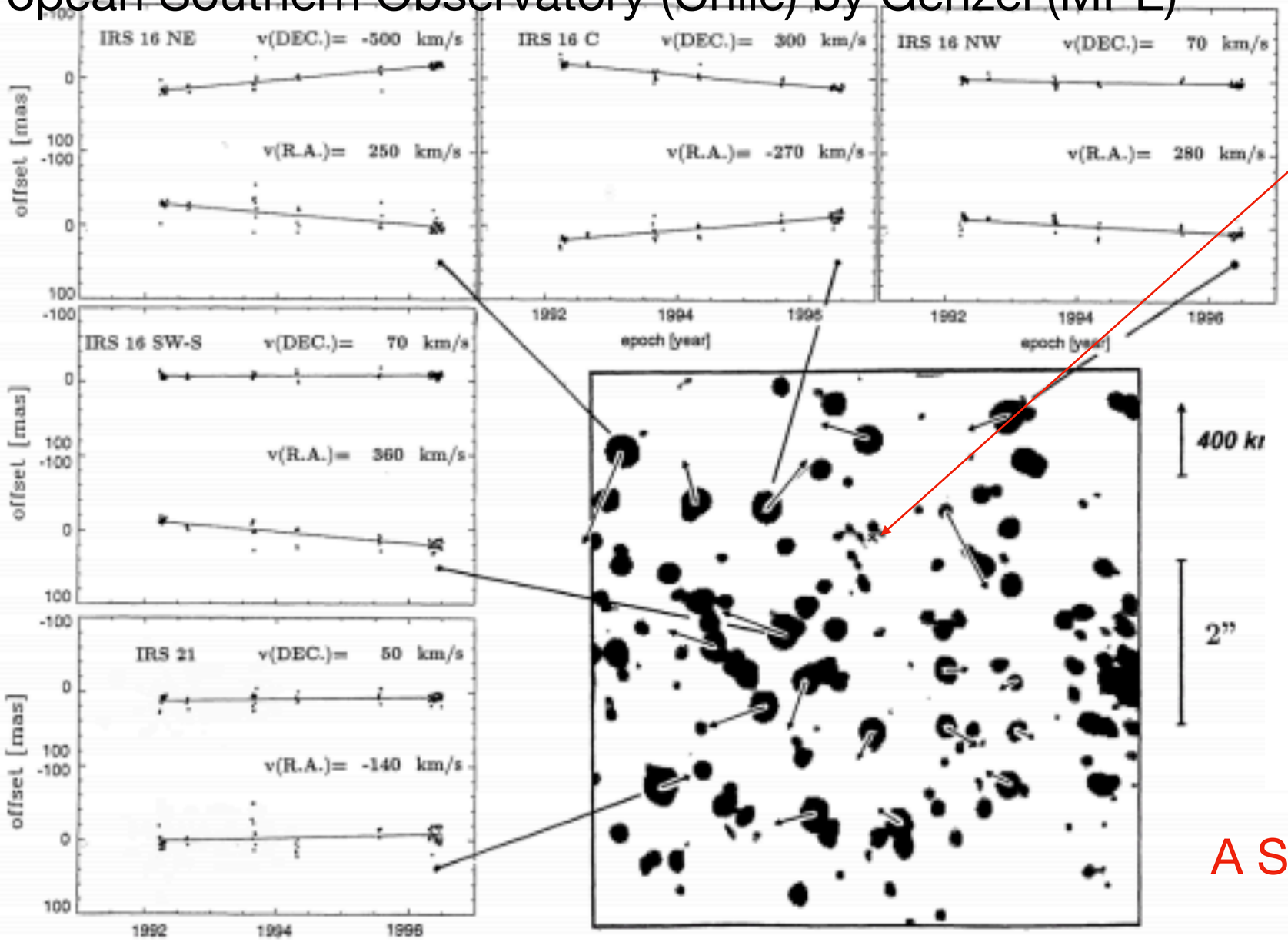
Likewise, distant objects from a galactic center are expected to slow down

But they do not slow down. They actually speed up.

This means that there are more mass than is visible.

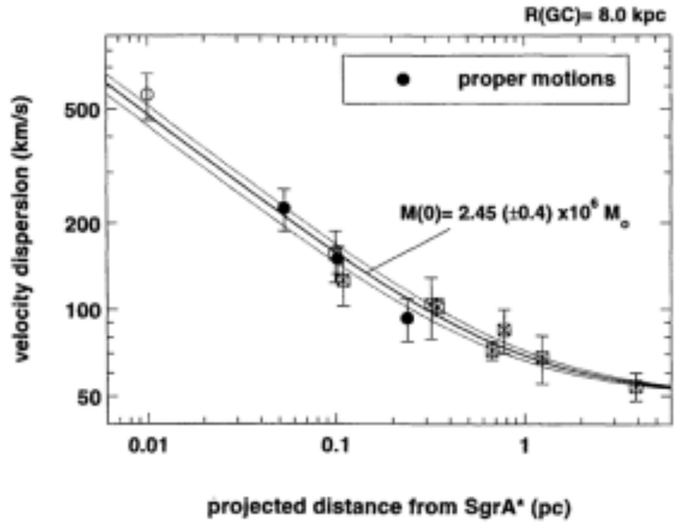
The difference becomes much larger in Galaxy cluster (=collection of galaxies) than in Galaxy.

European Southern Observatory (Chile) by Genzel (MPE)



Sgr A*

$$v = \sqrt{\frac{GM}{R}}$$



A Single Massive Black Hole!

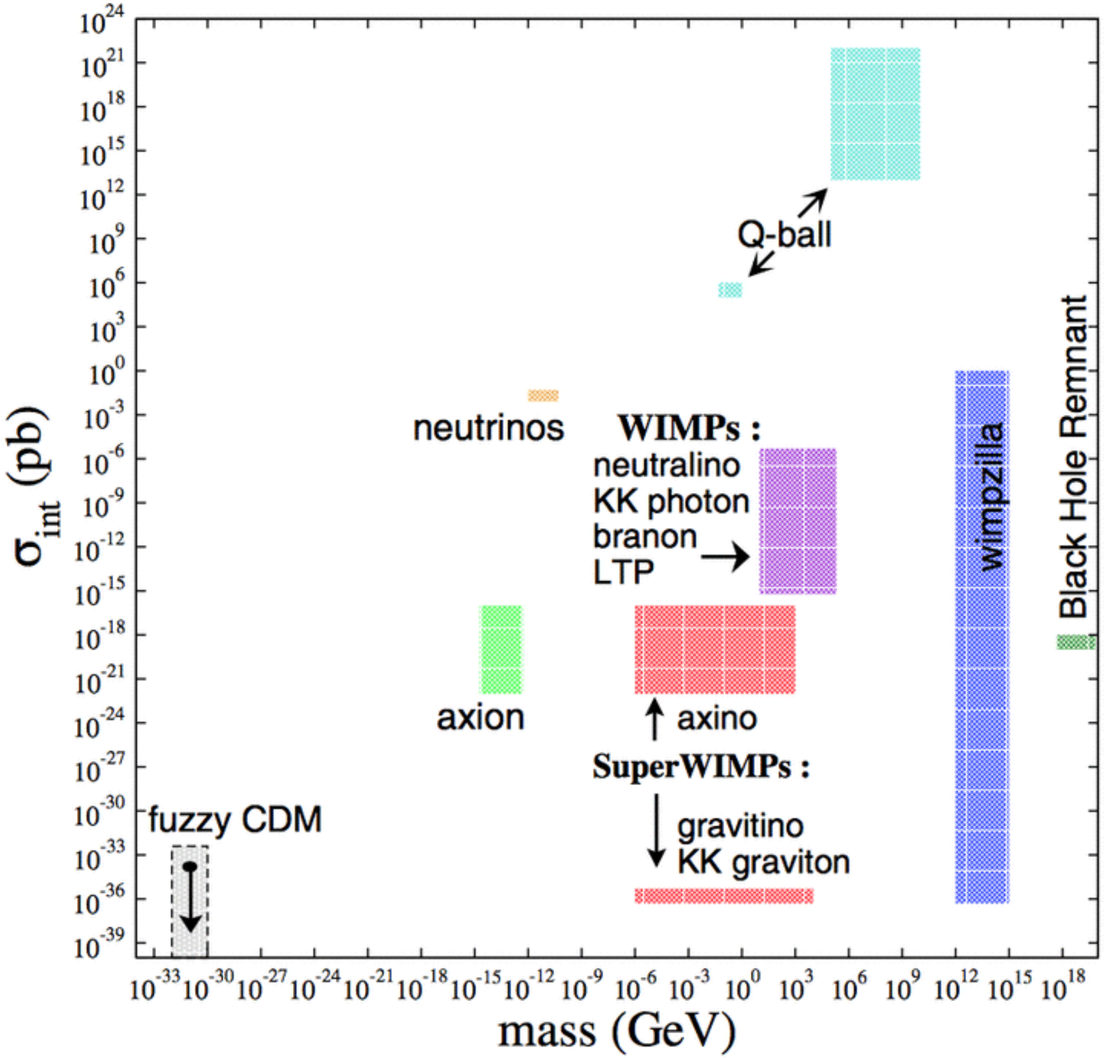
Question is whether the center is made of a single massive object or a large cluster of objects

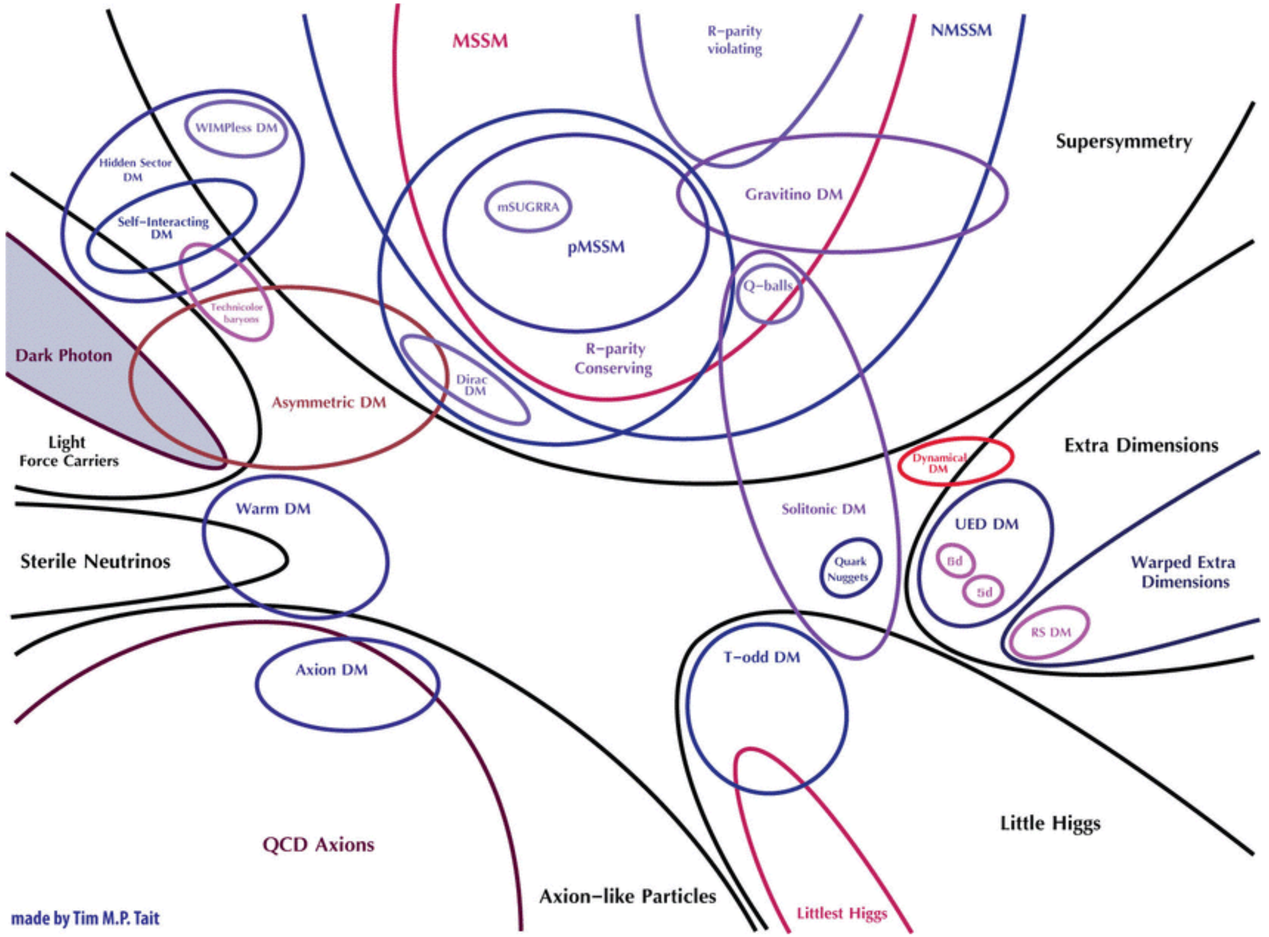
Pandora Galaxy cluster



NASA.gov

Dark Matter Candidates



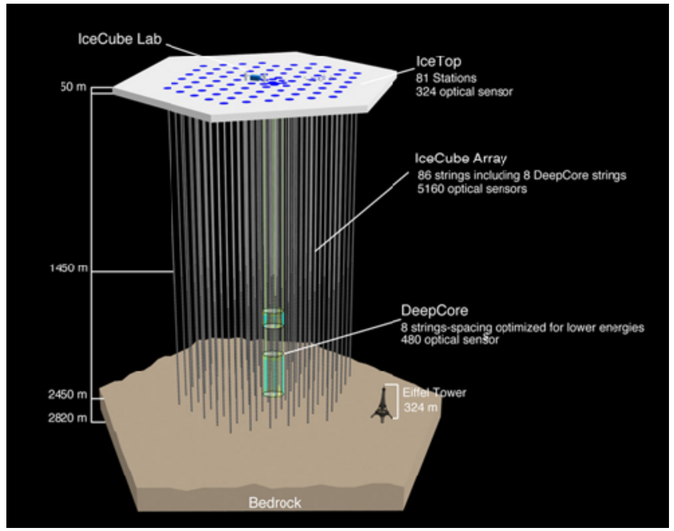


Weakly Interacting Massive Particles (WIMPs)

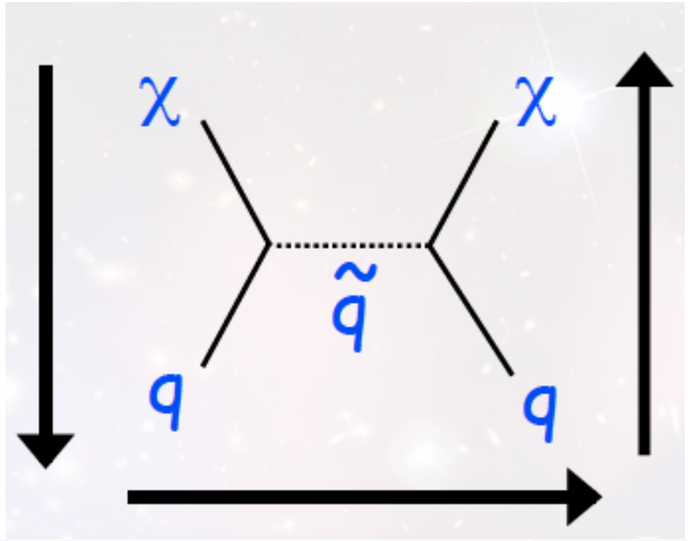
- Heavy enough (> 10^2 GeV) that accelerators can not find it yet but once the Big Bang made a lot.
- When the Universe had energy (Temperature) larger than $10^2\ GeV$, they were created as many as other particles. Then, temperature cools, the production stops while they kill each other to produce SM particles (weak interaction).
- At some point, they could not meet to kill each other because the Universe further expanded. Fewer per unit volume.
- This number is fixed now ($0.3\ GeV/cm^3$). Therefore, the Universe contains certain amount of WIMPs. Thermal relics (dark matter density from microwave background measurements).
- WIMP is a class of particle dark matter candidates
  - The relic density matches the scale of weak interaction in the early universe.
- Many BSM theories predict these WIMPs in the 1-10^5 GeV region.
- Elastic scattering cross-sections with normal matter at 10^{-40} - 10^{-50} cm^2
- Look for nuclear recoil around 1-100 keV

How to detect them?

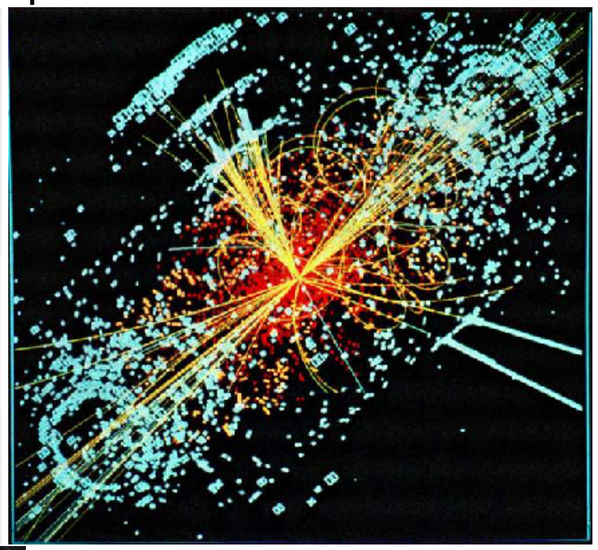
indirect detection

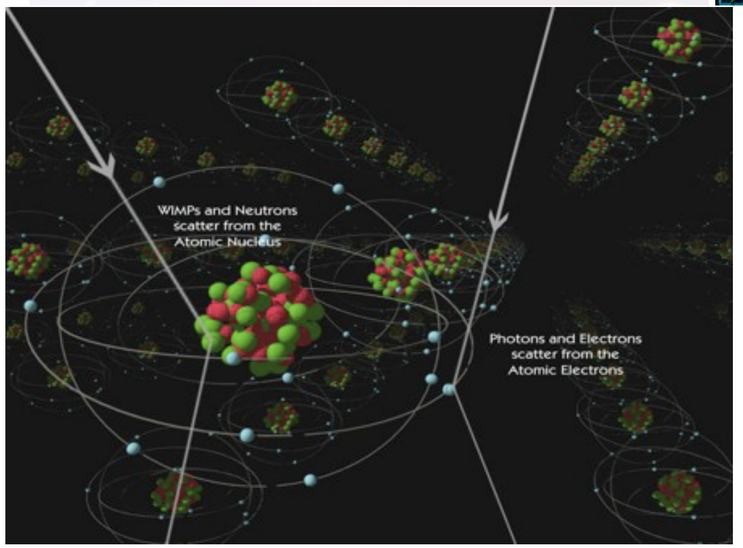


annihilation products
(neutrinos)
from e.g. Sun



production at LHC





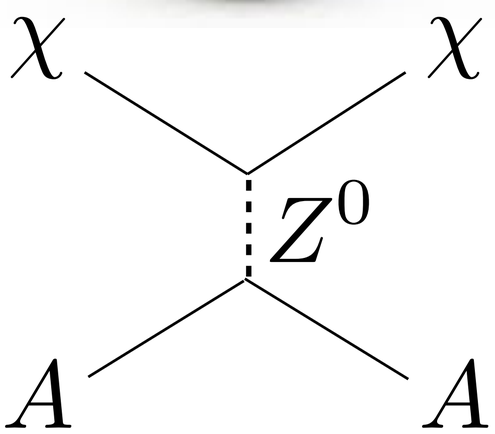
direct detection

WIMP-nucleon
scattering

WIMP interaction vs others
-Coherent Elastic Scattering : Nuclear Recoil

Coherent elastic Scatting





Elastic Scatting

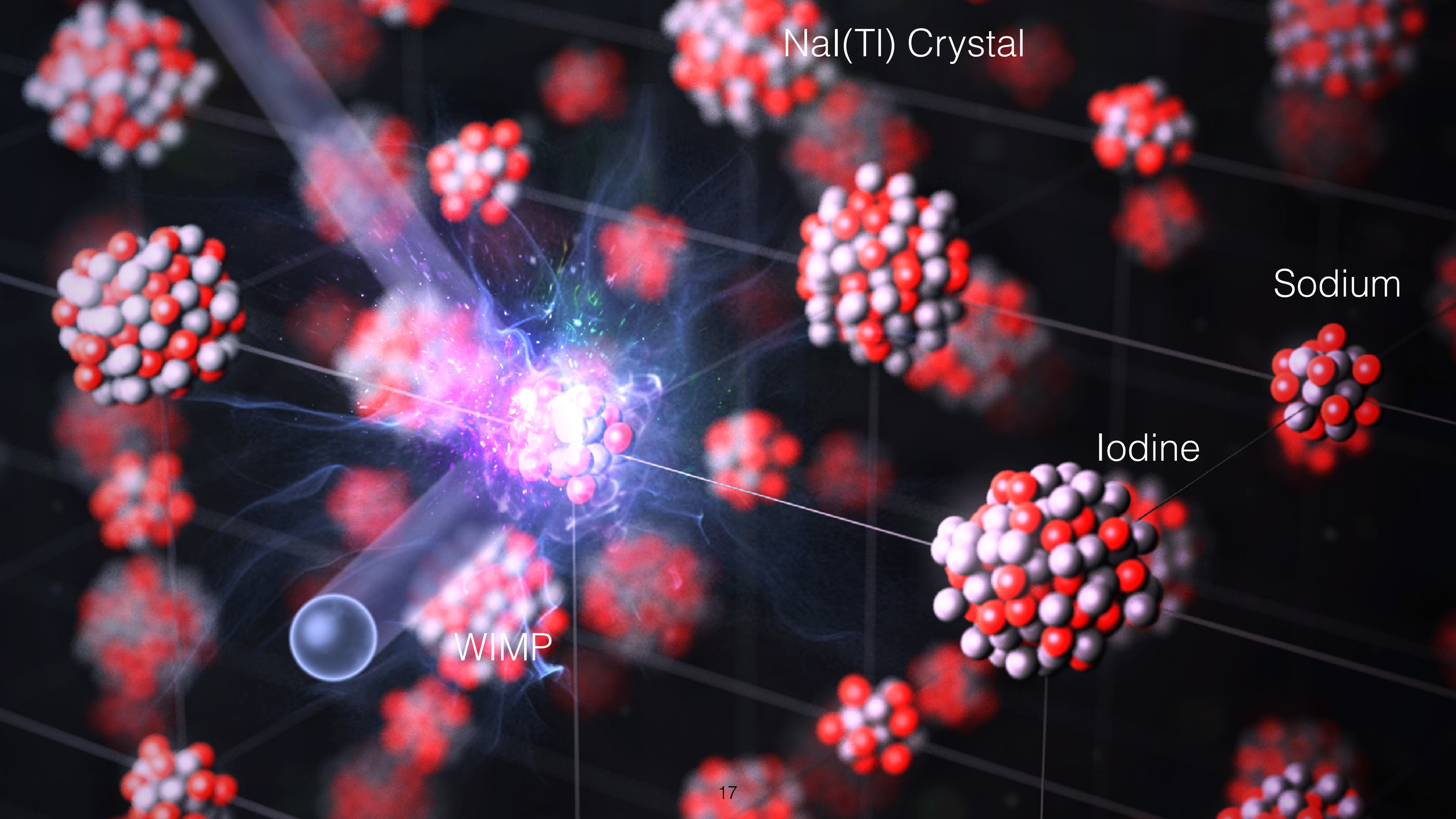




Inelastic Scatting

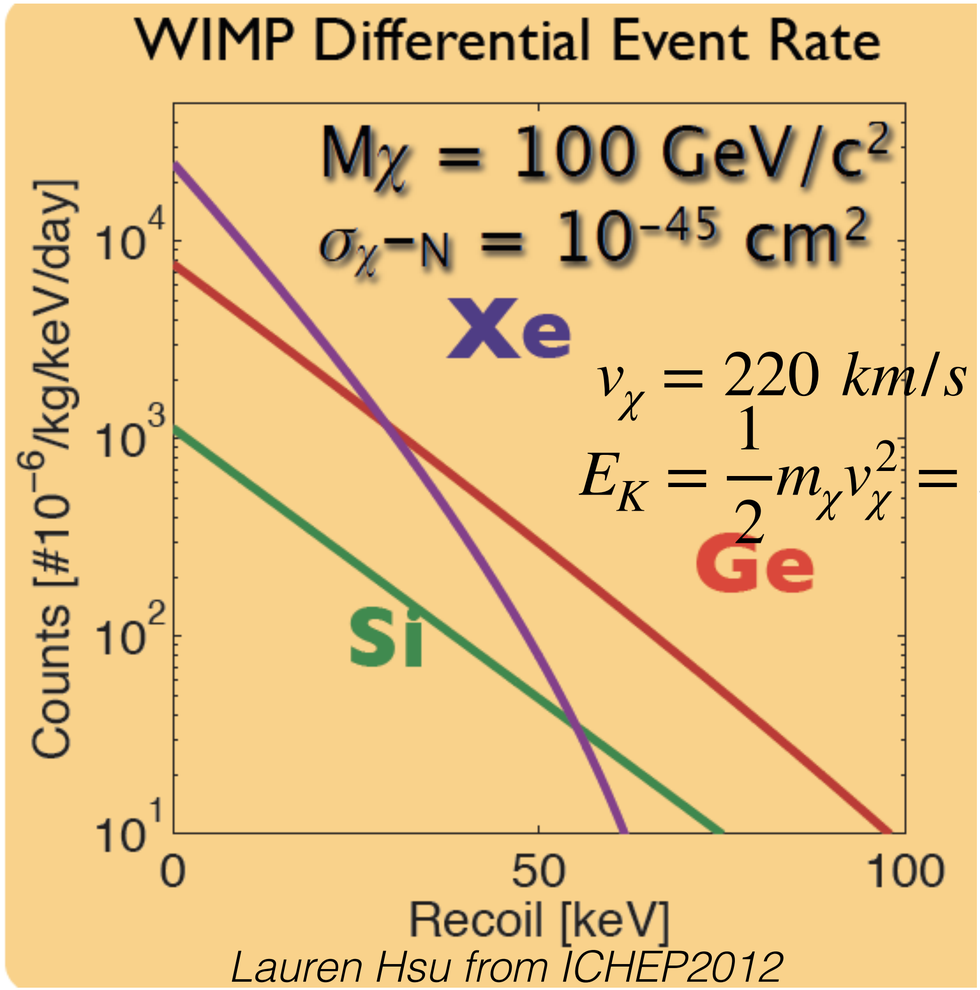





NaI(Tl) Crystal
Sodium
Iodine
WIMP

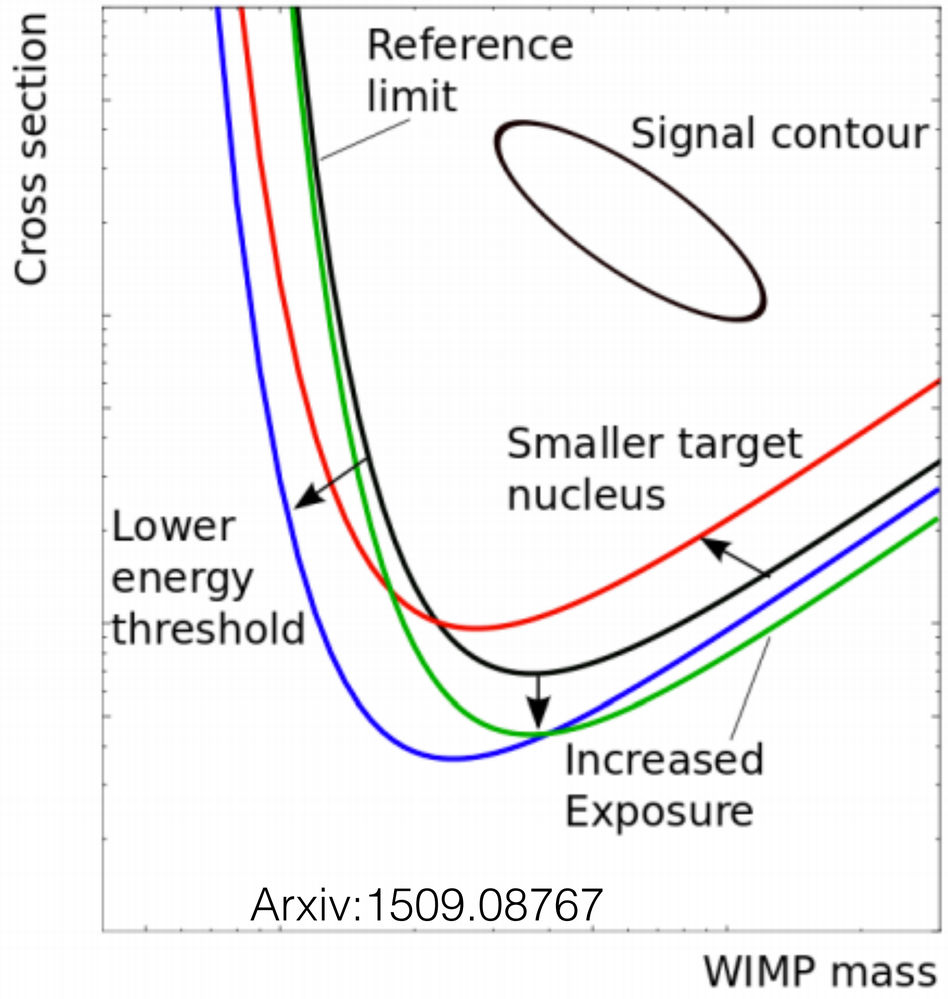
Direct Detection Event Rates

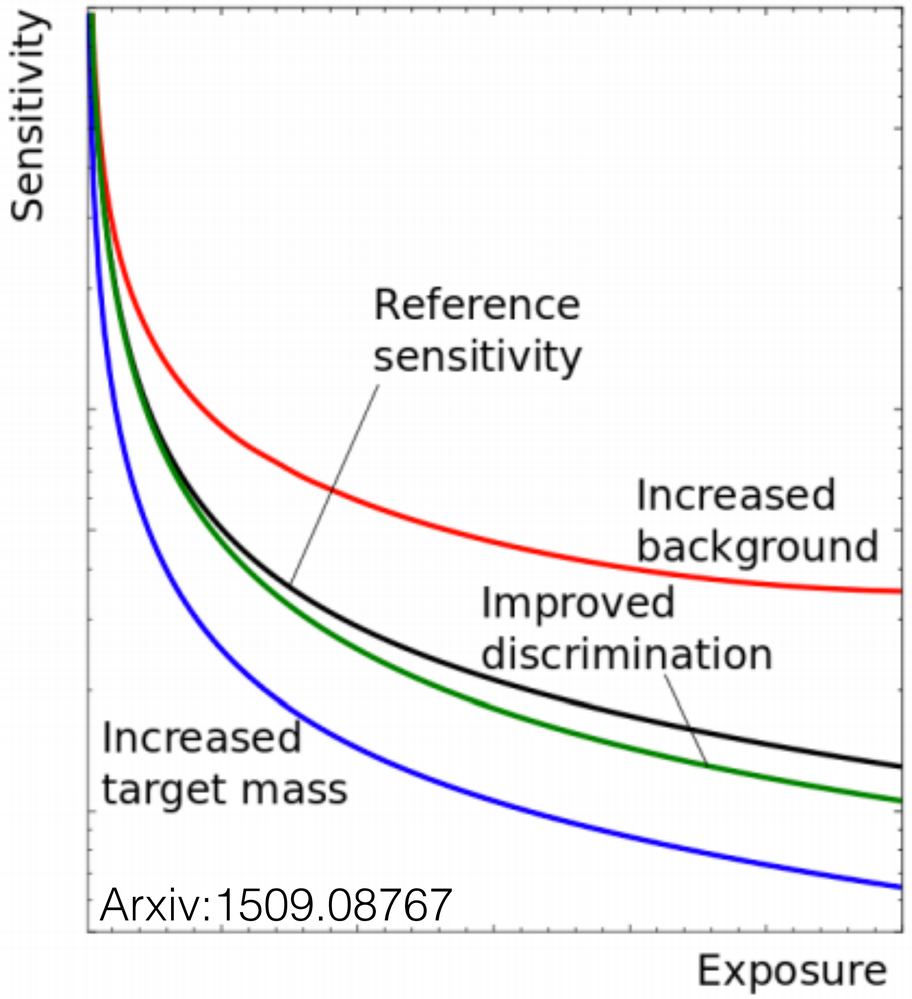
- Exponentially dropping nuclear recoil signal (small number of big push)
- Lower the energy threshold the better
- Choice of target materials
- Background control (e.g. natural radioactivity, material screening)
- Underground operation with large mass

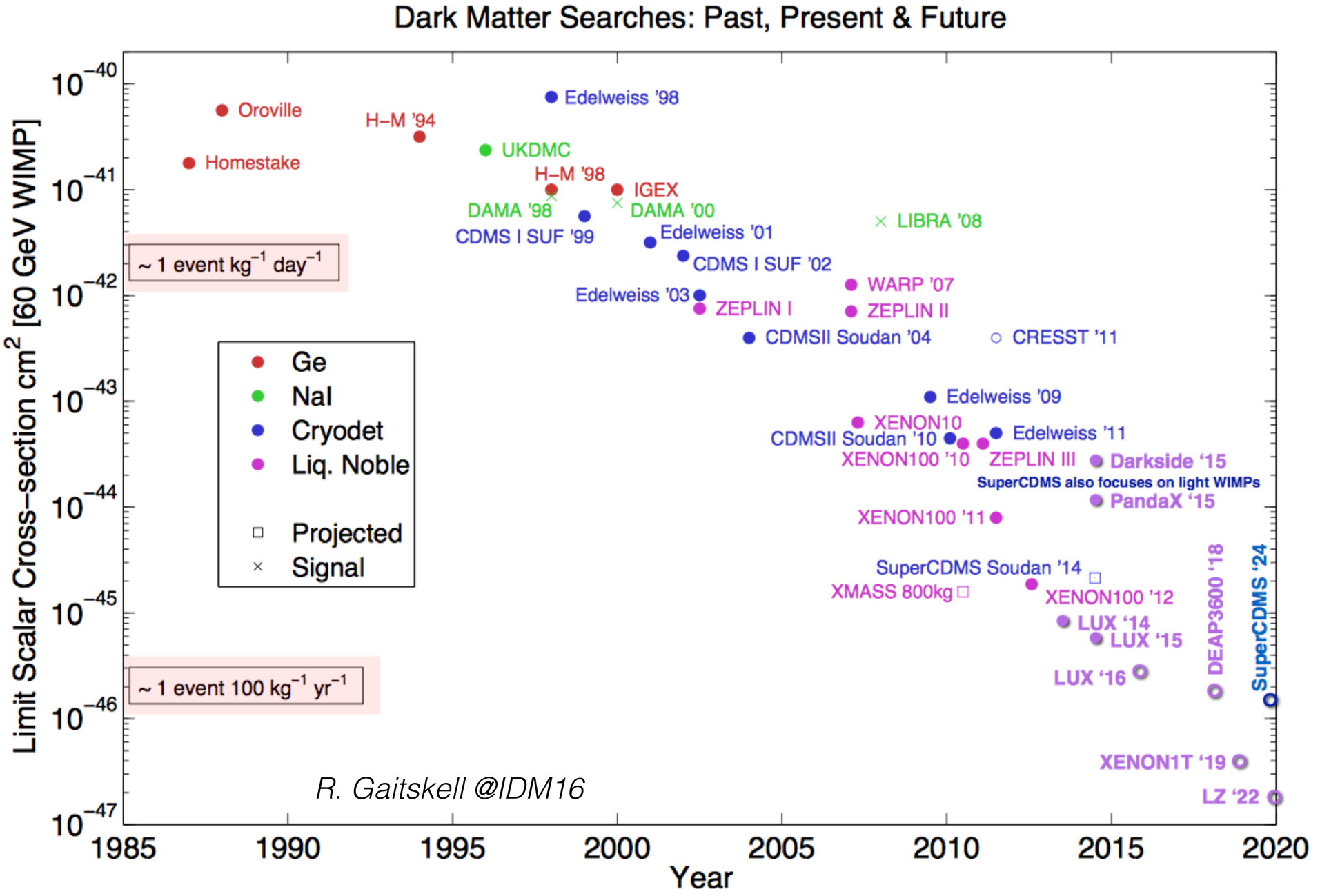


Lauren Hsu from ICHEP2012

Design of the detector based on the sensitivity

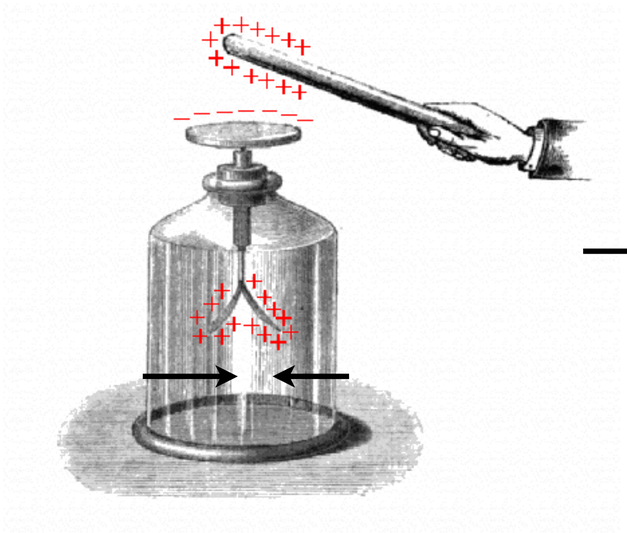




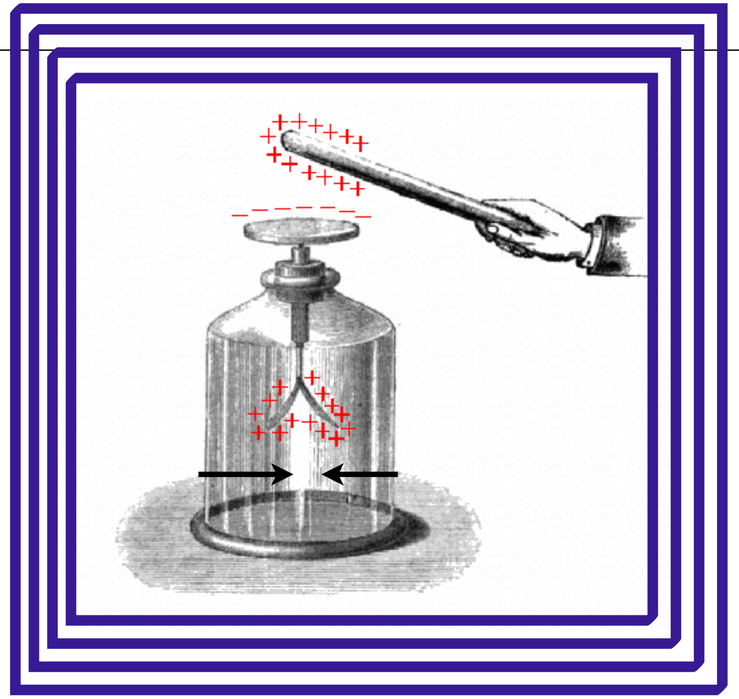

Dark Matter Searches: Past, Present & Future
Limit Scalar Cross−section cm^2 [60 GeV WIMP]
Year
Oroville
Homestake
H−M '94
Edelweiss '98
UKDMC
H−M '98
IGEX
DAMA '98
DAMA '00
CDMS I SUF '99
Edelweiss '01
LIBRA '08
CDMS I SUF '02
WARP '07
Edelweiss '03
ZEPLIN I
ZEPLIN II
CDMSII Soudan '04
CRESST '11
Edelweiss '09
XENON10
CDMSII Soudan '10
Edelweiss '11
XENON100 '10
ZEPLIN III
Darkside '15
SuperCDMS also focuses on light WIMPs
PandaX '15
XENON100 '11
SuperCDMS Soudan '14
XMASS 800kg
XENON100 '12
LUX '14
LUX '15
LUX '16
DEAP3600 '18
SuperCDMS '24
XENON1T '19
LZ '22
~ 1 event kg^{-1} day^{-1}
~ 1 event 100 kg^{-1} yr^{-1}
Ge
NaI
Cryodet
Liq. Noble
Projected
Signal
R. Gaitskell @IDM16

Why do they go underground? Mysterious Radiation-Cosmic Rays

- Charges in the electroscopes were easily discharged even with very good shielding



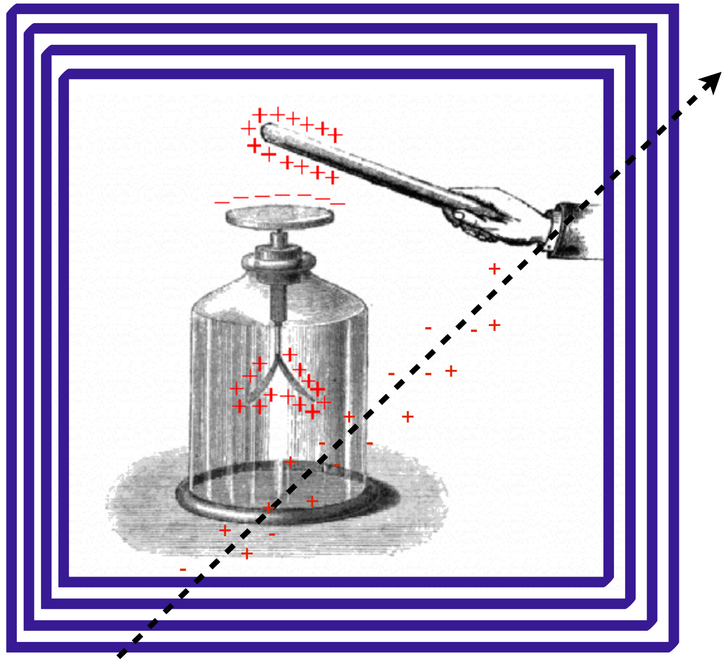
After some time, two leaves get closer



The same thing happens with good shielding

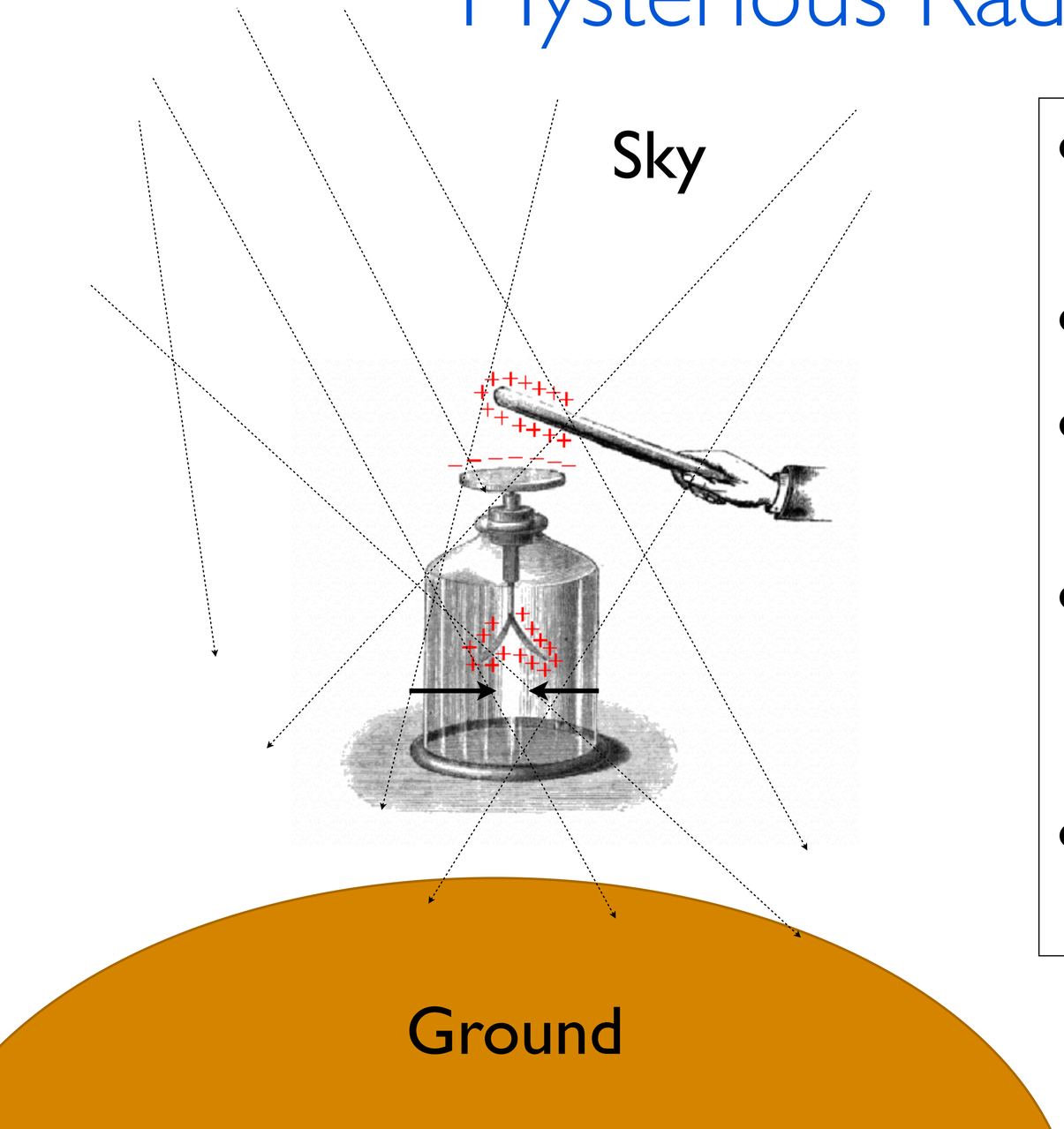
Mysterious Radiation-Cosmic Rays

- Until 1910, ionization measured in electroscopes was thought to be from the Earth (Radon etc)



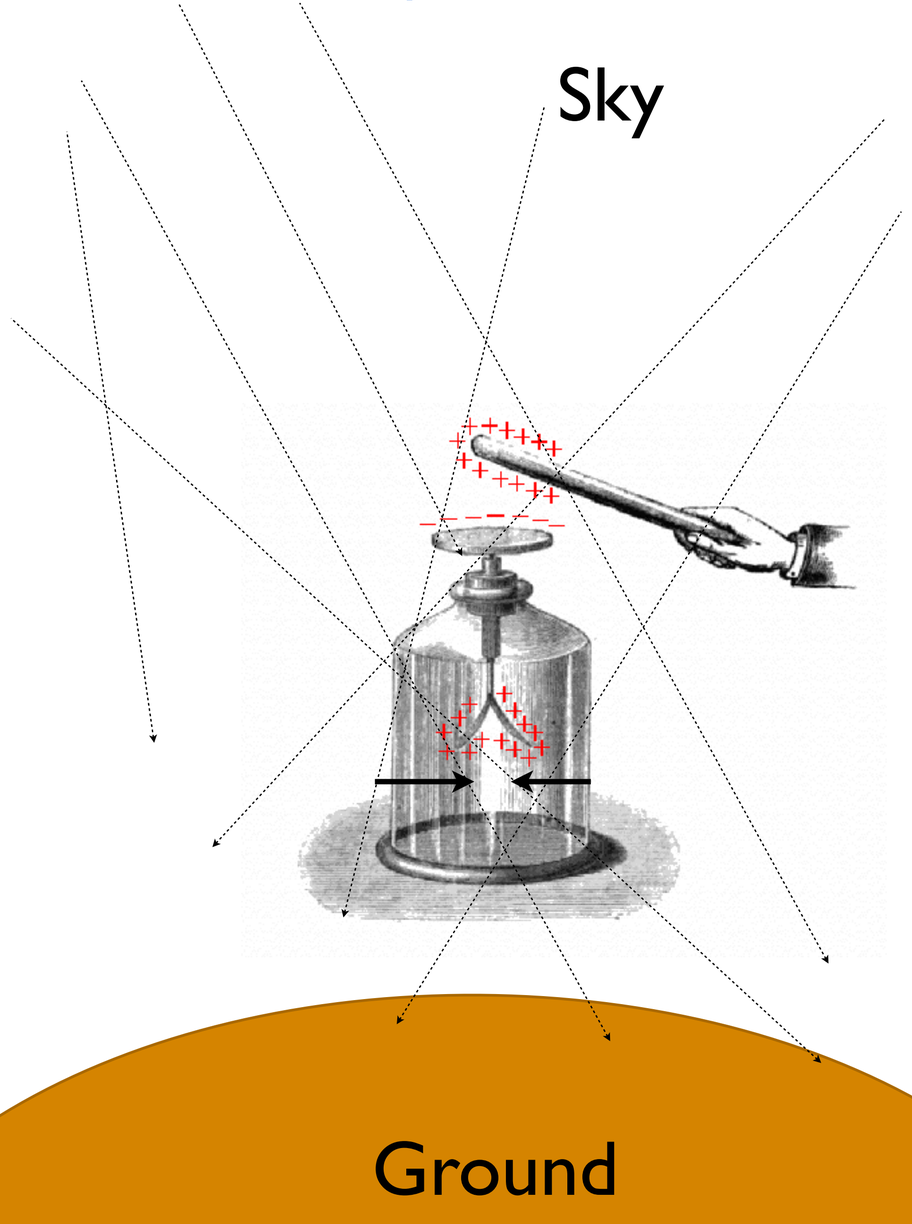
Radon induced particle ionizes the air, creating balance inside electroscope

Mysterious Radiation-Cosmic Rays

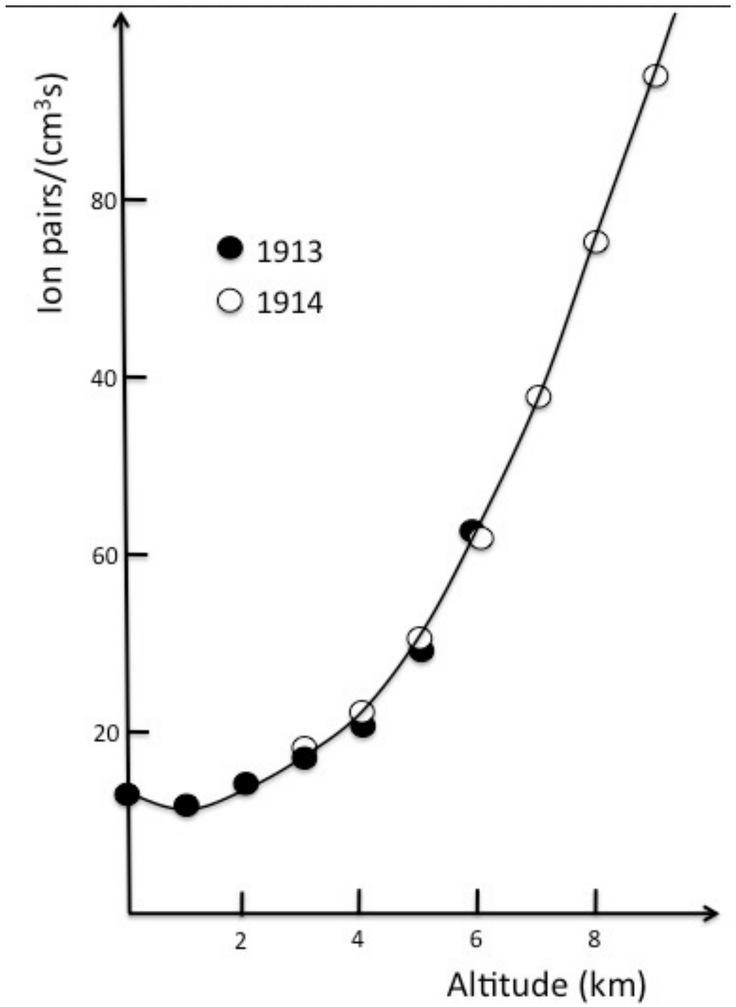


- Radiation intensity decreases as function of distance squared.
- So, let's go far away from the Earth
- Measurement on top of Eiffel Tower & other balloon experiments inconclusive
- Hess designed instruments that can sustain at high altitude environment and found the radiation increases as he goes up high.
- He concluded *"a radiation of very high penetrating power enters our atmosphere from above."*

Mysterious Radiation-Cosmic Rays



~9 km !

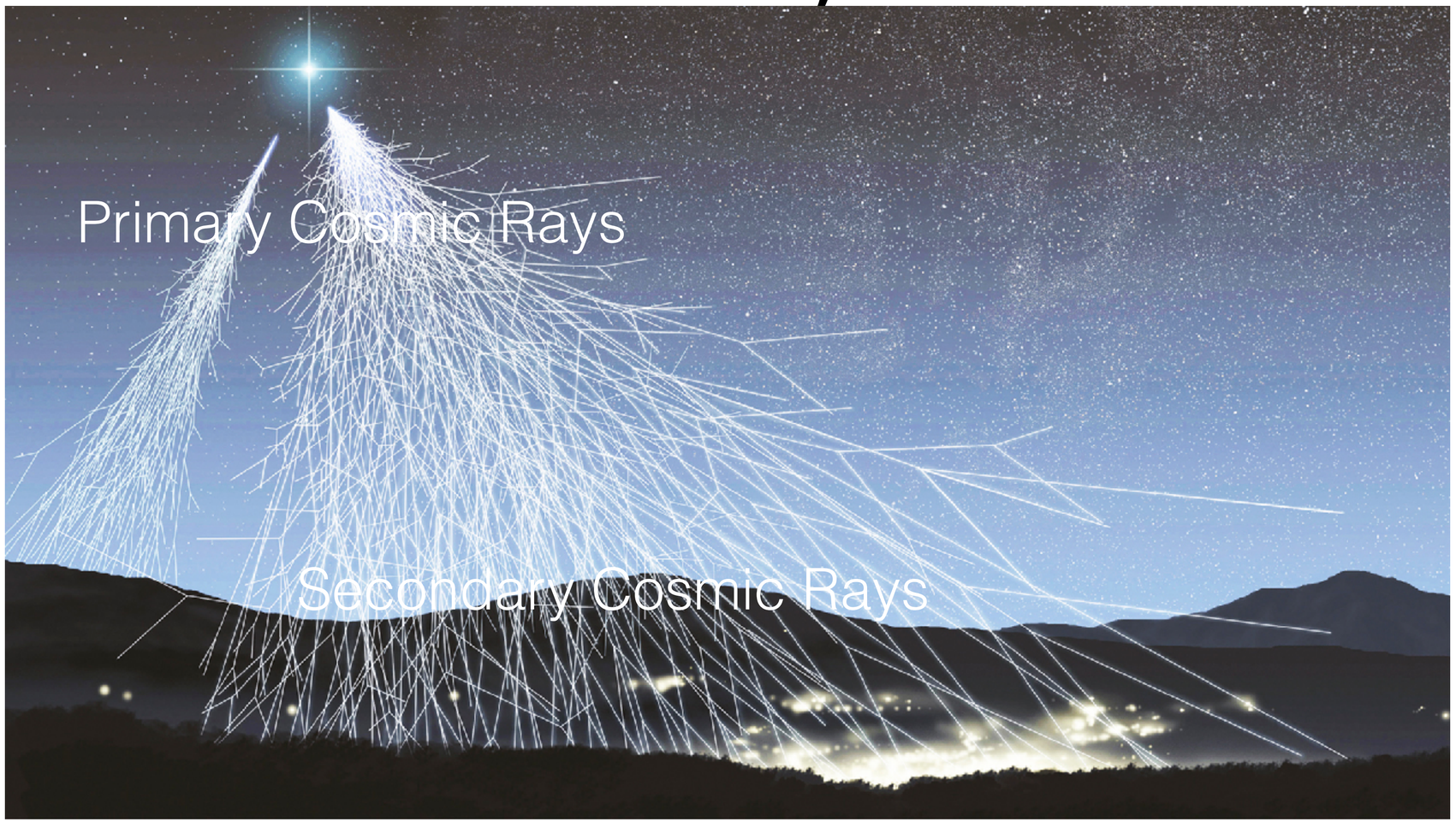


Mysterious Radiation-Cosmic Rays



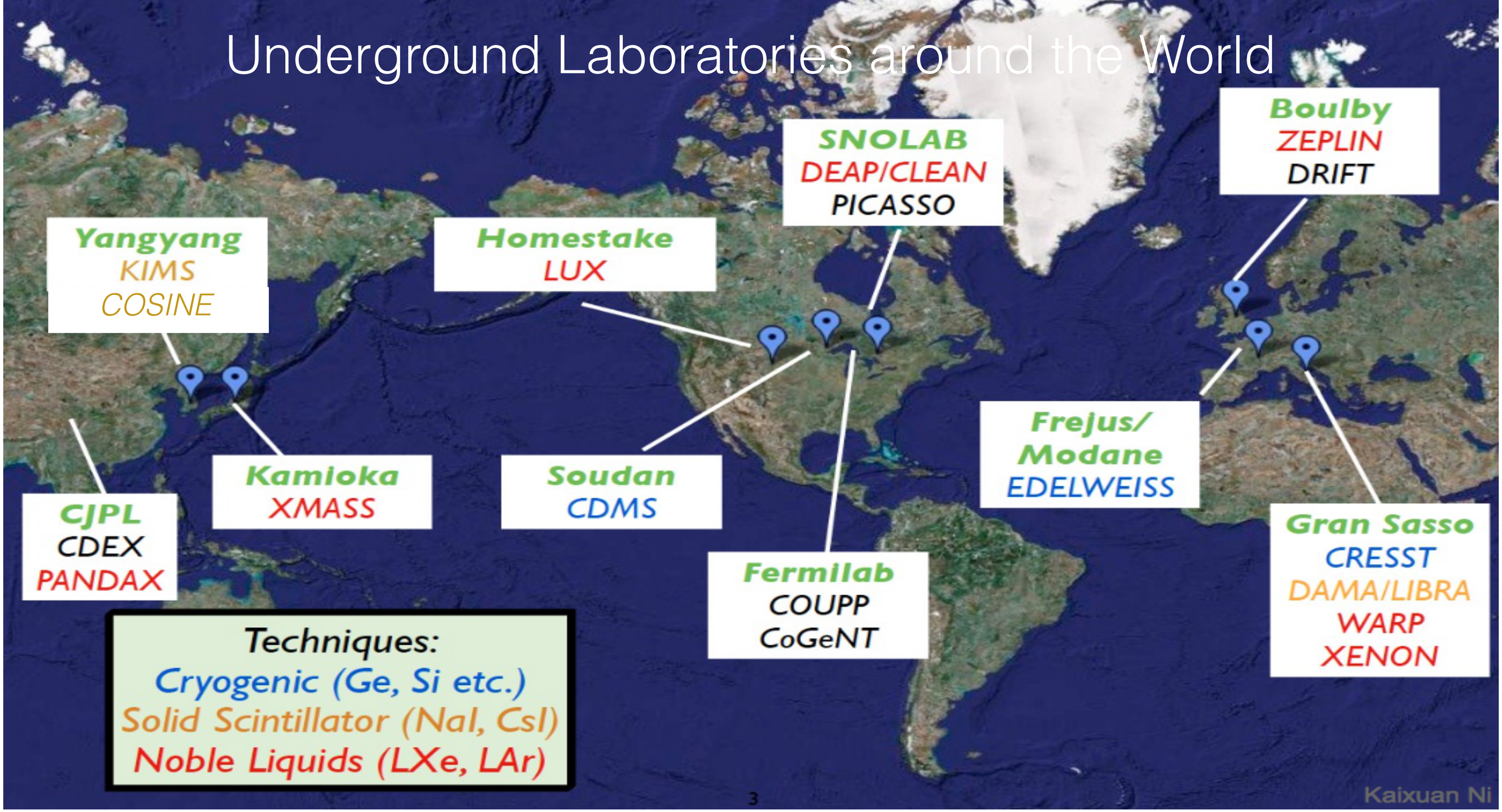
- But where does it come from?
- Does it come from the Sun?
- Hess launched another balloon flight during total eclipse of the Sun and found the radiation did not decrease.
- Hess concluded *"the source of the radiation could not be the sun itself; it had to be coming from further out in space."*
- Robert Millikan later confirmed Hess' discovery and name the radiation "Cosmic Rays"
- Victor Hess was awarded Nobel Prize in 1936

Cosmic Ray Muons

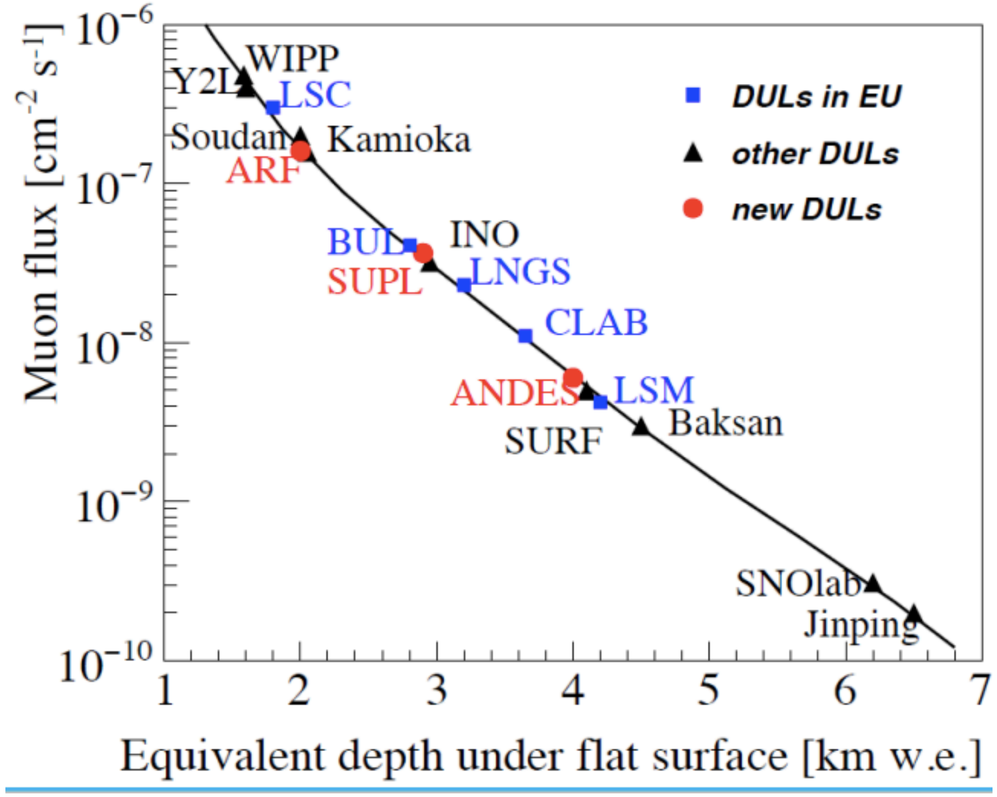


Muon are coming at the rate of ~200/sec/m^2
These make background noise to dark matter experiments

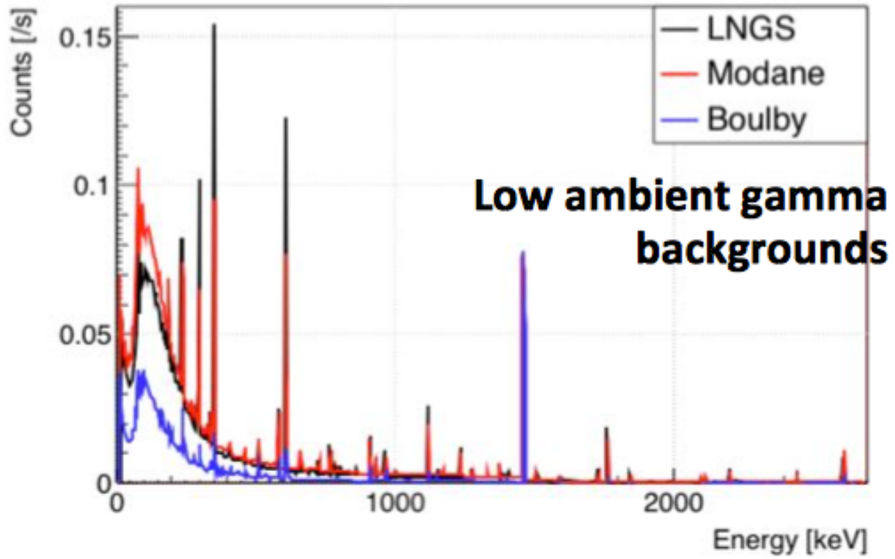
Underground Laboratories around the World



Low-background environment at various underground labs

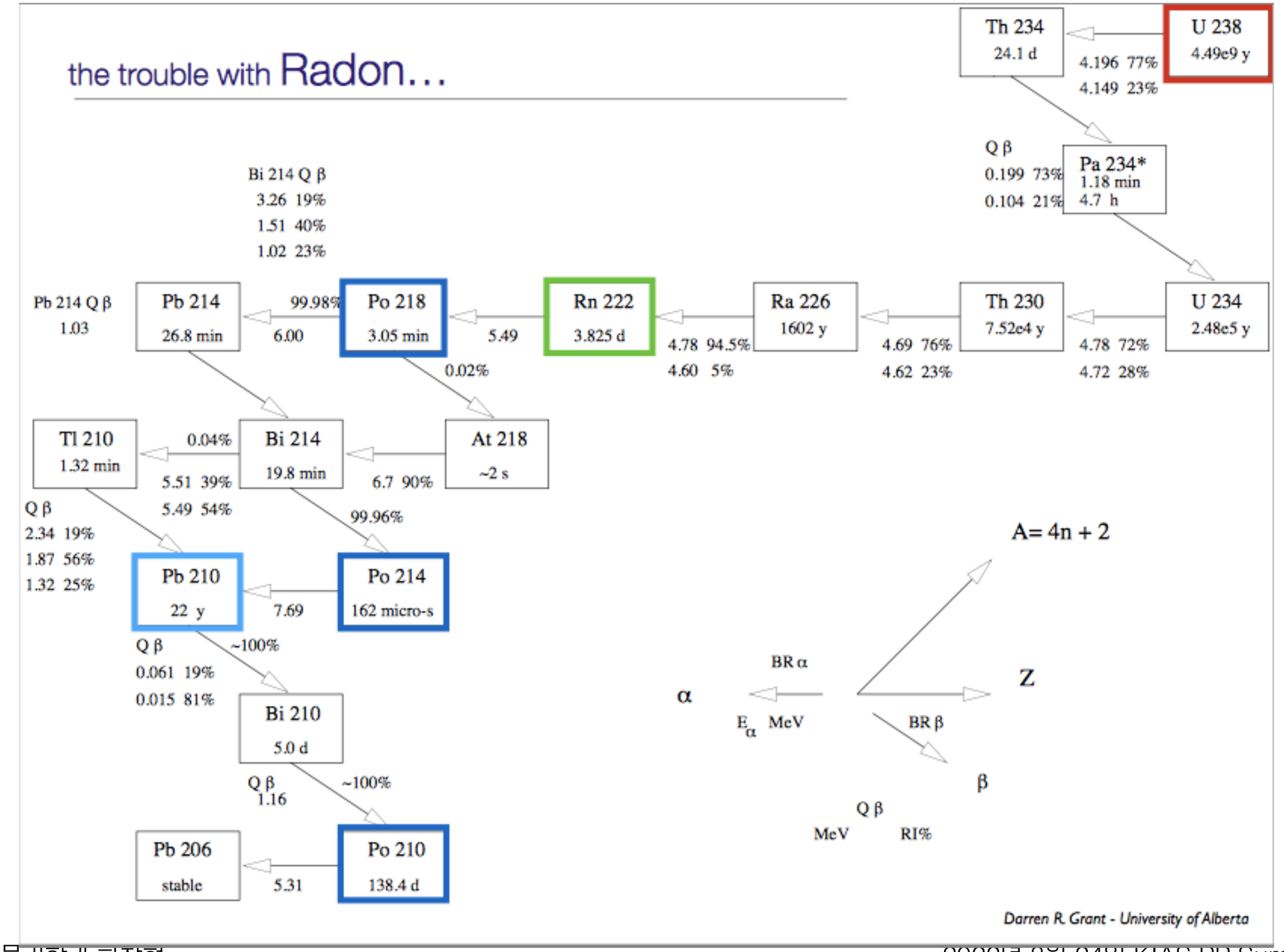


S. Paling (IDM16)



- Low cosmic-ray muon/neutron flux
- Low radon & low gamma bkg. level
- Infrastructure & Access

"A hole in the ground does not make a facility"


the trouble with Radon…
Th 234
24.1 d
U 238
4.49e9 y
4.196 77%
4.149 23%
Q β
0.199 73%
0.104 21%
Pa 234*
1.18 min
4.7 h
Bi 214 Q β
3.26 19%
1.51 40%
1.02 23%
Pb 214 Q β
1.03
Pb 214
26.8 min
99.98%
6.00
Po 218
3.05 min
5.49
Rn 222
3.825 d
4.78 94.5%
4.60 5%
Ra 226
1602 y
4.69 76%
4.62 23%
Th 230
7.52e4 y
4.78 72%
4.72 28%
U 234
2.48e5 y
0.02%
Tl 210
1.32 min
0.04%
5.51 39%
5.49 54%
Bi 214
19.8 min
6.7 90%
At 218
~2 s
99.96%
Q β
2.34 19%
1.87 56%
1.32 25%
Pb 210
22 y
7.69
Po 214
162 micro-s
Q β
0.061 19%
0.015 81%
~100%
Bi 210
5.0 d
Q β
1.16
~100%
Pb 206
stable
5.31
Po 210
138.4 d
A= 4n + 2
Z
BR α
α
E α MeV
BR β
β
Q β
MeV
RI%
Darren R. Grant - University of Alberta

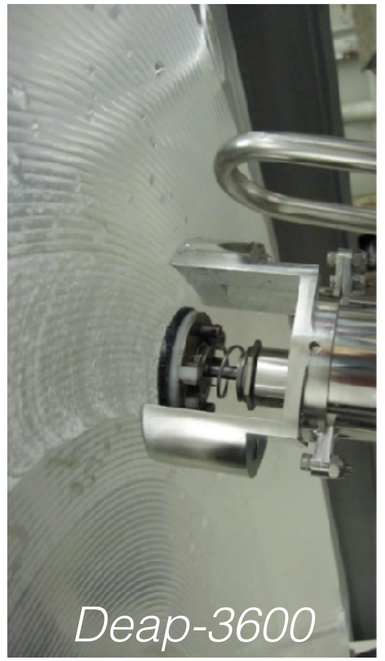
Ultra low background Materials



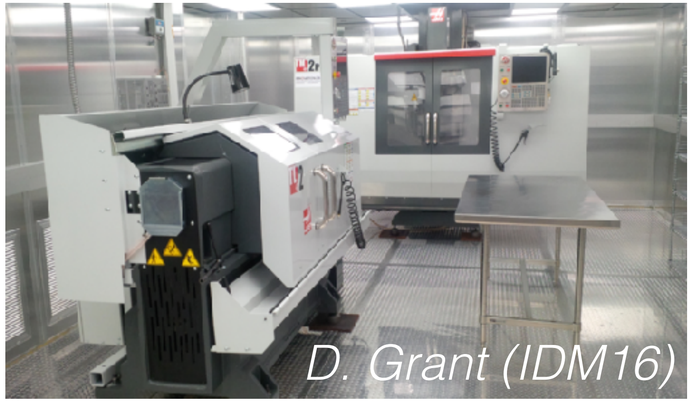
Underground Cu forming



Chemical Cleaning



Mechanical Surfacing

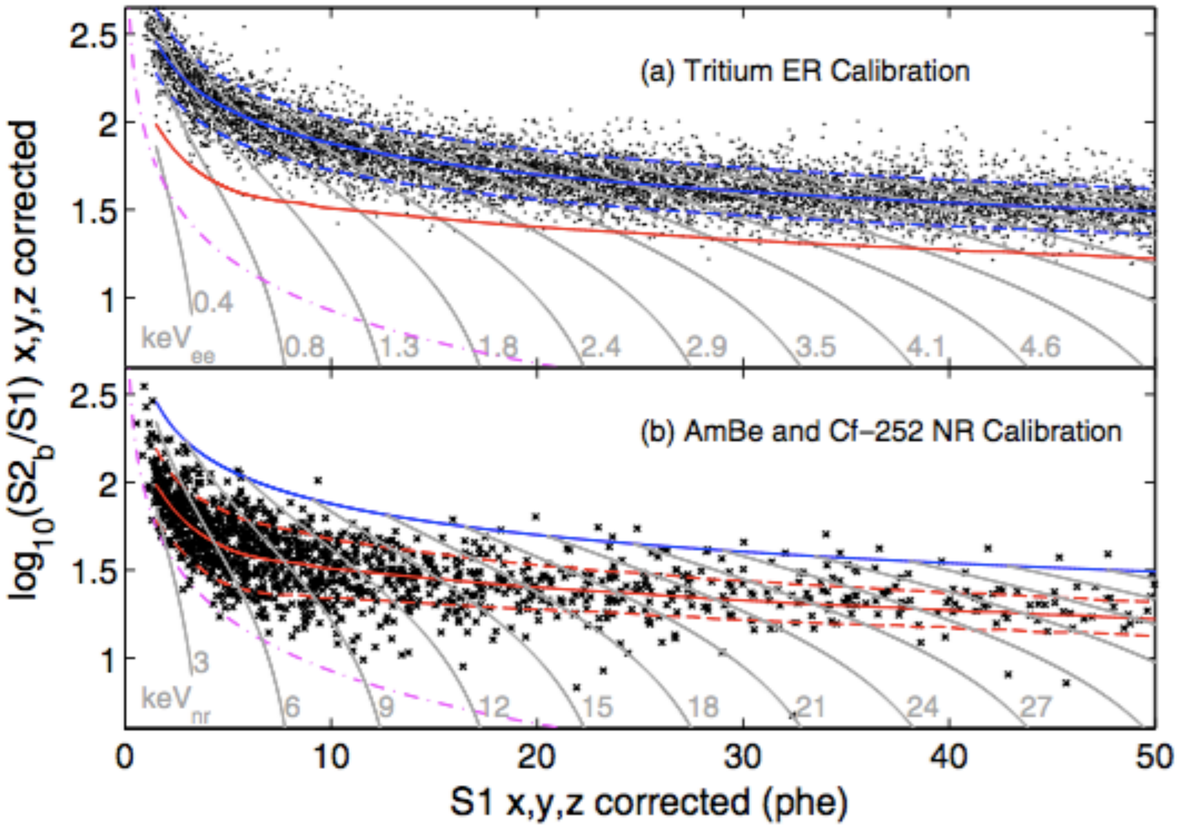


Rn-reduced clean room

- Selecting/Fabricating Low-bkg. materials
- Chemical/Mechanical cleaning of the materials
- Measurement of the materials
  - (HPGe, Rn monitor, alpha counter, ICP-MS …)

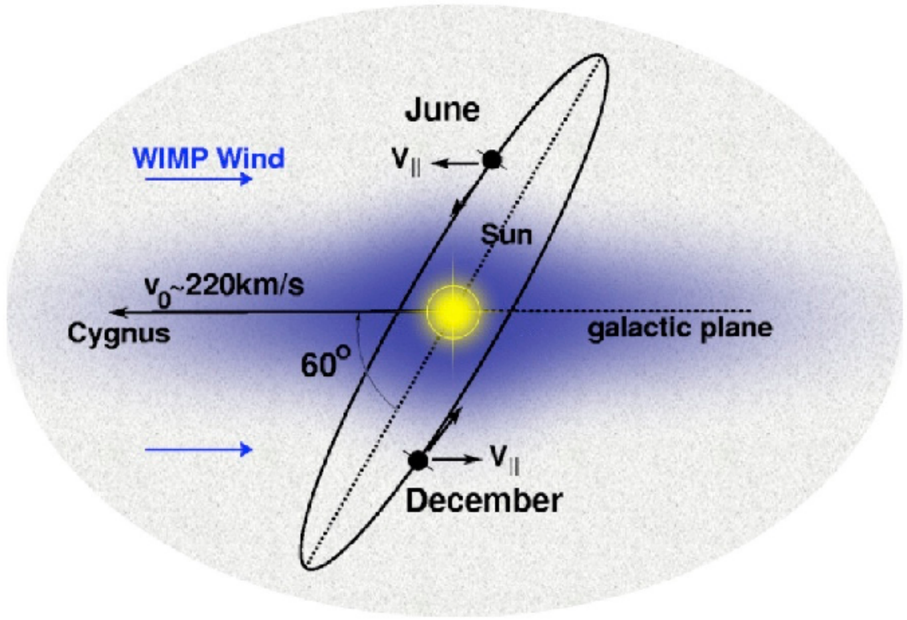
Signals & Backgrounds

Discrimination of nuclear recoils (Signal)
from electron/gamma recoils(Background)



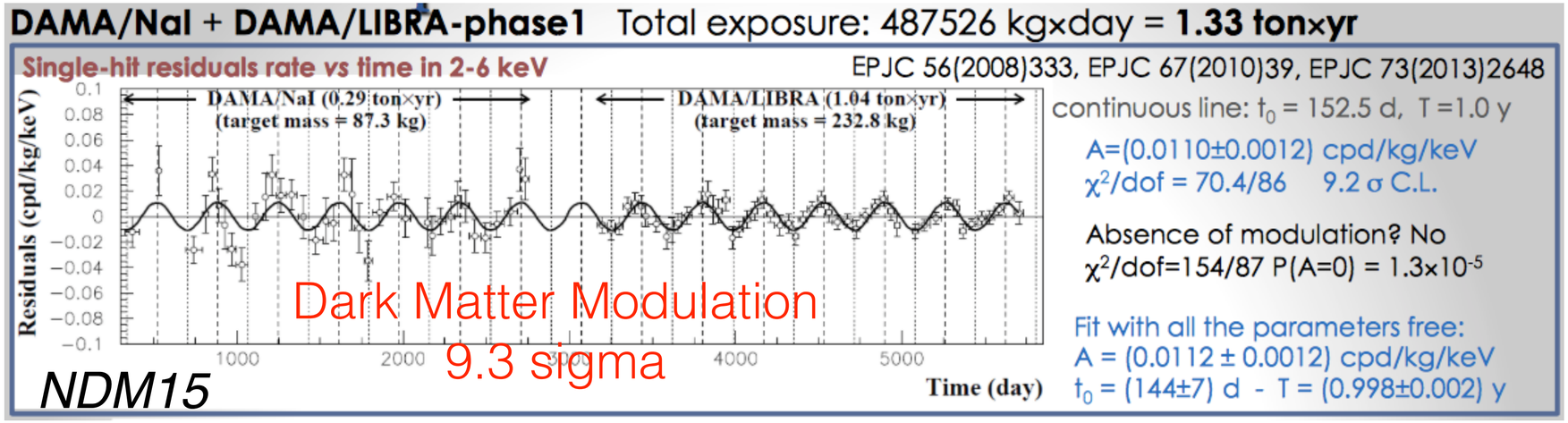
LUX Collaboration, Phys. Rev. Lett., (2014)

Annual modulation signal

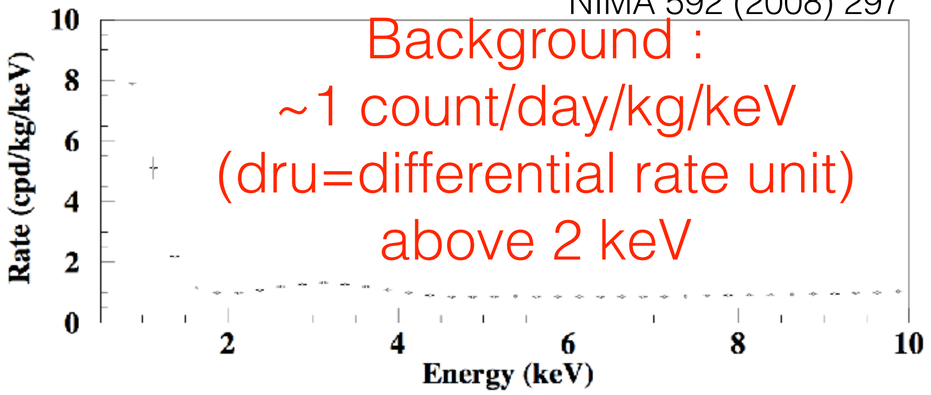


Directional dark matter search

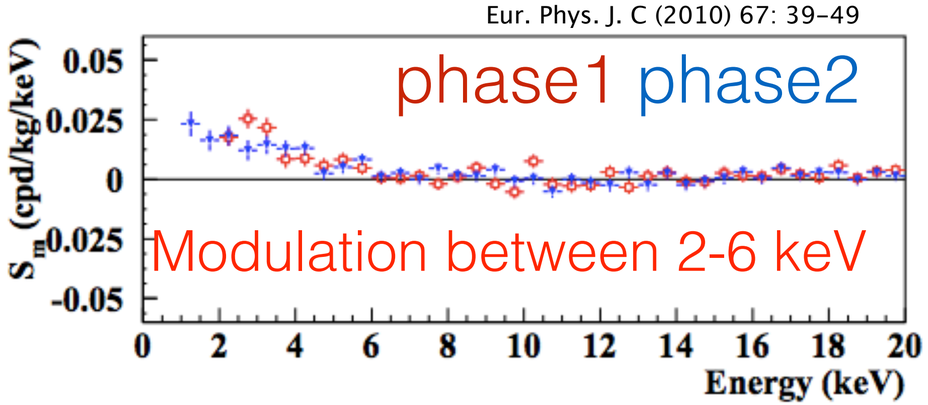
The DAMA annual modulation signal, to be confirmed with independent measurements by the same NaI(Tl) target material

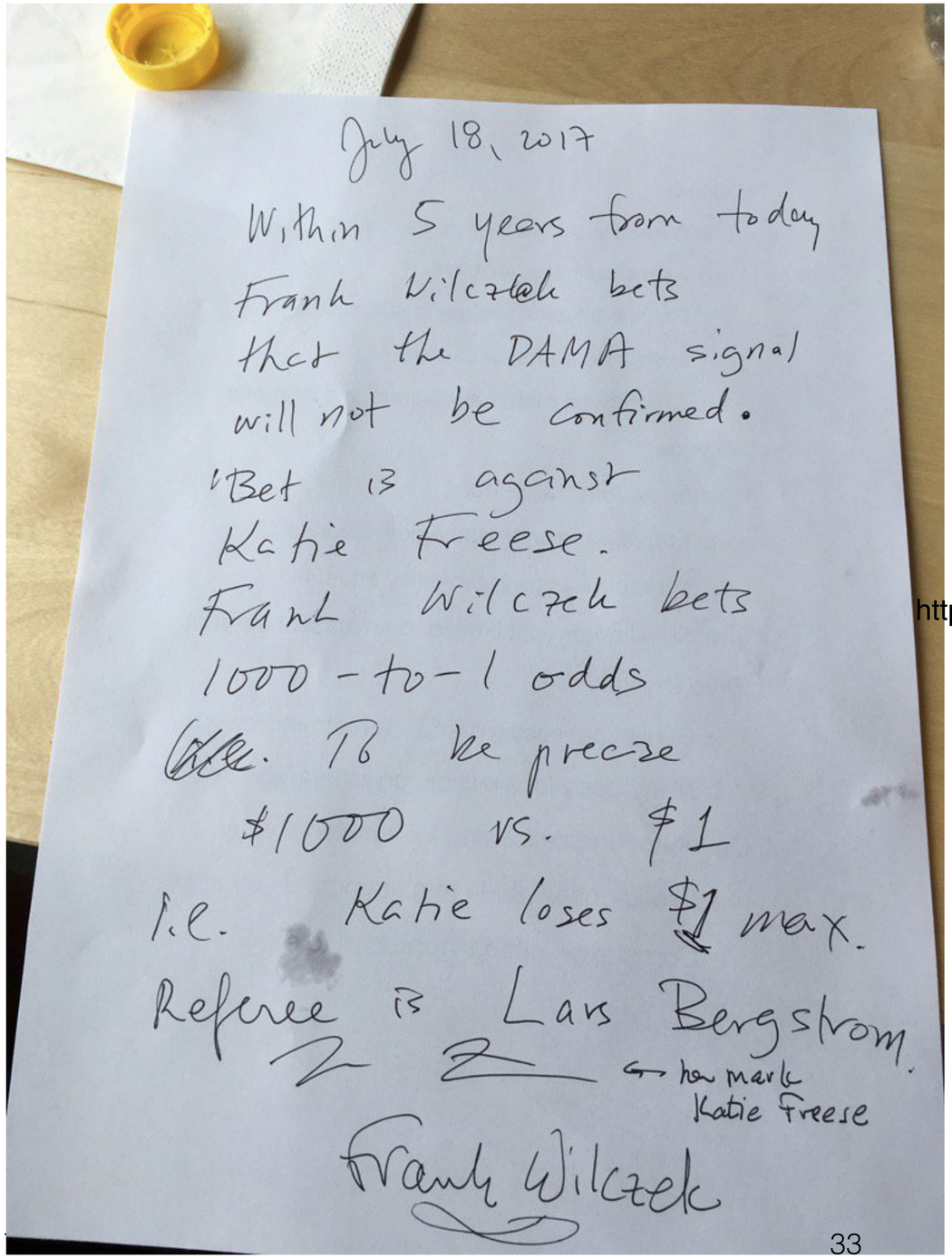


NIMA 592 (2008) 297



Eur. Phys. J. C (2010) 67: 39–49





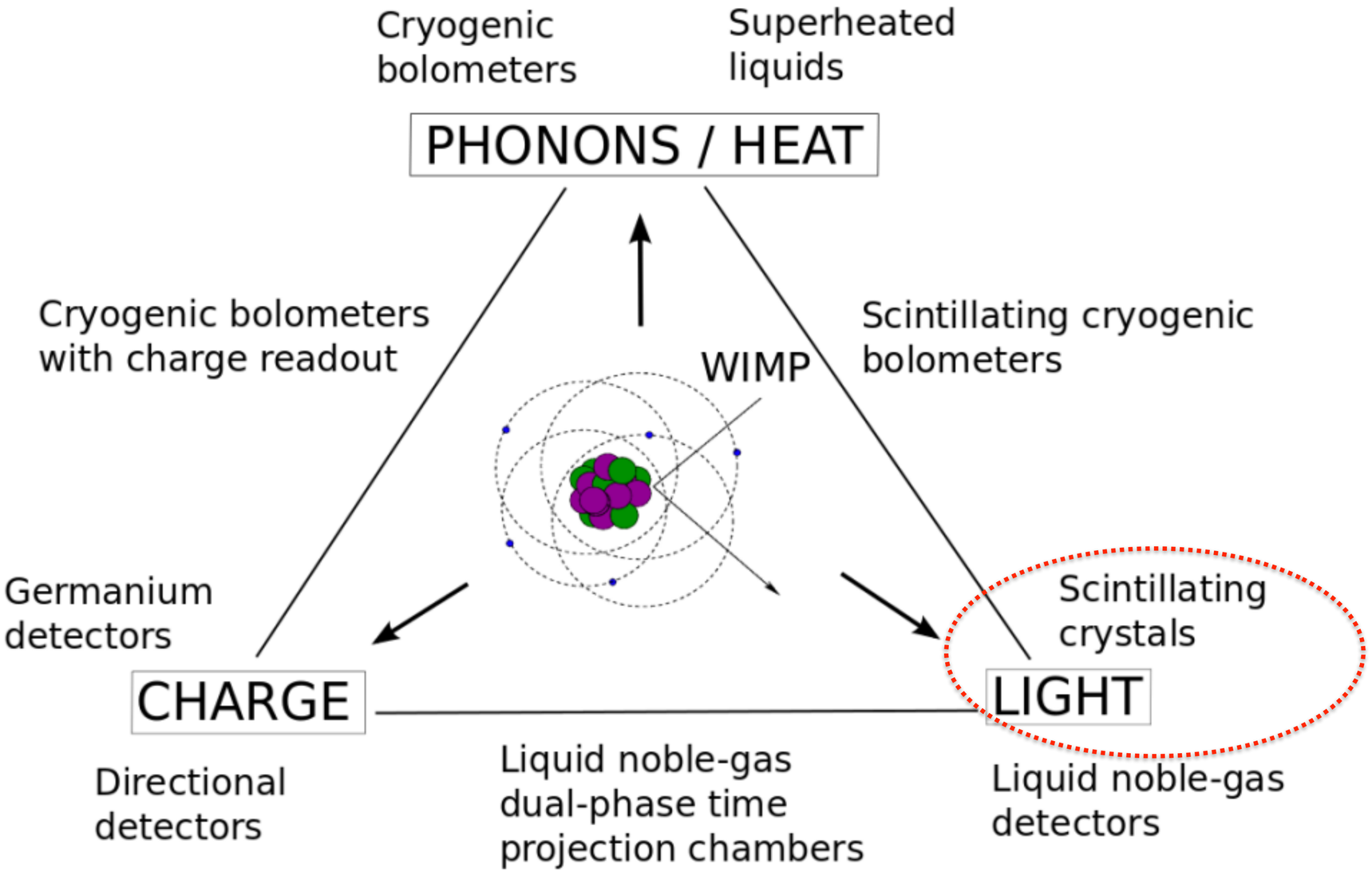
You Bet!

https://twitter.com/ktfreese/status/888730718477713408

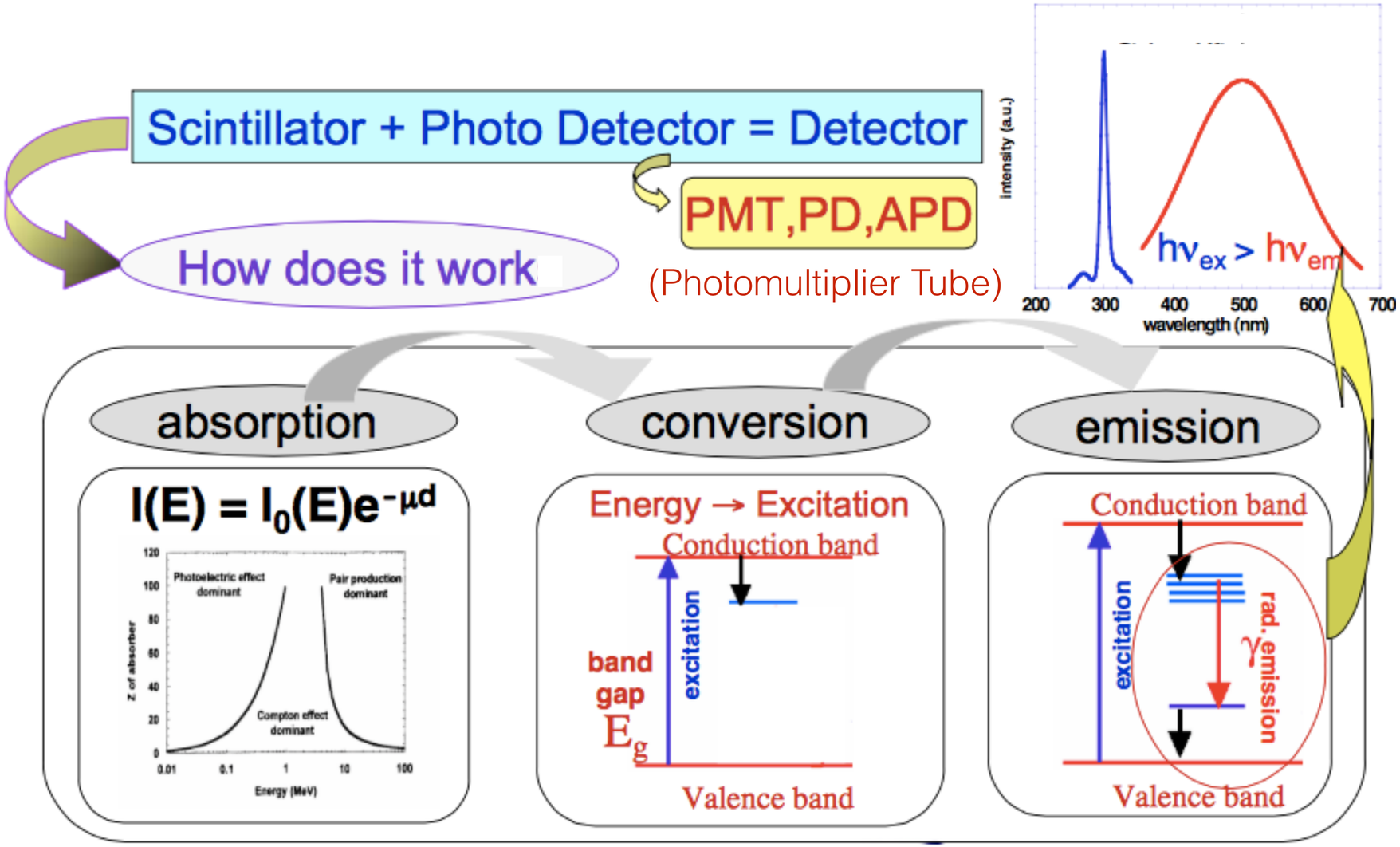
I have a bet with Frank Wilczek on status of DAMA dark matter detector in 5 years - Katie Freese

tweet on 7/22/2017

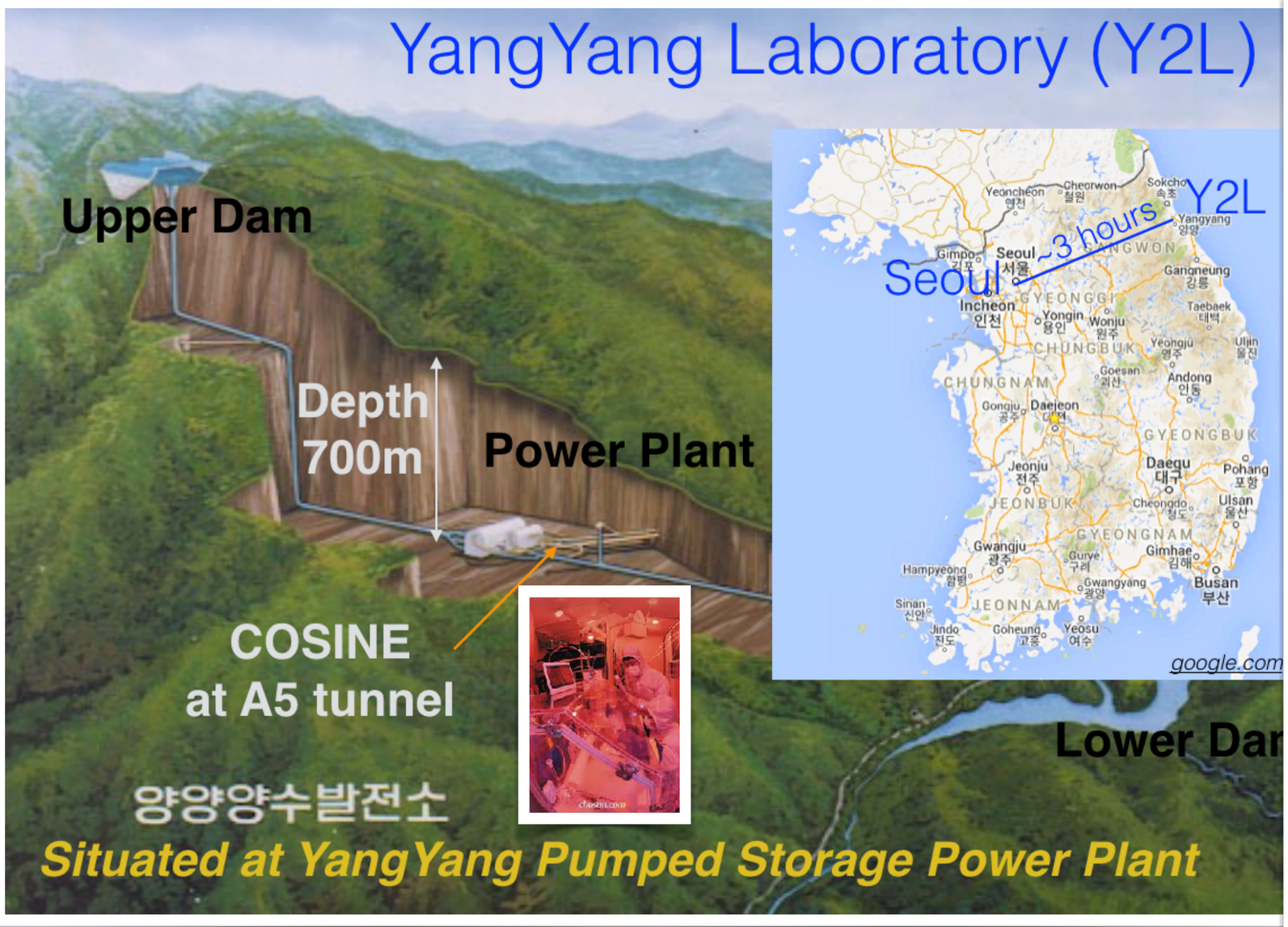
Dark Matter Detection Techniques



Target material : NaI(Tl) crystal scintillator
Goal : collect as much visible light as possible



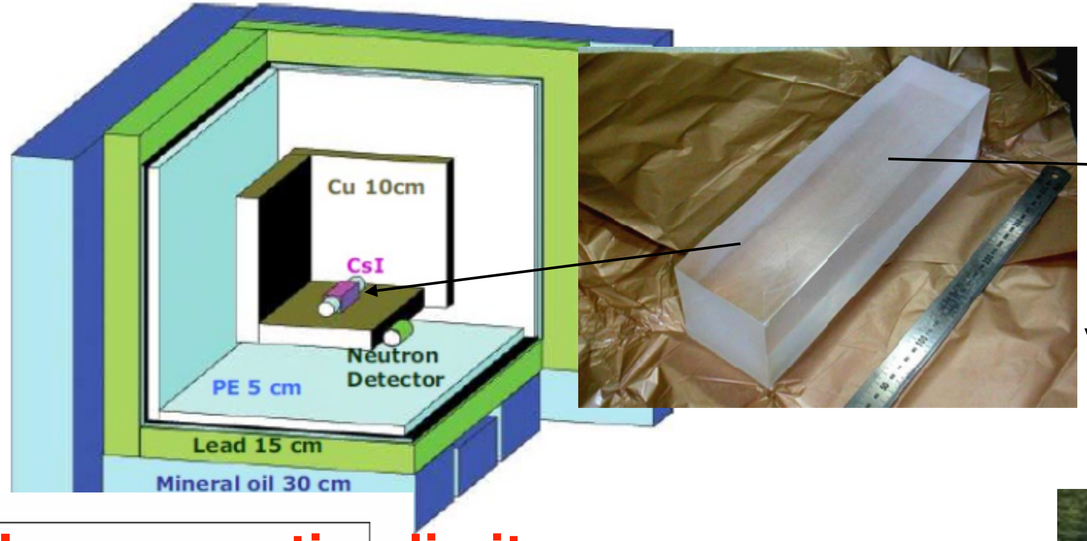
Yangyang underground lab





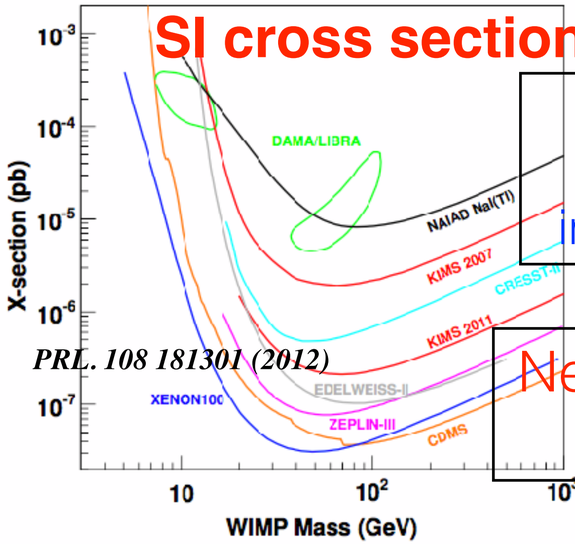
Korea Invisible Mass Search (KIMS) since 2000

12 CsI(Tl) 8.7 kg crystals (103 kg total)
Background level achieved at ~3 dru (counts/keV/kg/day) at 3 keV





SI cross section limit



PRL. 108 181301 (2012)

KIMS-CsI results
rejects DAMA signal
in WIMP-Iodine interactions

Need to investigate WIMP-Sodium interactions



The COSINE-100 Experiment

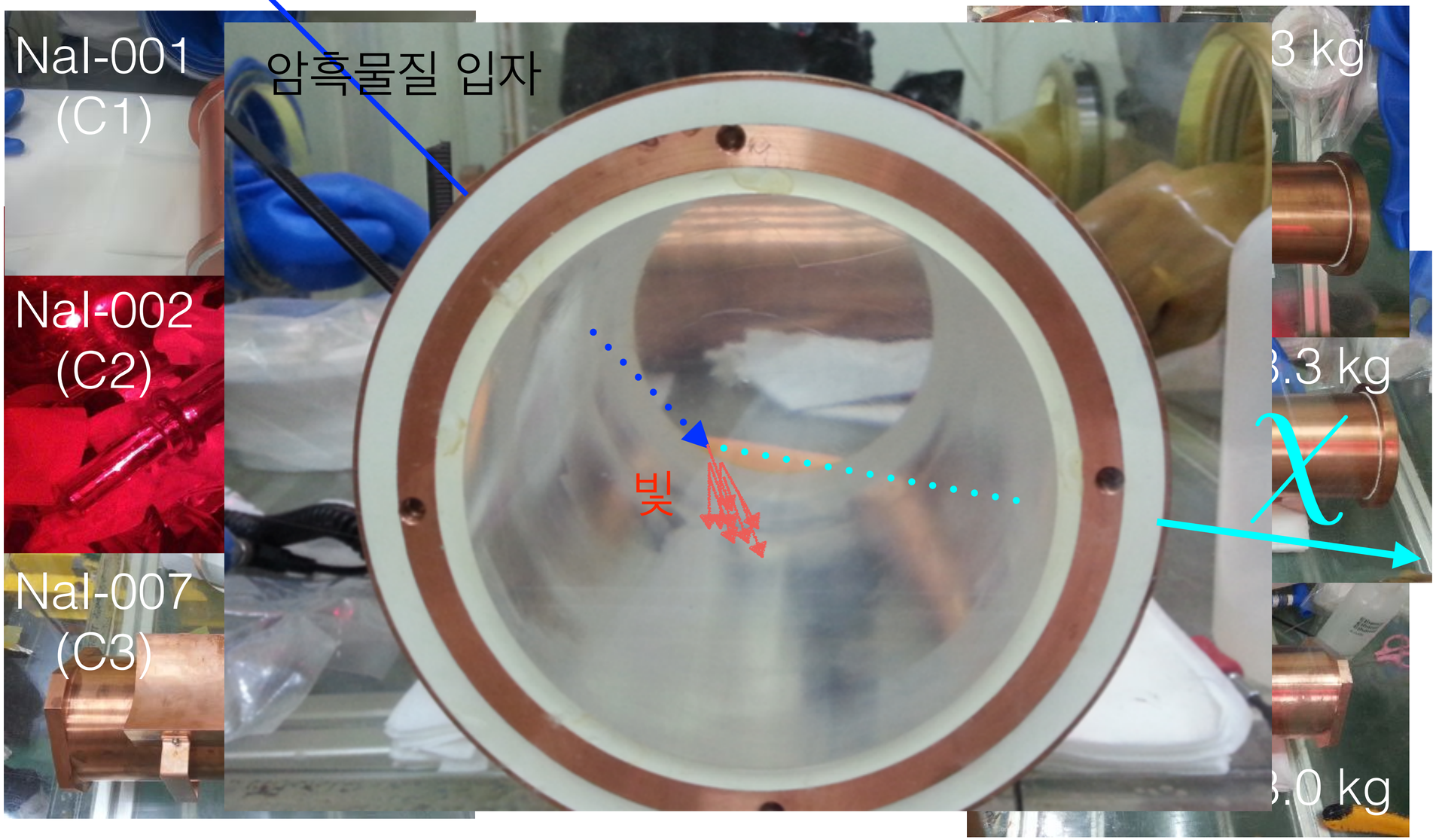
Joint collaboration between KIMS and DM-Ice to search for dark matter interactions in NaI(Tl) scintillating crystals.

KIMS Korea Invisible Mass Search Experiment + DM-ICE

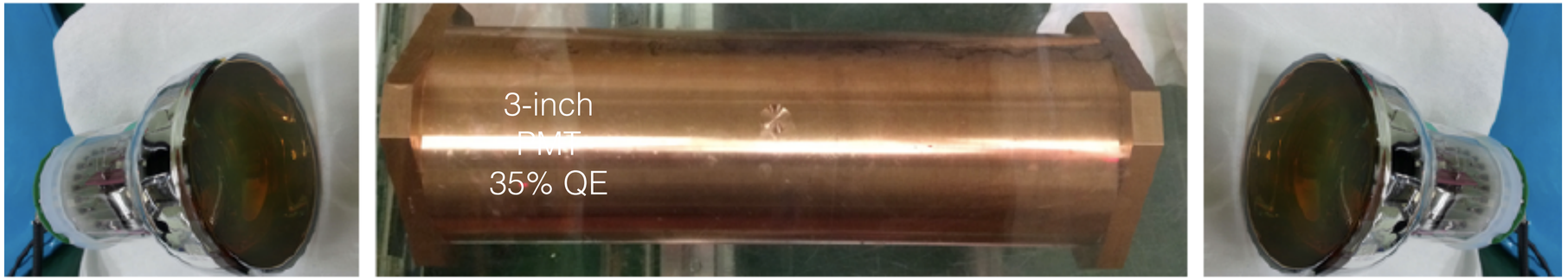
COSINE

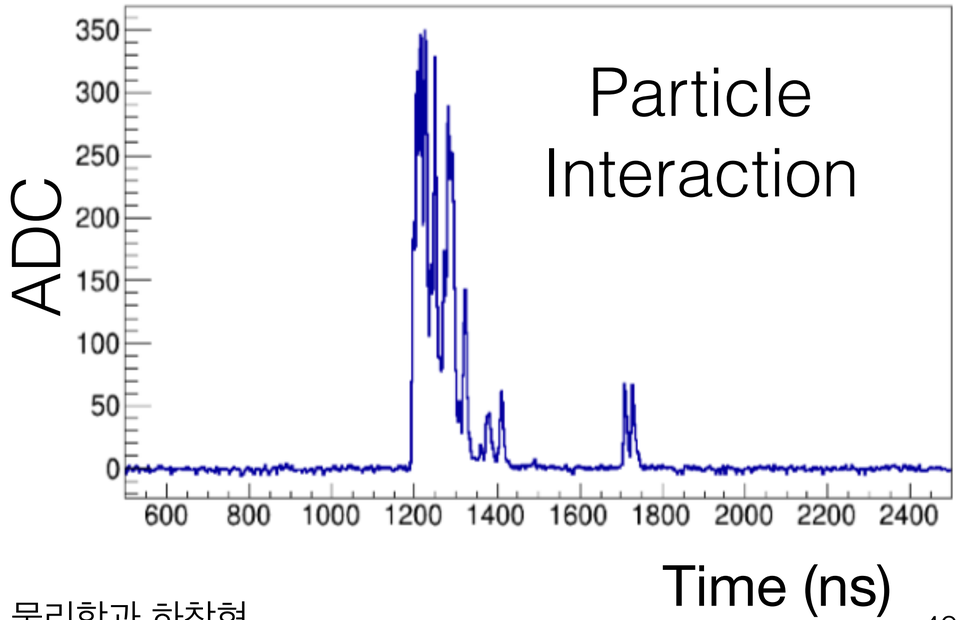
5 countries, 15 institutes
50 scientists

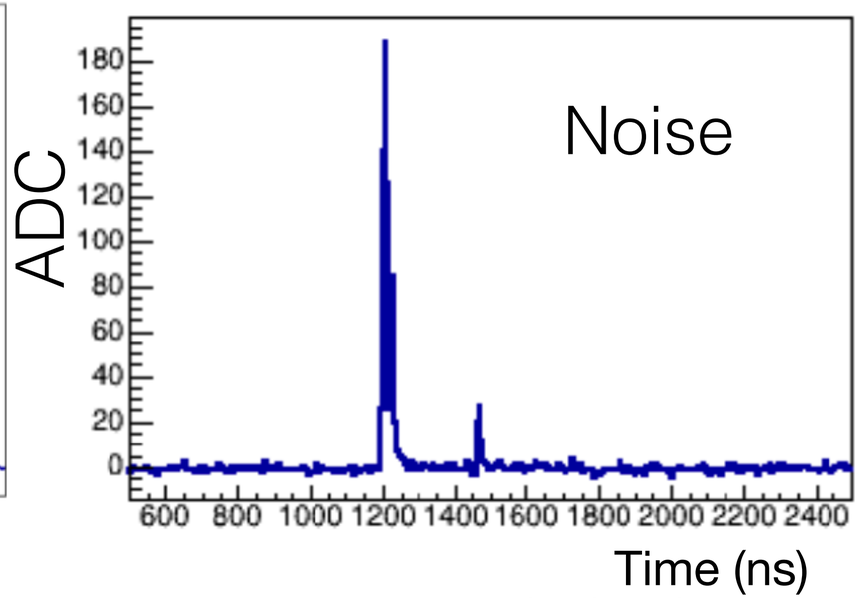
Dark matter target crystal (NaI)



Photomultiplier Tube (PMT)
(Event : a timestamped digital signal in a sensor)







COSINE-100 Construction Timeline

Dec. 2015



Jan. 2016



Feb. 2016





Mar. 2016



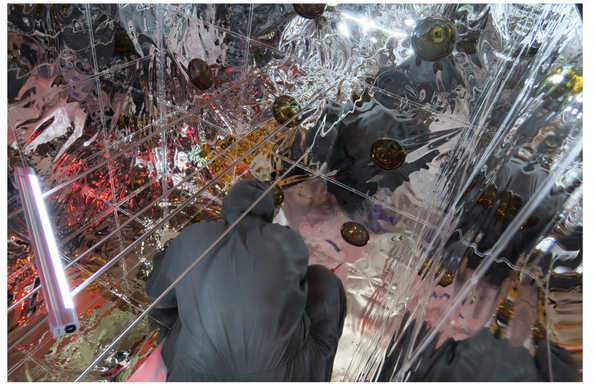
May. 2016



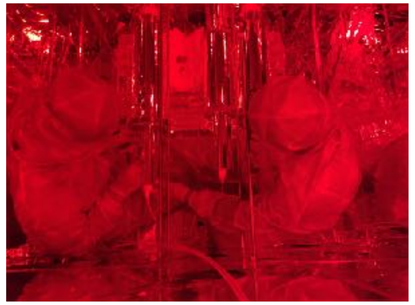
Jun. 2016



Apr. 2016

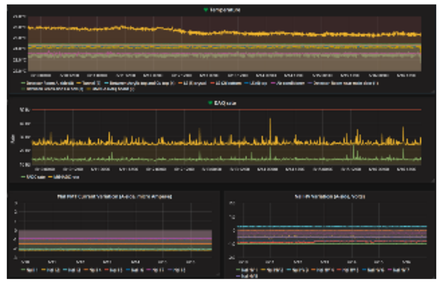


Sep. 2016







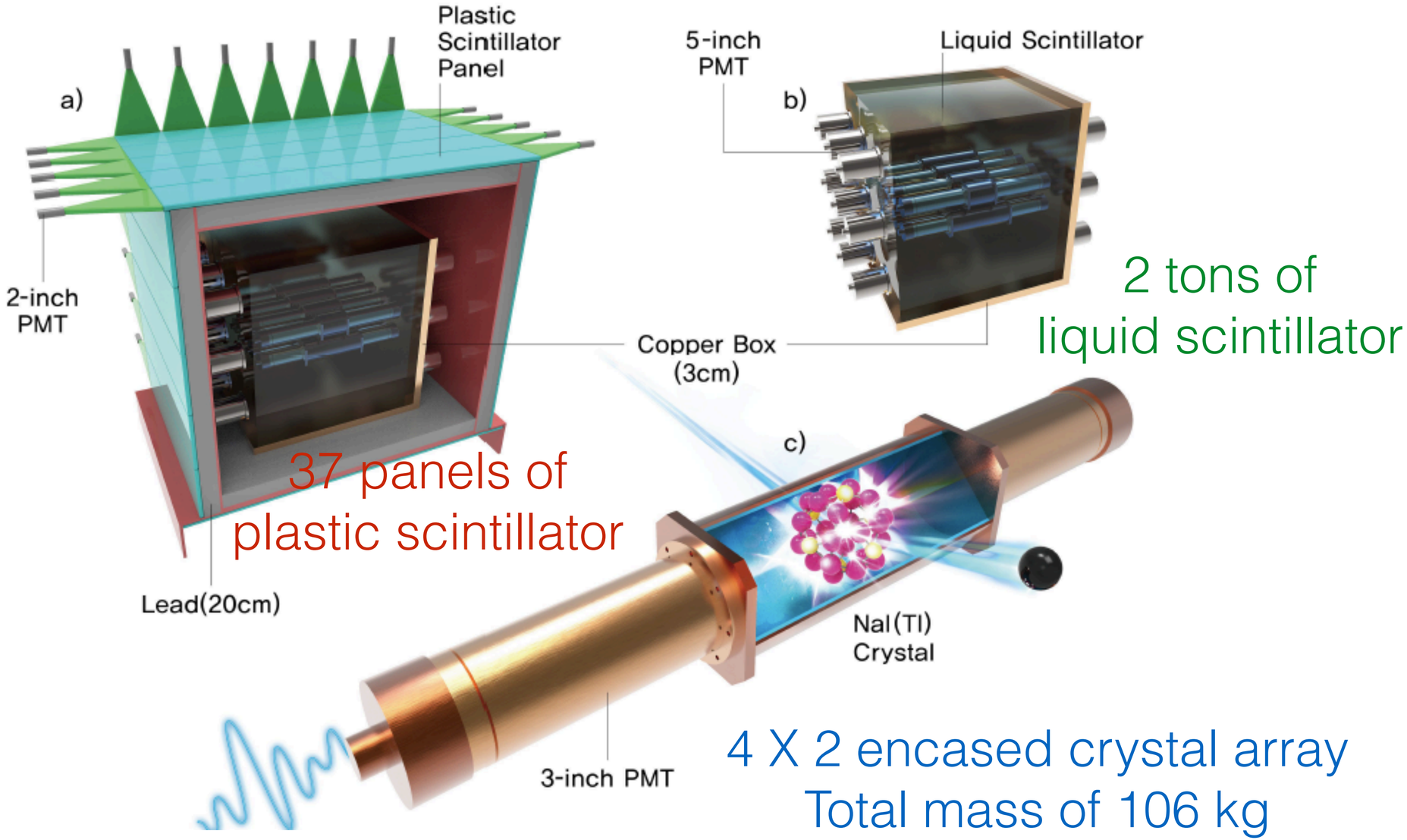


You want to analyze your heartbeat for a long term.



Simple Idea : You want to listen to the tiny signal —> Reduce background noise!

The COSINE-100 detector components

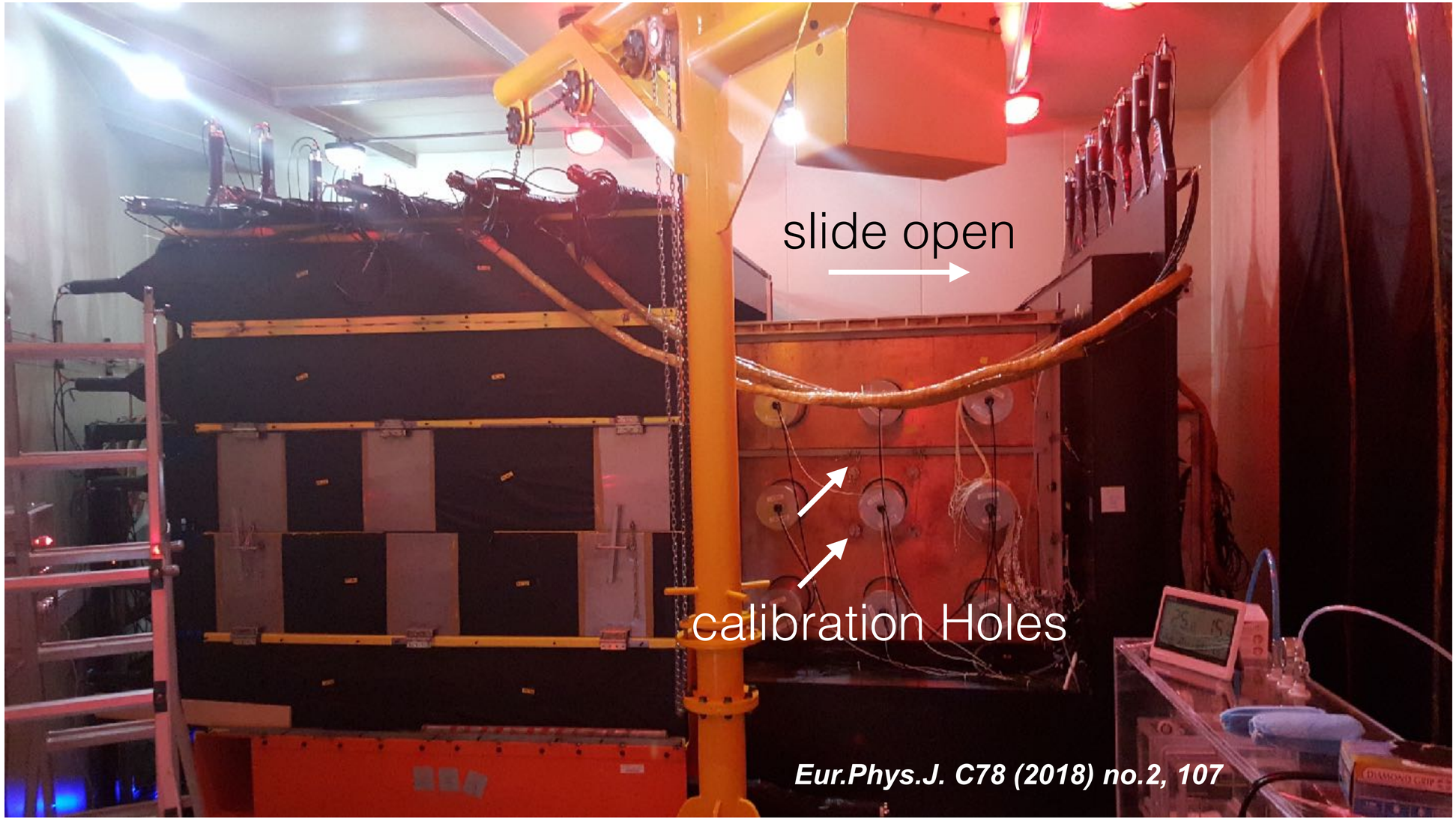


2 tons of
liquid scintillator

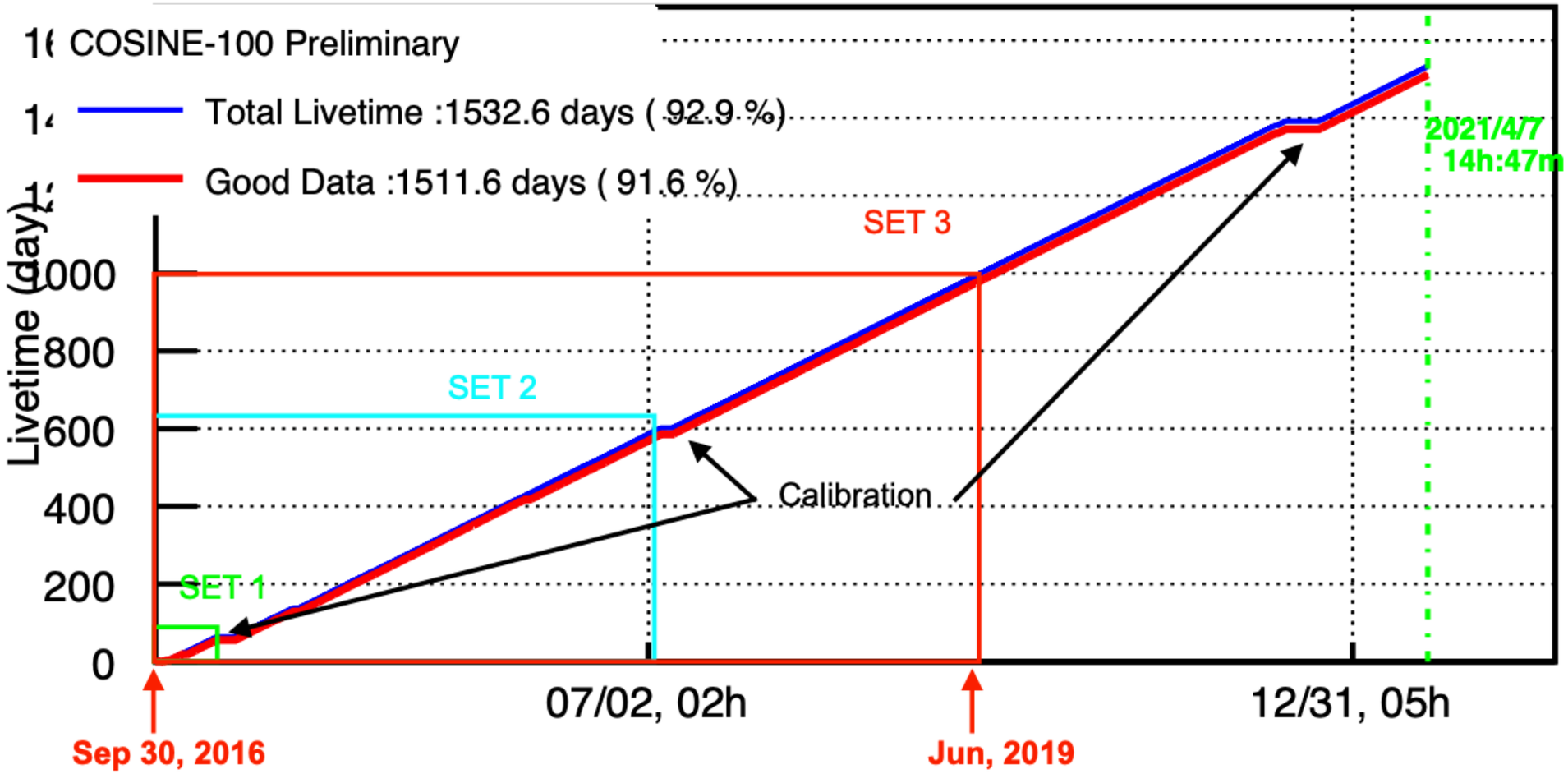
37 panels of
plastic scintillator

4 X 2 encased crystal array
Total mass of 106 kg

The COSINE-100 Detector

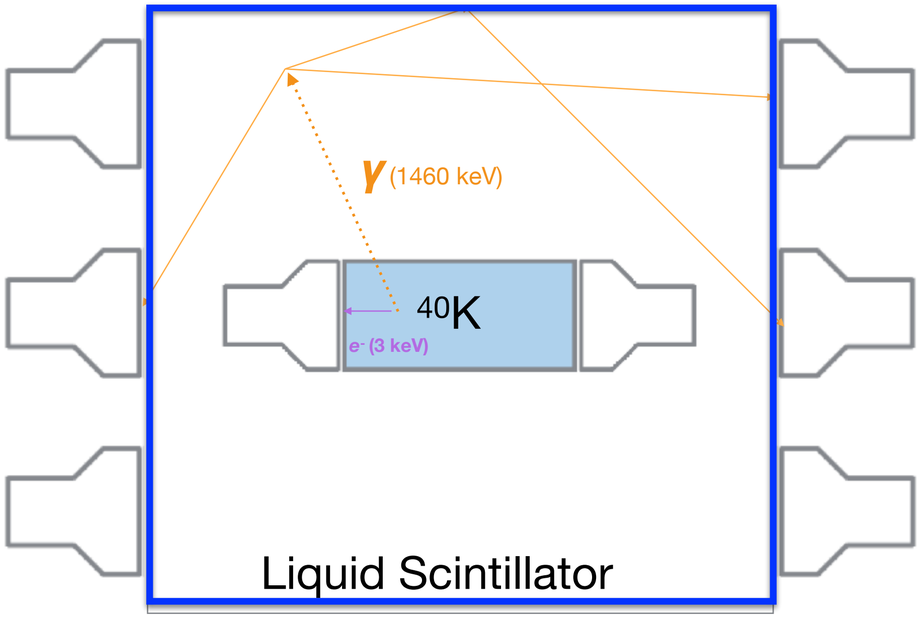


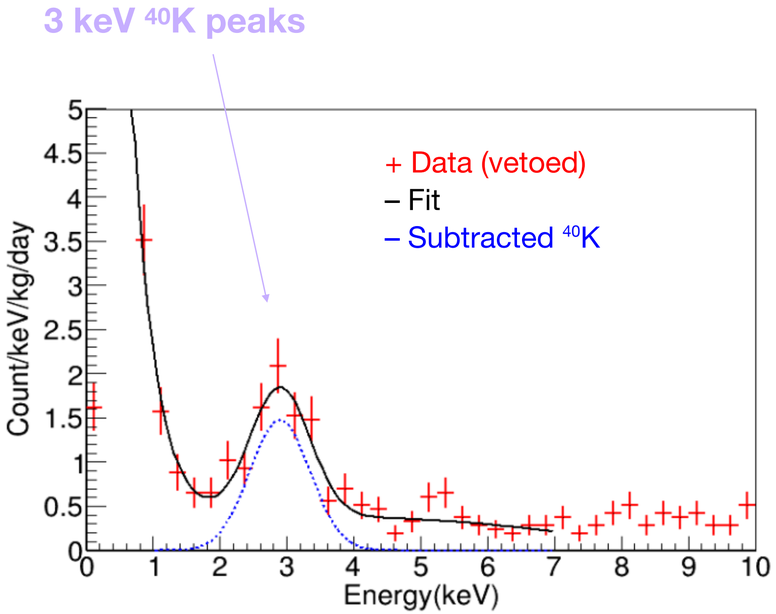
Exposure (Running for more than 5 years)

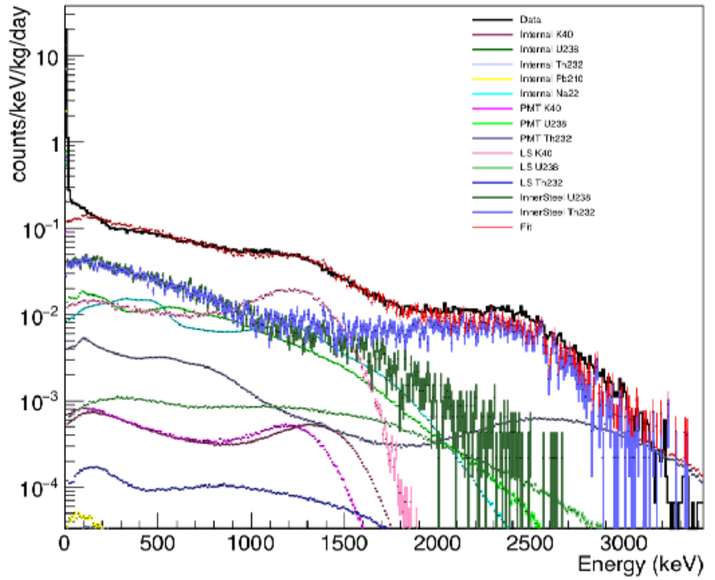


Stable running of the detector for 5 years. Good runs are more than 90%

Crystal-LS coincidence

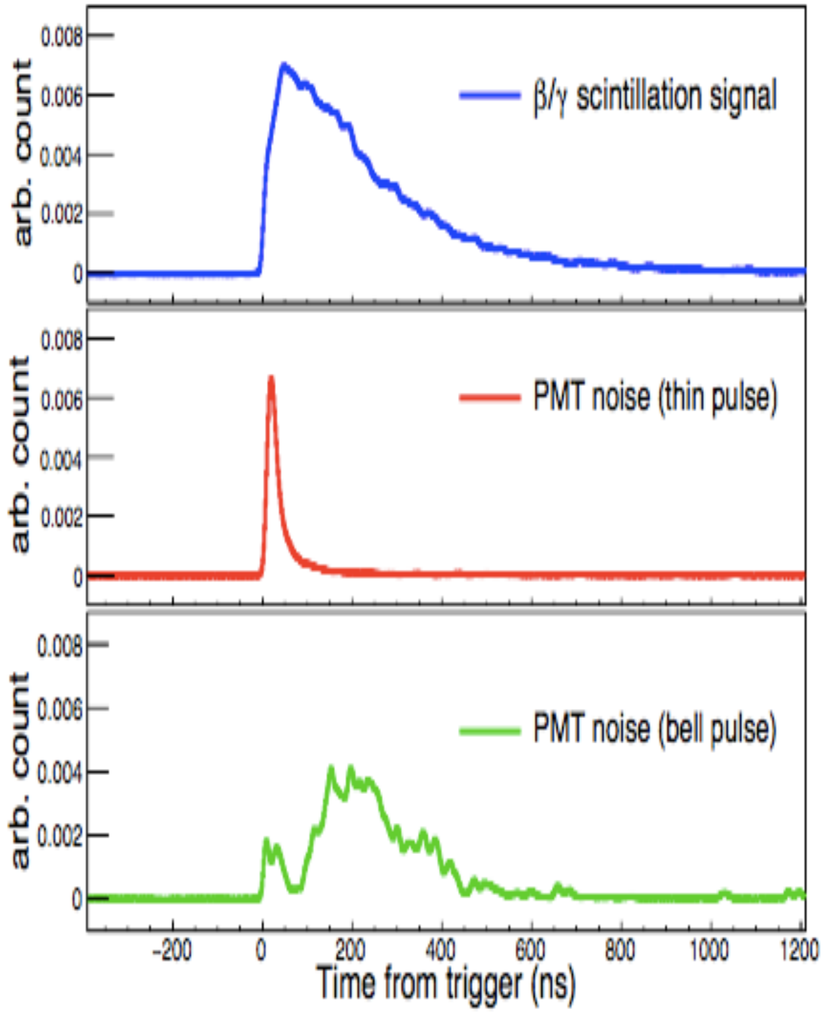


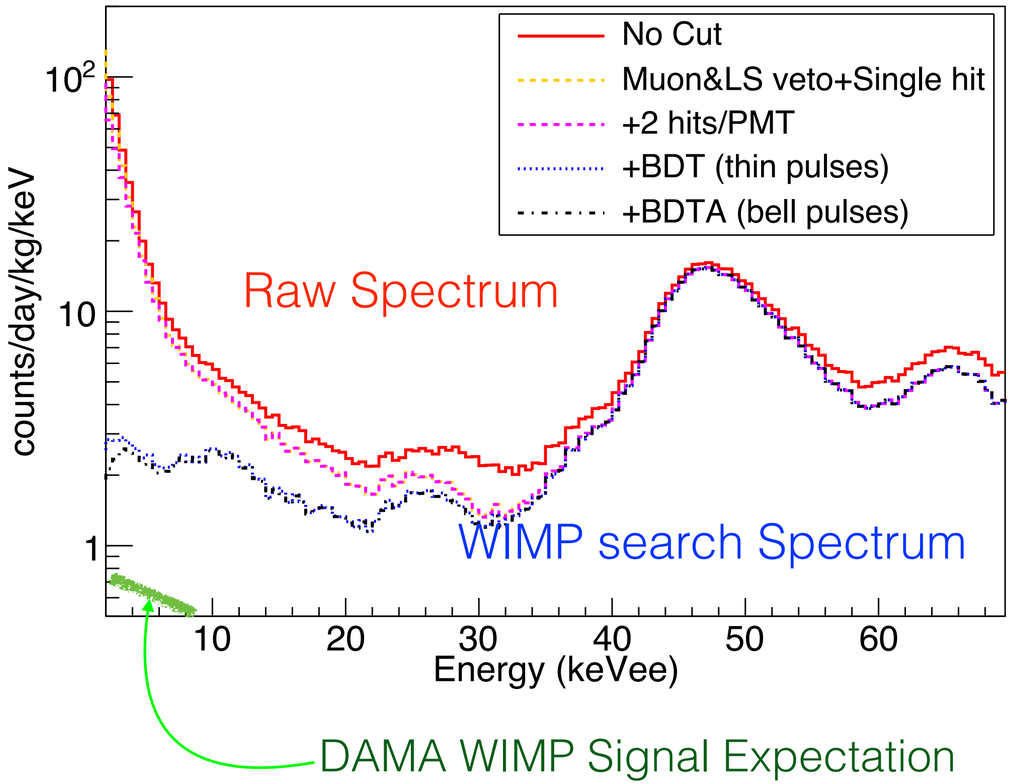




- Liquid scintillator light is passively read out when there is a trigger in a crystal.
- A crystal trigger with LS energy deposit larger than 80 keV is defined as multiple hit events.
- ^{40}K emits 1460 keV gamma with 3 keV Auger electron energy deposition in NaI crystal
- Tagging 1460 keV events with LS enables **vetoing of 3 keV background events (70-80%)**
- Liquid scintillator internal contamination well modeled with simulation

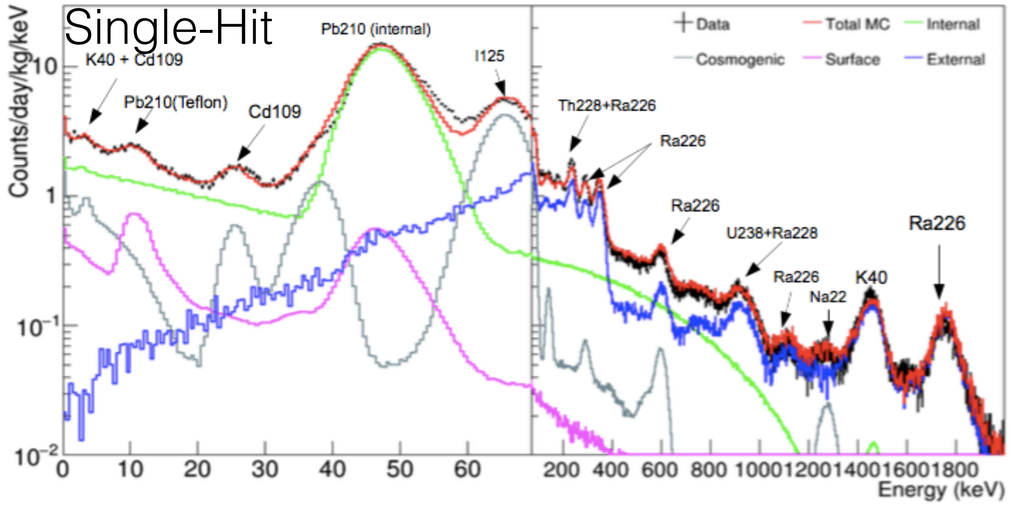
PMT noise reduction
Every experiment has noise and WIMP search=Noise Reduction

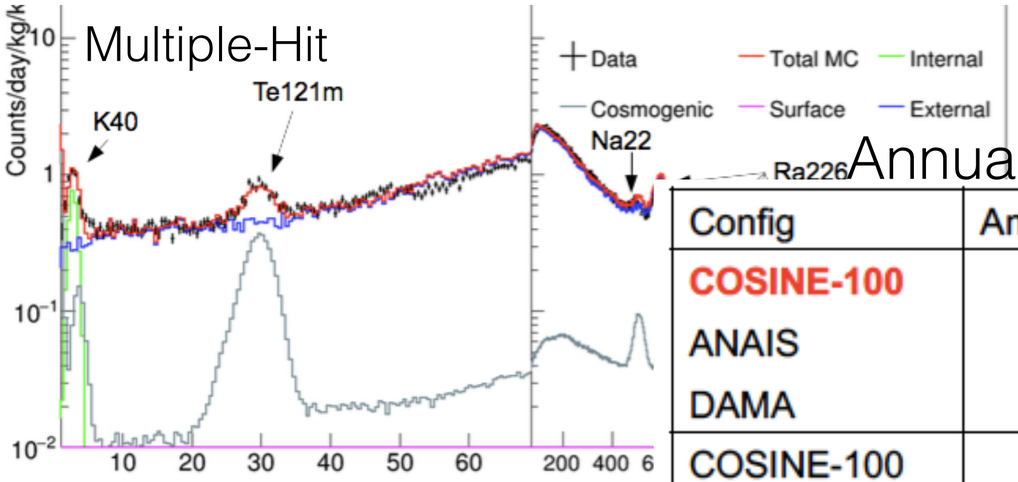




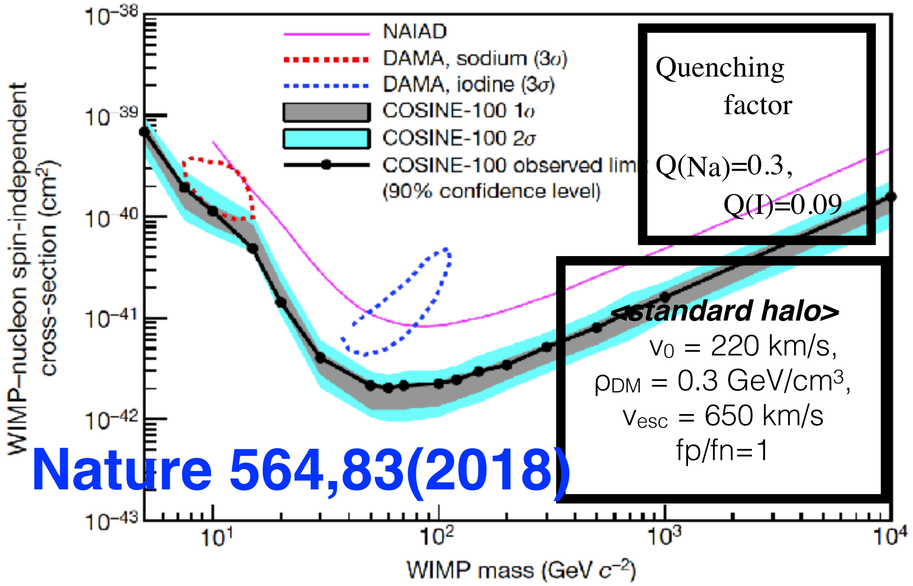
1. Constant Rate Analysis
2. Annual Modulation Analysis

COSINE-100
(2-keV Threshold Analyses)



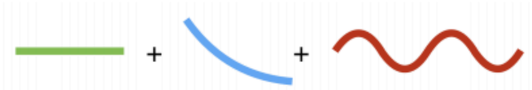


EPJC 78, 490 (2018)



Nature 564,83(2018)

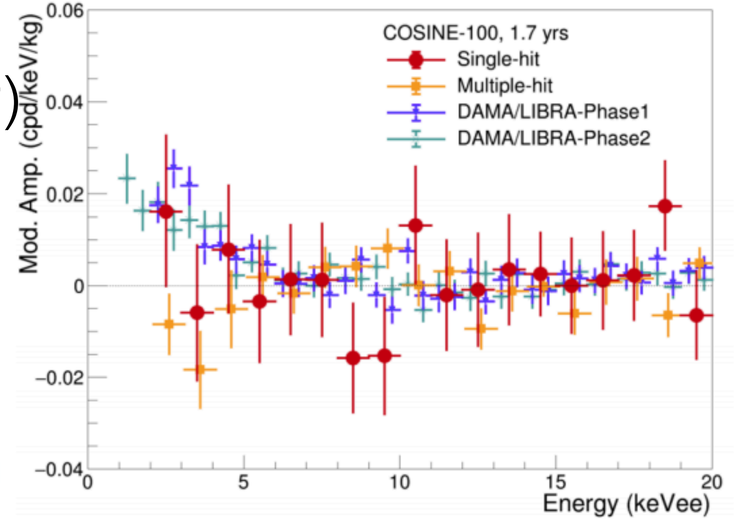
Offset + Exponential + Cosine is fit to data at 2-6 keV.



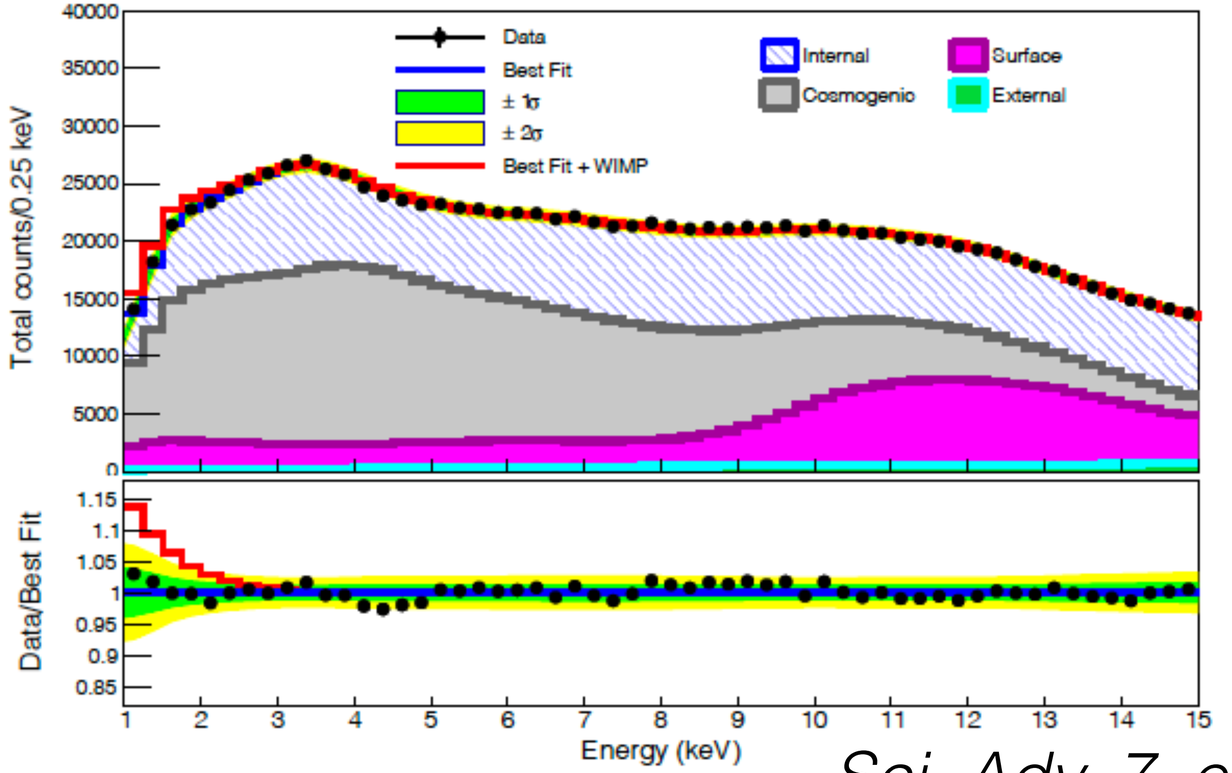
PRL 123,031302 (2019)

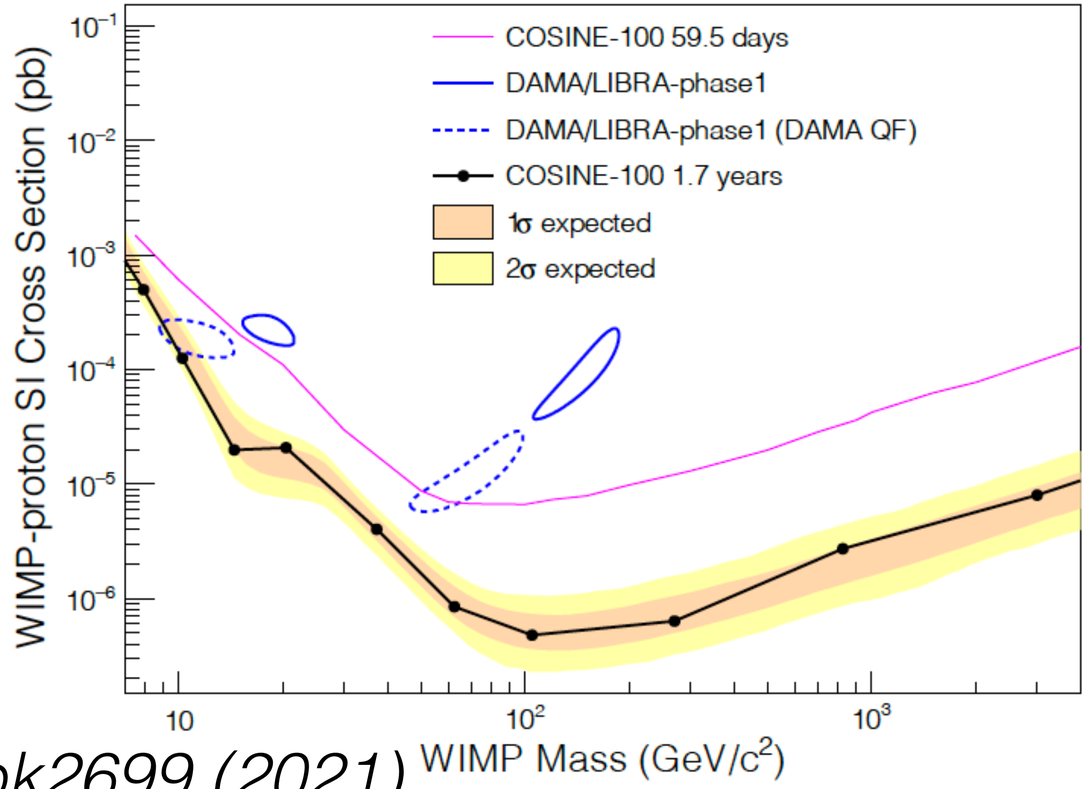
Annual Modulation Analysis(1.7 yr)

Config	Amplitude (2-6 keV)	Phase (days)
COSINE-100	0.0083 ± 0.0068	152.5 (fixed)
ANAIS	-0.0044 ± 0.0058	152.5 (fixed)
DAMA	0.0095 ± 0.0008	152.5 (fixed)
COSINE-100	0.0092 ± 0.0067	127 ± 46
DAMA	0.0096 ± 0.0008	145 ± 5



Constant Rate Analysis with 1-keV threshold (1.7 yr)

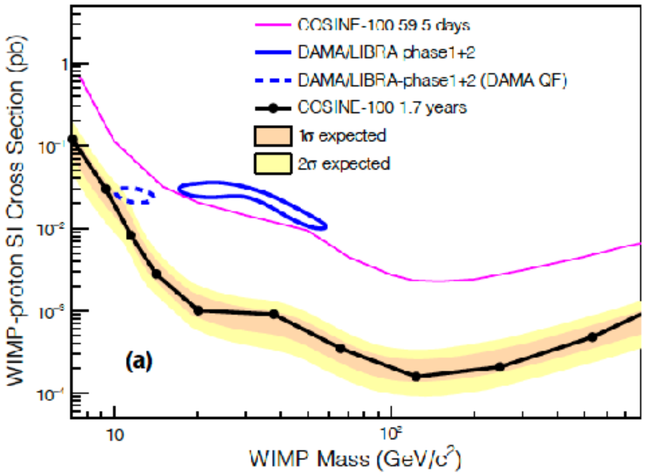


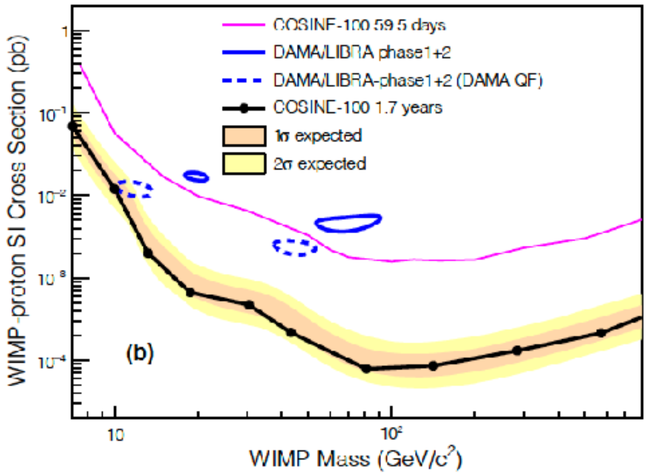


Sci. Adv. 7, eabk2699 (2021)

A factor of 10 improved result compared to the first result

Constant Rate Analysis with 1-keV threshold (1.7 yr)

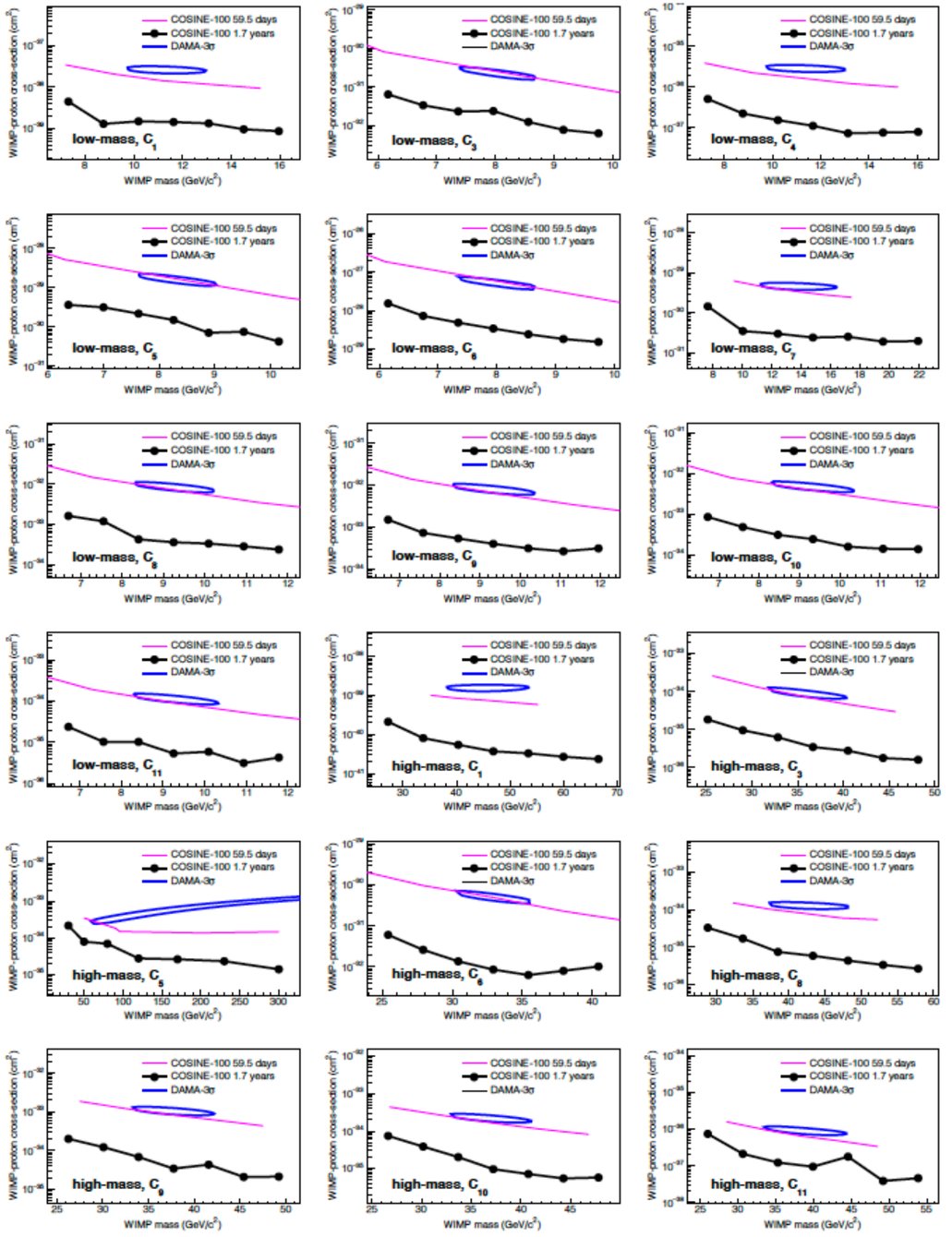




Sci. Adv. 7, eabk2699 (2021)

Additionally, we checked alternative hypotheses for isospin-violating cases and EFT operators with the same threshold and the updated quenching factors as DAMA/LIBRA.

We find, in general, those are incompatible with COSINE-100 data. There is no excess of events over the expected background, that can be interpreted as DAMA's annual modulation signal under the assumption of dark matter interactions based on the Standard Halo Model.

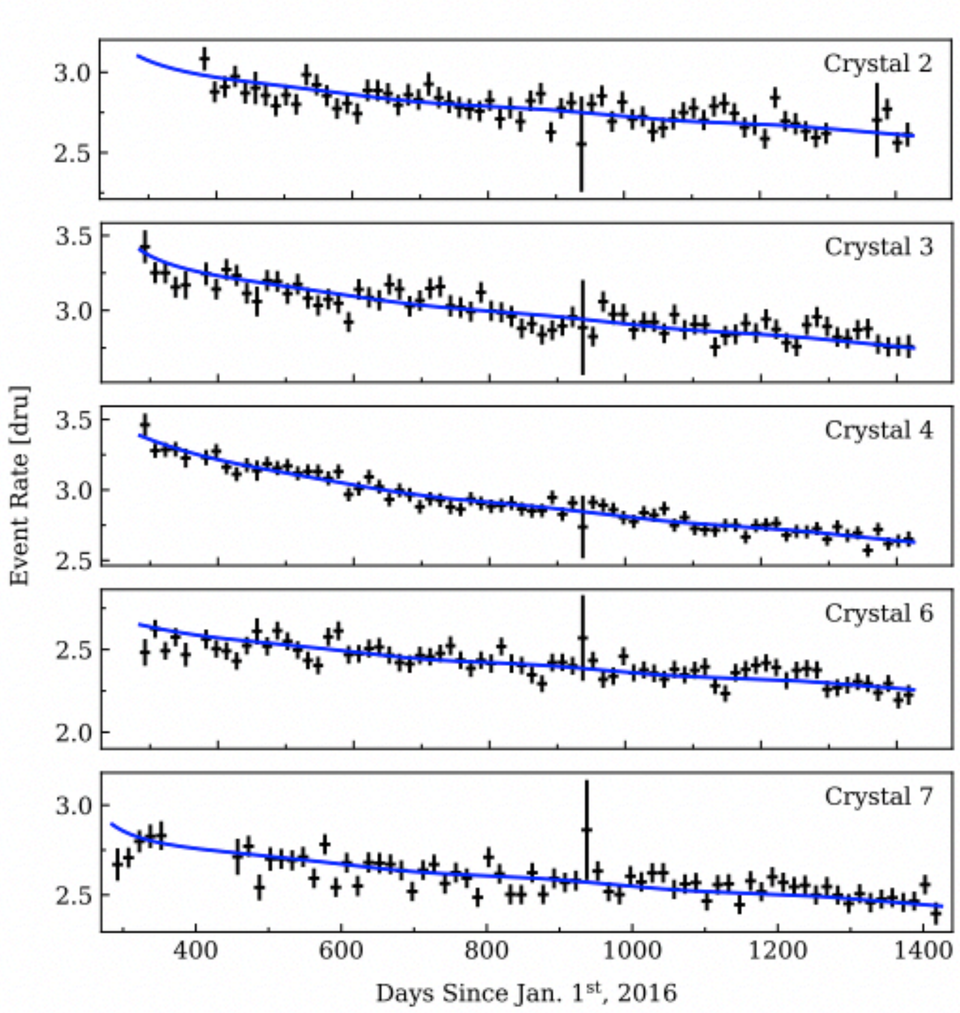


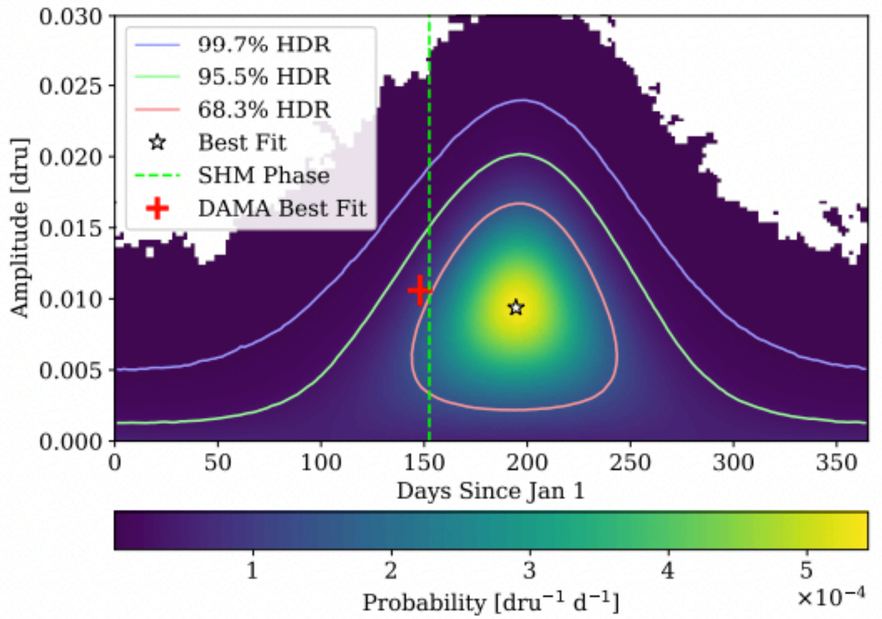
Annual Modulation Analysis with 1-keV threshold (3 yr)

https://arxiv.org/abs/2111.08863

Better Modeling of Backgrounds

Better Pseudo experiments





COSINE-100 Results : 0.0067±0.0042 dru

DAMA/LIBRA : 0.0106 ±0.0011 dru

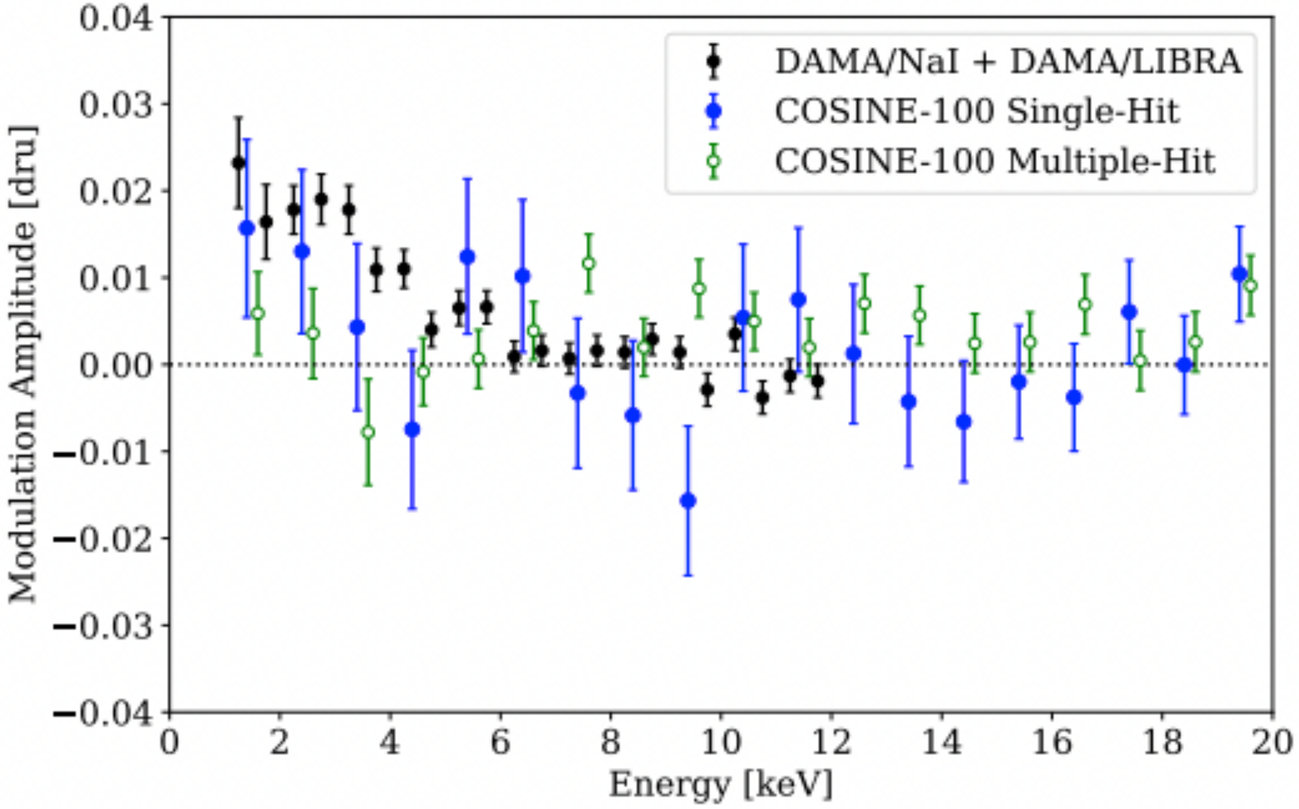
Keep pounding! Need more data! Need better crystals!

Annual Modulation Analysis with 1-keV threshold (3 yr)

https://arxiv.org/abs/2111.08863

Better Modeling of Backgrounds

Better Pseudo experiments



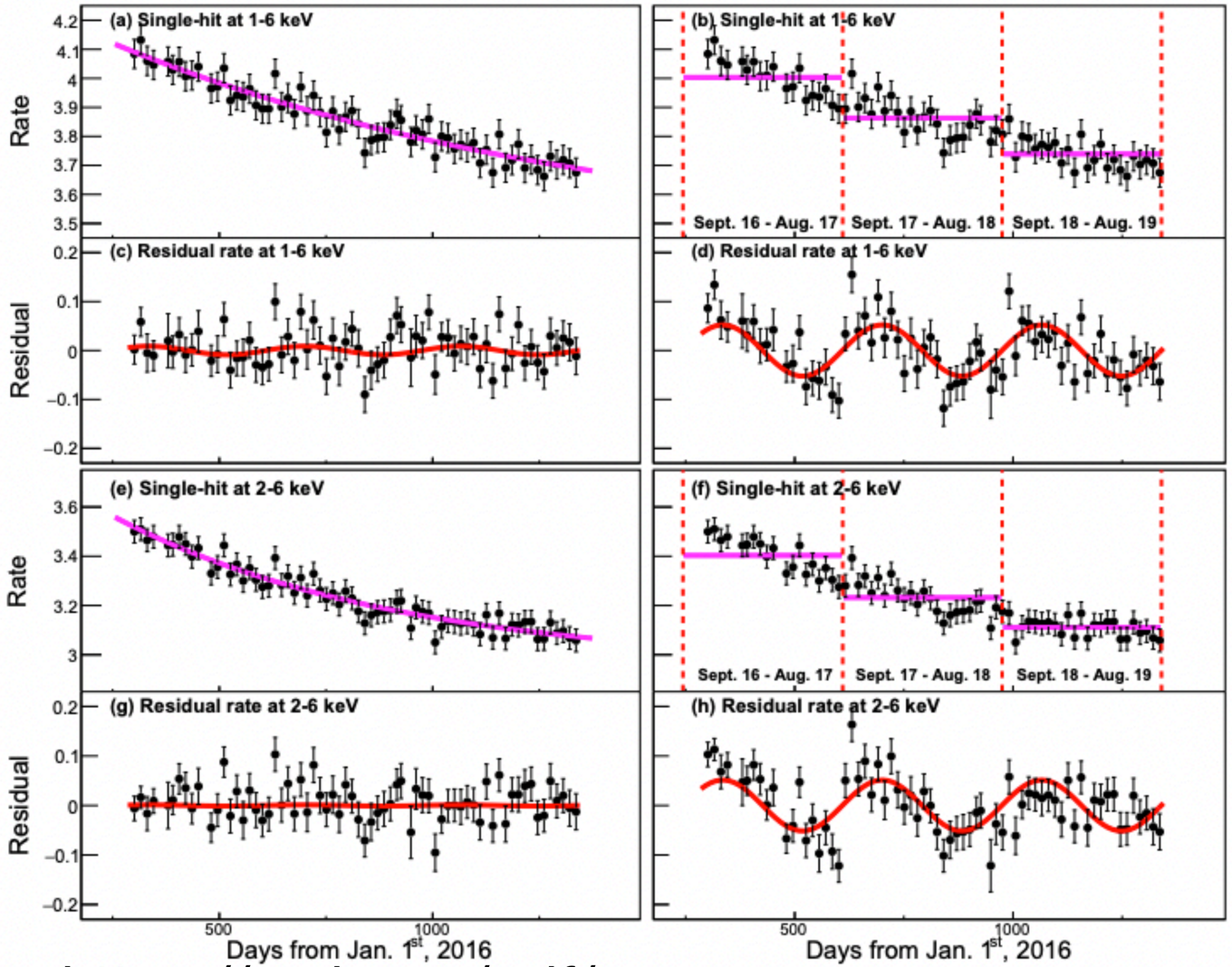
Configuration	Amplitude [dru]	Phase [days]
COSINE-100 1–6 keV (This result)	0.0067±0.0042	152.5 (fixed)
COSINE-100 2–6 keV (This result)	0.0050±0.0047	152.5 (fixed)
COSINE-100 2–6 keV (2019 result [14])	0.0083±0.0068	152.5 (fixed)
ANAIS 1–6 keV (2021 result [16])	-0.0034±0.0042	152.5 (fixed)
ANAIS 2–6 keV (2021 result [16])	0.0003±0.0037	152.5 (fixed)
DAMA/LIBRA 1–6 keV (phase2 [7])	0.0105±0.0011	152.5 (fixed)
DAMA/NaI+LIBRA 2–6 keV [7]	0.0102±0.0008	152.5 (fixed)
COSINE-100 1–6 keV (This result)	$0.0094^{+0.0073}_{-0.0072}$	$194.5^{+49.0}_{-50.5}$
COSINE-100 2–6 keV (This result)	$0.0061^{+0.0064}_{-0.0061}$	Unconstrained
COSINE-100 2–6 keV (2019 result [14])	0.0092±0.0067	127.2±45.9
DAMA/LIBRA 1–6 keV (phase2 [7])	0.0106±0.0011	148±6
DAMA/NaI+LIBRA 2–6 keV [7]	0.0103±0.0008	145±5

COSINE-100 Results : 0.0067±0.0042 dru

DAMA/LIBRA : 0.0106 ±0.0011 dru

Keep pounding! Need more data! Need better crystals!

DAMA-like Analysis

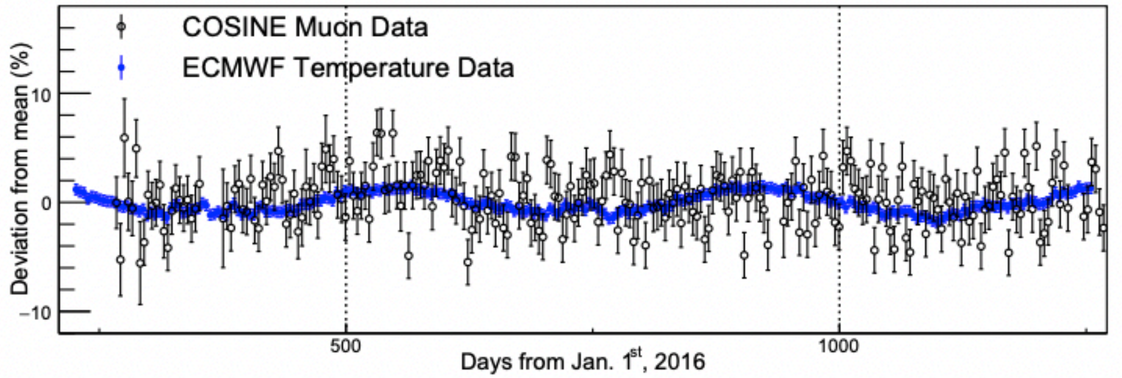


https://arxiv.org/pdf/2208.05158.pdf

Negative Amplitude

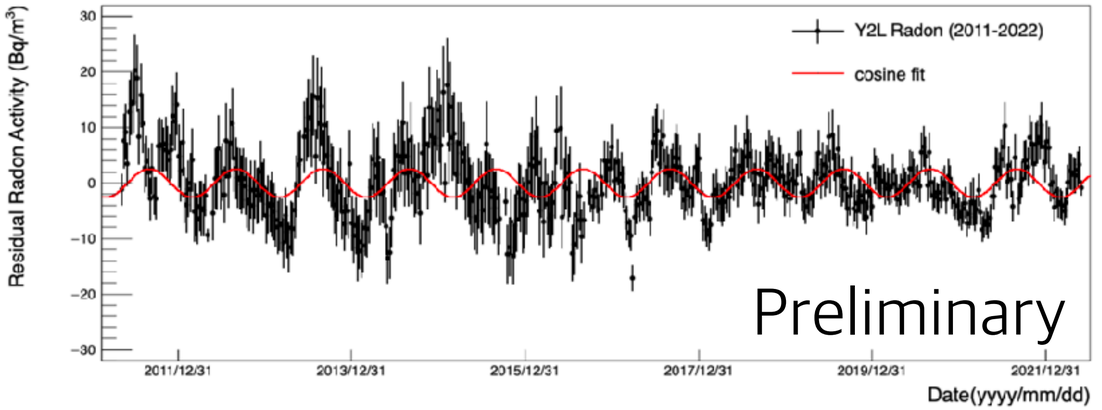
CR Muon Modulation

JCAP 2 (2021) 013



Max : July 1st

Radon Modulation



Max : August 31st

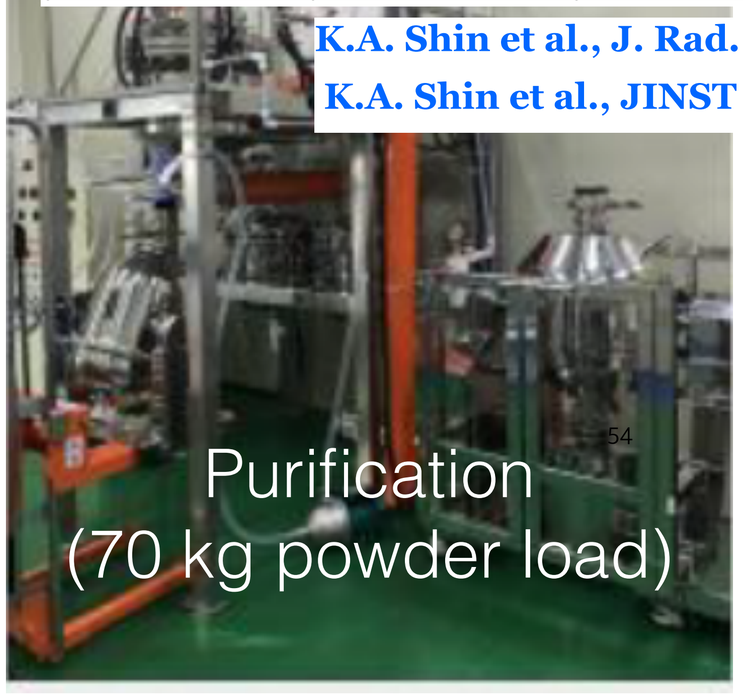
중앙대학교 물리학과 하창현

COSINE-200 Preparations (much work done in Korea)

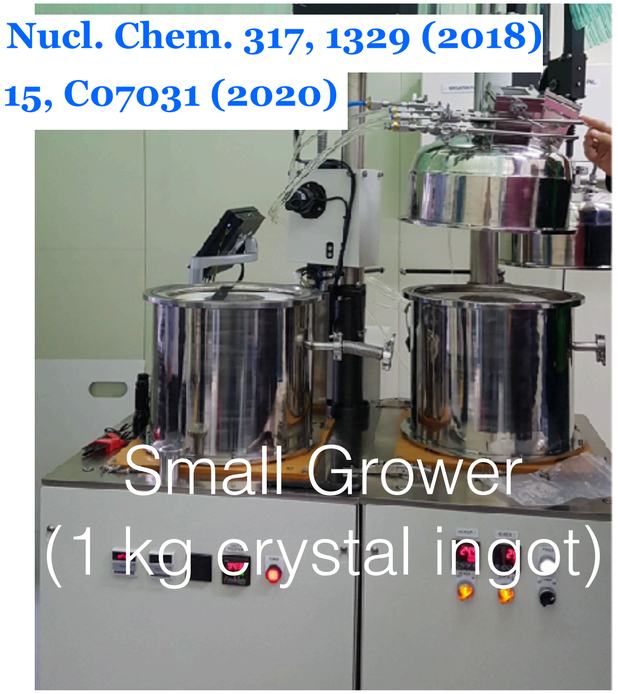
Powder Purification

	K (ppb)	Pb (ppb)	U (ppb)	Th (ppb)
Initial NaI	248	19.0	<0.01	<0.01
Purified NaI	<16	0.4	<0.01	<0.01

K.A. Shin et al., J. Rad. Nucl. Chem. 317, 1329 (2018)
K.A. Shin et al., JINST 15, C07031 (2020)



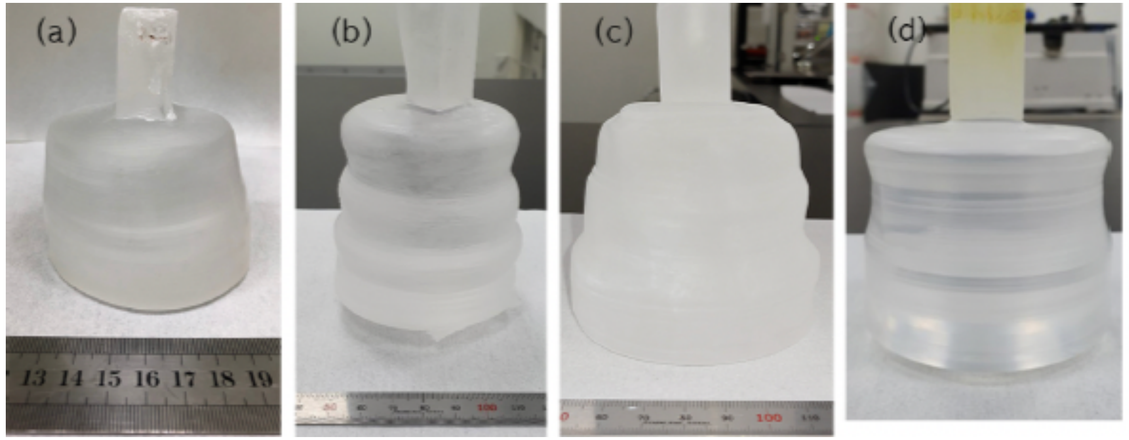
Purification
(70 kg powder load)

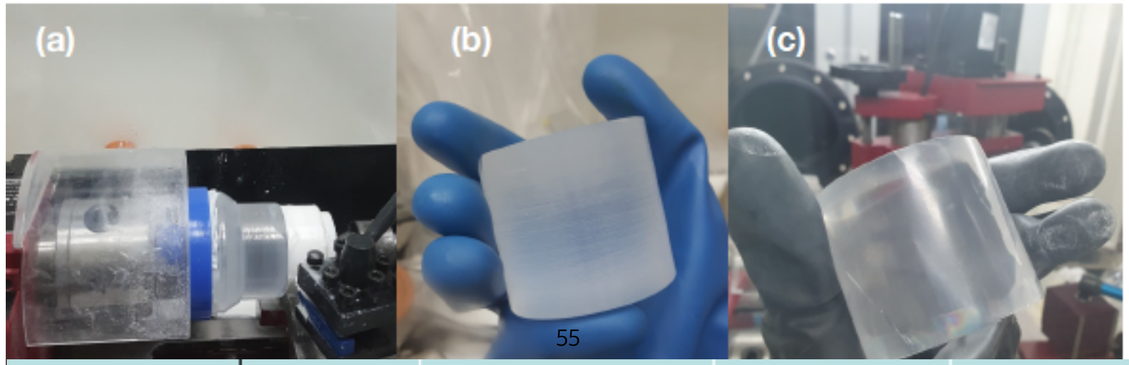

Small Grower
(1 kg crystal ingot)


Full-sized Grower
(100 kg crystal ingot)

Background rate should be less than 1 dru (DAMA)

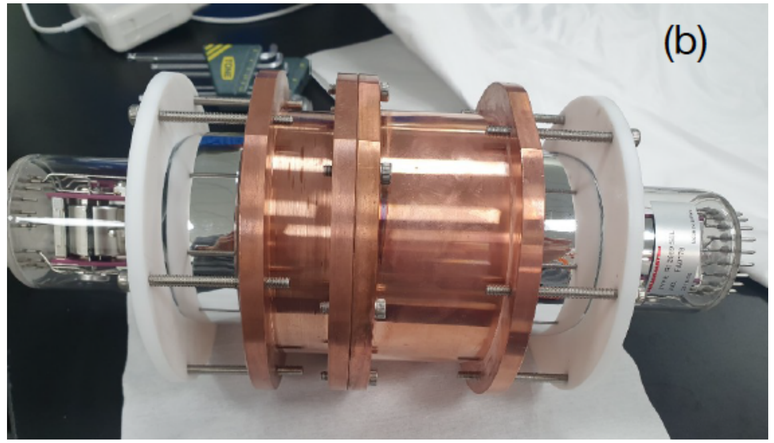
Prototype NaI(Tl) crystal detector

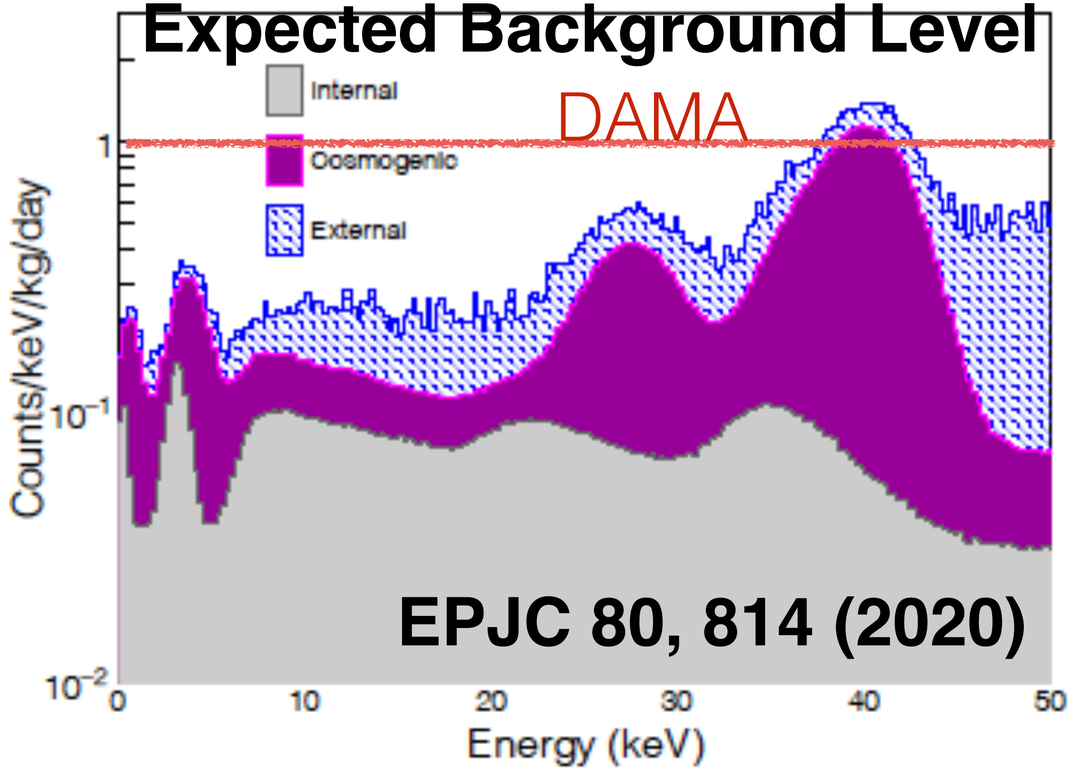




55

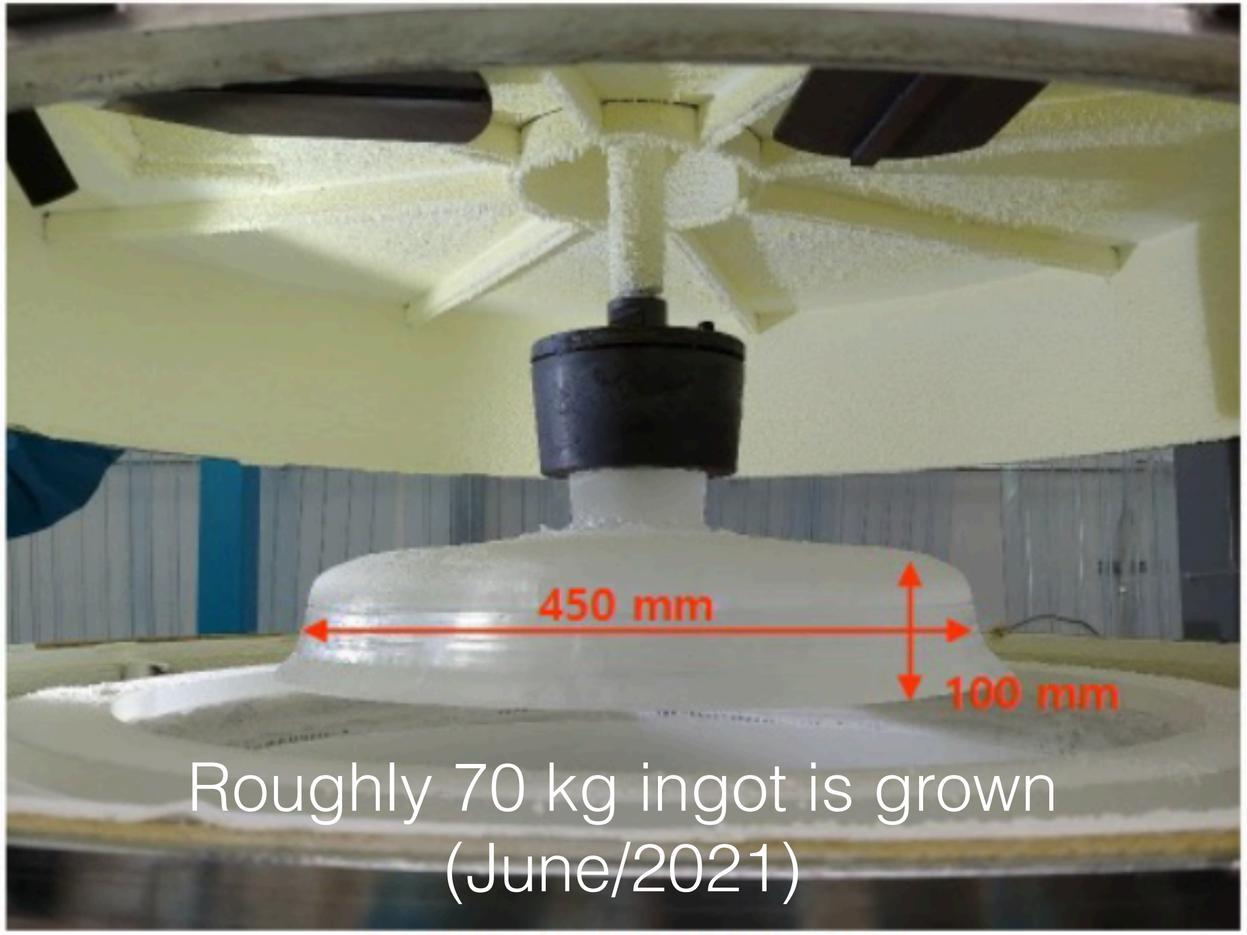
	K (ppb)	^{210}Pb (mBq/kg)	^{238}U (μBq/kg)	^{232}Th(μBq/
Powder	5	-	<20	<20
Aug/2018	684	3.8+/-0.3	26+/-7	<6
Sept/2019	**8**	**0.01+/-0.02**	**11+/-4**	**7+/-2**
DAMA	<20	0.01~0.03	8.7~124	2~31





Large Size NaI(Tl) crystal growth at CUP

Test growing without Thallium doping



Roughly 70 kg ingot is grown
(June/2021)

195 kg NaI Merck Powder loaded

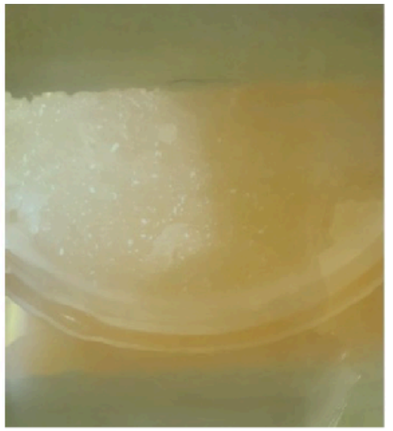












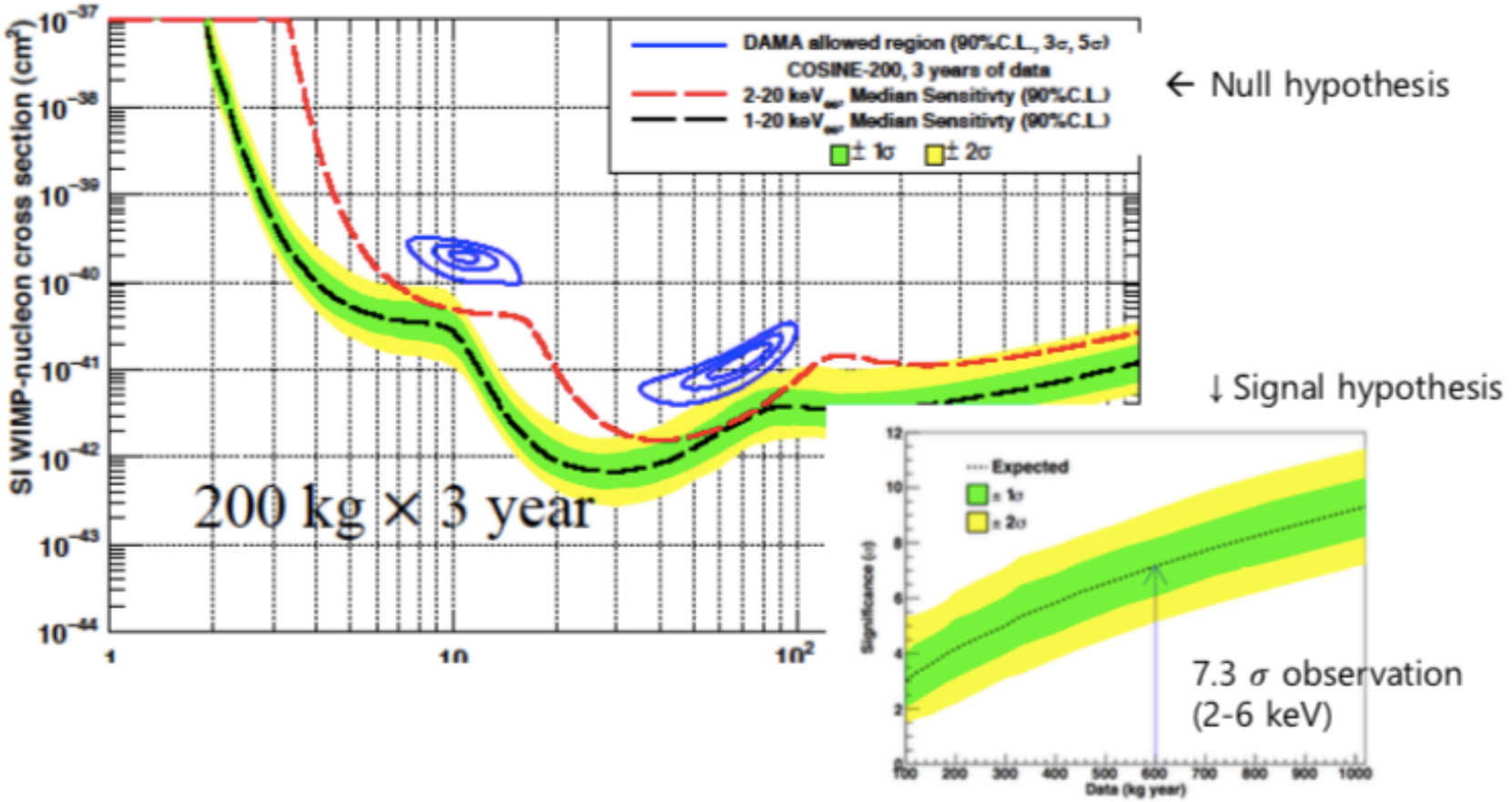
Sequence of crystallization

In-house Crystal growing starts working. Large-size Tl-doped and low-bkg crystal growth is the next step.

COSINE-200 (starting 2022)

- 1 counts/day/kg/keV background assumed (same as DAMA/LIBRA)

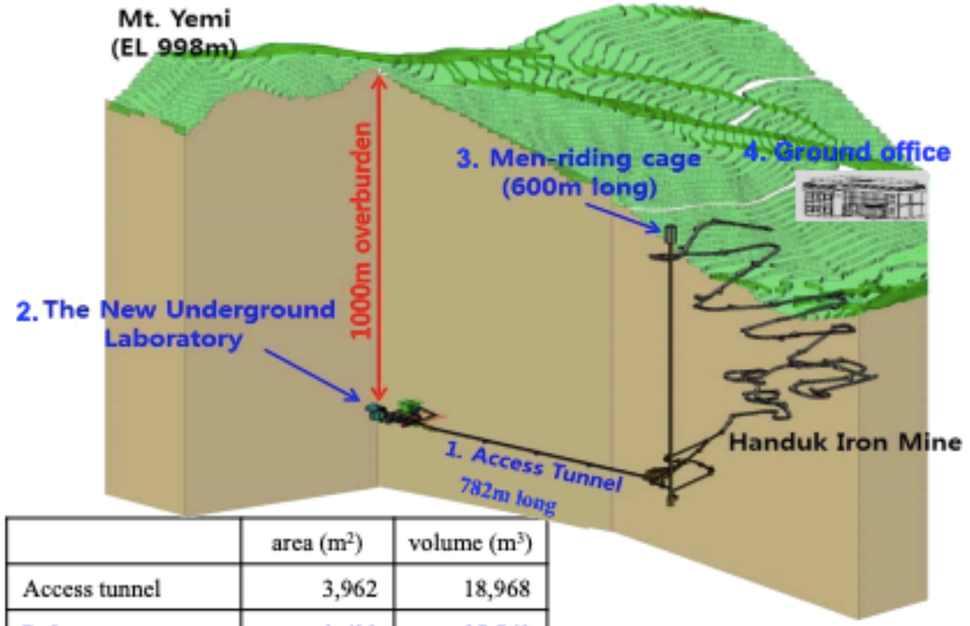
Annual Modulation Analysis



We have been preparing 200 kg experiment (COSINE-200) using better crystals with lower background

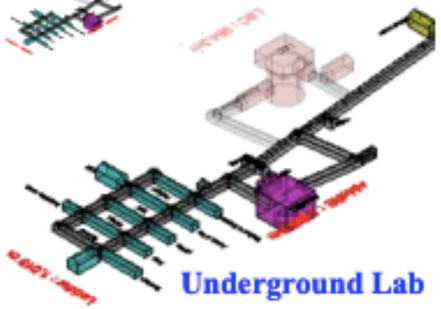
Yemilab Status

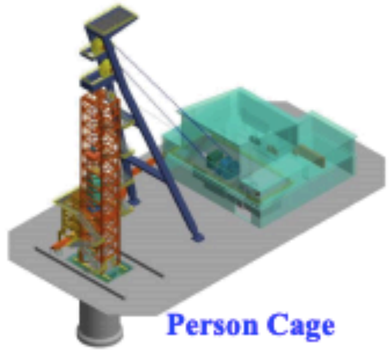
1. **Access Tunnel**, 782 m long with 12% down slope
2. **Underground Lab.** with 2600 m^2
3. **Person Cage**, running vertical 587 m
4. **Ground Office** with 2500 m^2



	area (m^2)	volume (m^3)
Access tunnel	3,962	18,968
Lab space	**2,600**	**25,562**
Connecting tunnel	4,847	14,161
amount	**11,525**	**58,691**

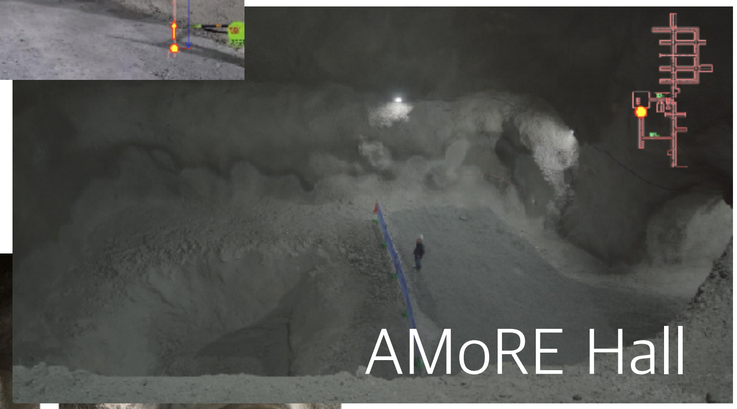


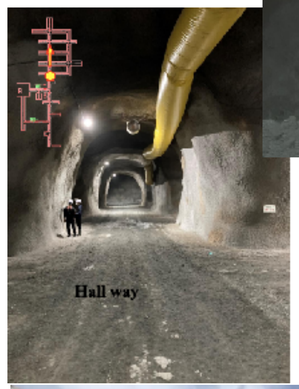
















The ground office exterior



The reinforcement

Some more photos of the tunnel


Cage


Tunnel


AMoRE Hall

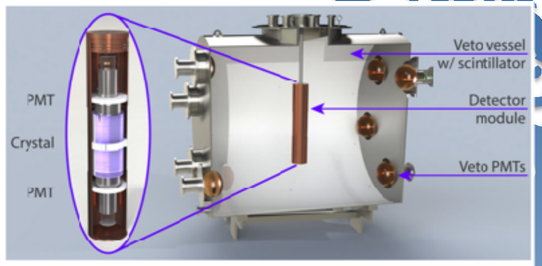

AMoRE Hall


COSINE Hall



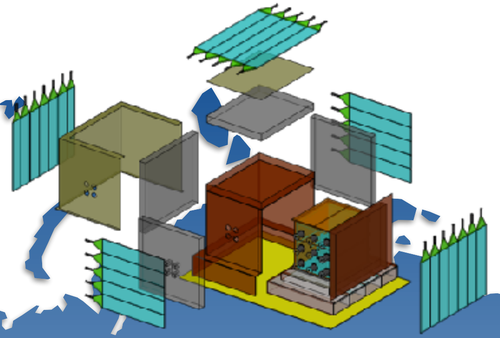

AMoRE Pit

Global NaI(Tl) efforts

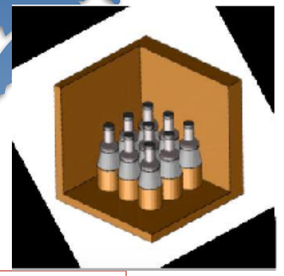


DAMA/LIBRA @ LNGS

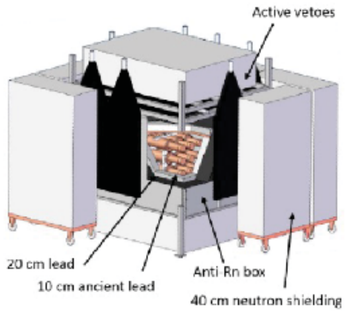
SABRE @ LNGS



COSINE-100 @ Y2L

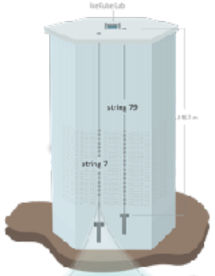


PICO-LON @ Kamioka

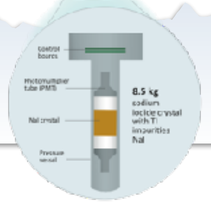


ANAIS @ Canfranc

SABRE @ Stawell



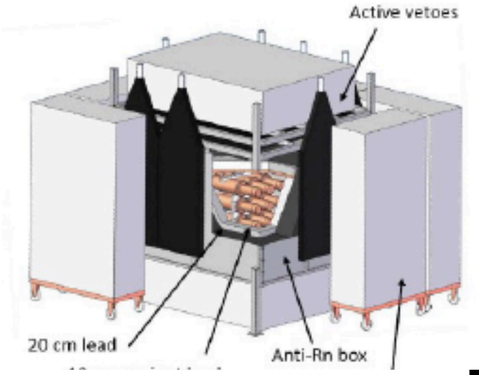
DM-Ice17 @ South Pole

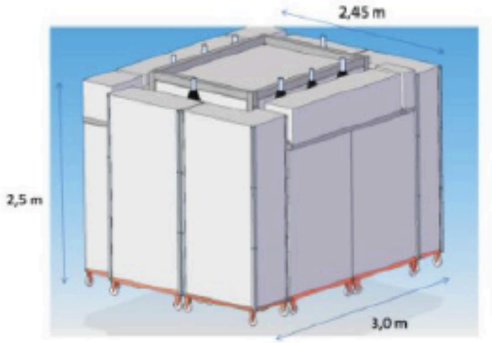


ANAIS (Annual modulation with NAI Scintillators)

- Installed at LSC in a convenient shielding







Null hypothesis is well supported by the χ^2 test (p-values of 0.63 and 0.09 for 2-6 and 1-6 keV energy regions)

Best fits for the modulation hypothesis have p-values slightly lower than for the null hypothesis

NEW !!!

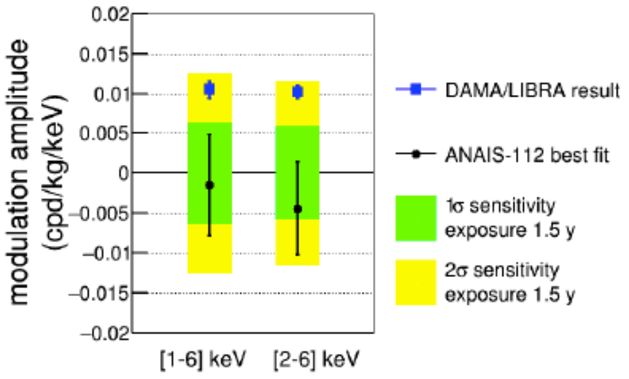
2-6 keV -> $S_m = -0.0029 \pm 0.0050\ cpd/kg/keV$ $(S_m^{DAMA} = 0.0102 \pm 0.0008$ cpd/kg/keV)

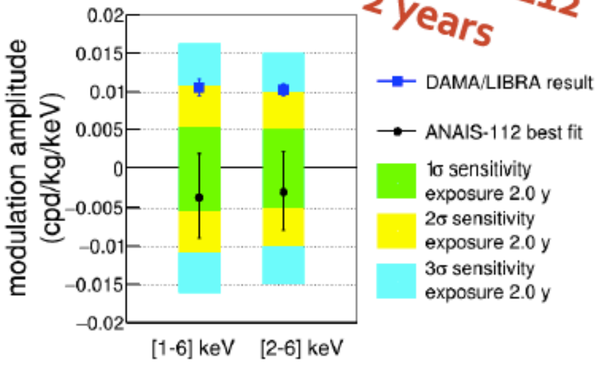
1-6 keV -> $S_m = -0.0036 \pm 0.0054\ cpd/kg/keV$ $(S_m^{DAMA} = 0.0105 \pm 0.0011$ cpd/kg/keV)

PRELIMINARY

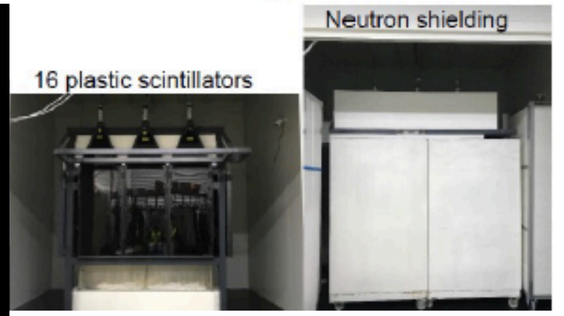
ANAIS-112

2 years





ANAIS-112 annual modulation

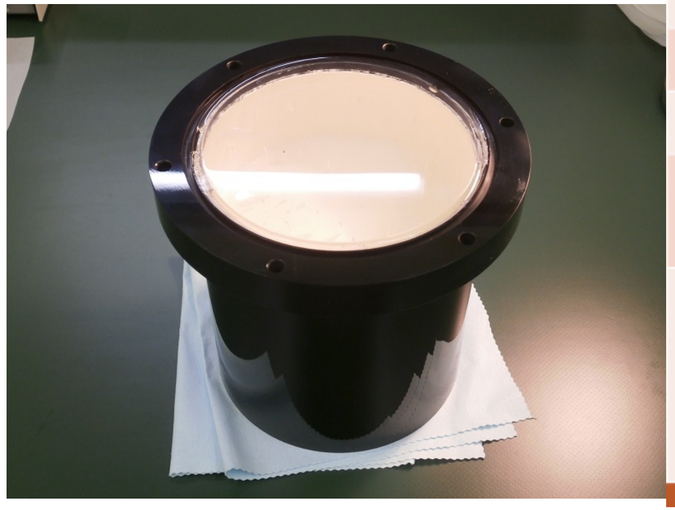


113 kg active mass

M.L. Sarsa et al @ TAUP 2019

PICOLON (Pure Inorganic Crystal Observatory for LOw-energy Neutr(al)ino)

K.Fushimi et al @ TAUP 2019



Status of NaI(Tl) purification (~April 2019)

RI	Ingot26 (2015)	Ingot37 (2016)	Ingot71 (2018)	Ingot76 (2019)	Goal
Size	3”ϕX3”	4”ϕX3#	3”ϕX3”	5”ϕX4”(*)	5”ϕX5”
^{40}K (ppb)	2630	120	<20	<20	<20
^{232}Th (ppt)	0.4±0.5	3.7±0.5	1.7±0.2	--	<4
^{238}U (ppt)	4.7±0.3	5.9±0.3	9.7±0.8	4.4±0.2	<10
^{210}Pb (μBq/kg)	30±7	2300	1076	~560	<50
Method	Resin for Pb	I26+cation resin	double re-crystallization	Pb resin + double re-crystallization	

Factory moved.

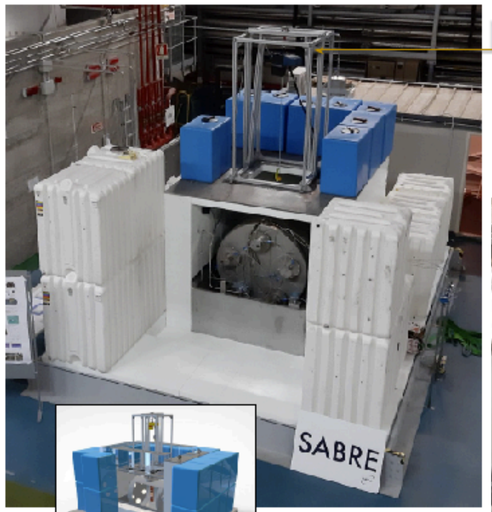
TAUP2019 TOYAMA 2019/SEP/11 16

SABRE (Sodium iodide with Active Background REjection)

STAWELL UNDERGROUND PHYSICS LAB

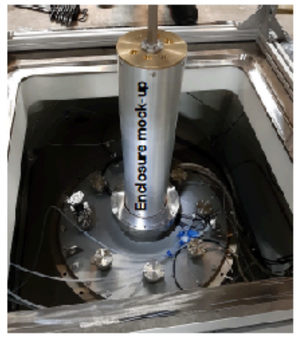
Proof of Principle status

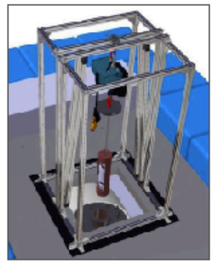
North



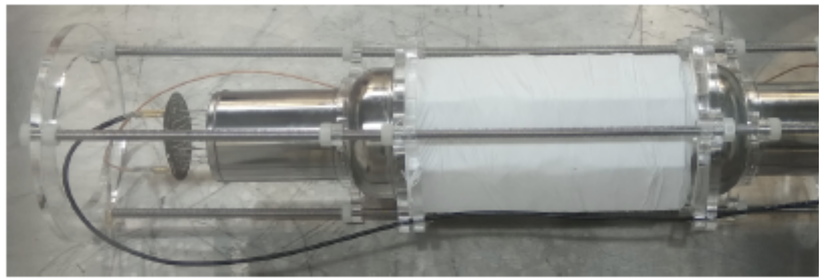
Crystal Insertion System

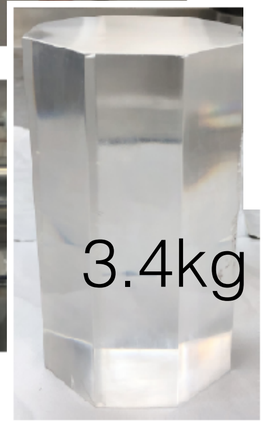
A **frame** is mounted on a steel plate above the vessel. A **motorized pulley** connected to an alignment system, **guides the enclosure into the copper tube**. The enclosure is connected to a flange via a steel bar.



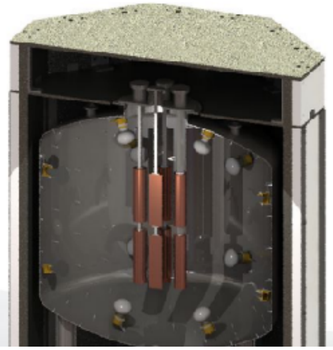




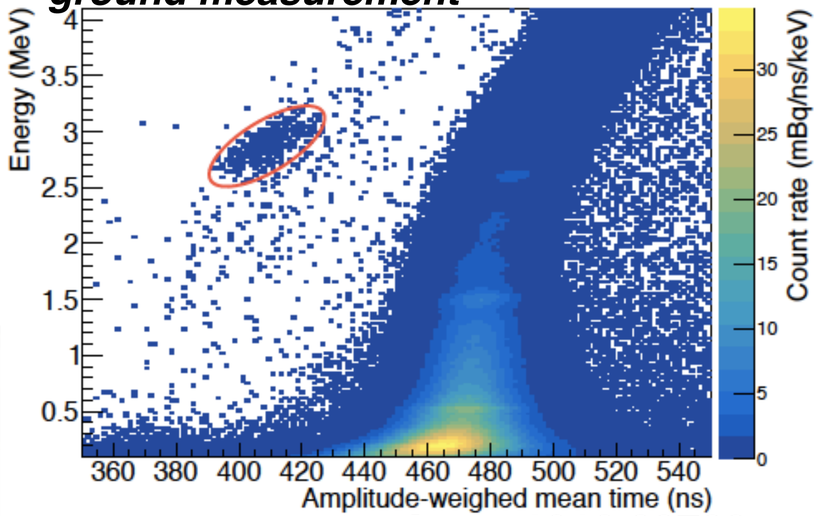




South



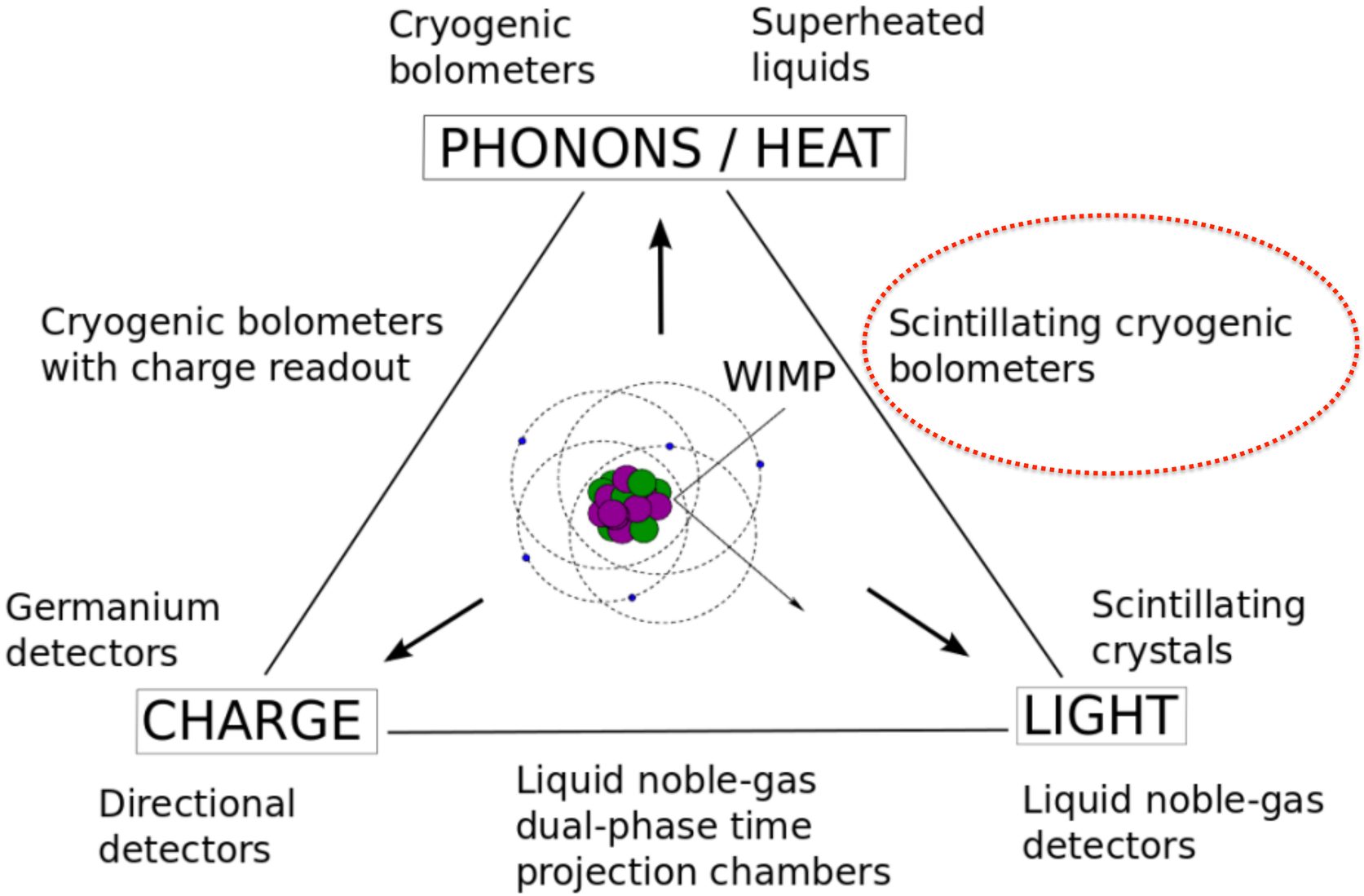
ground measurement



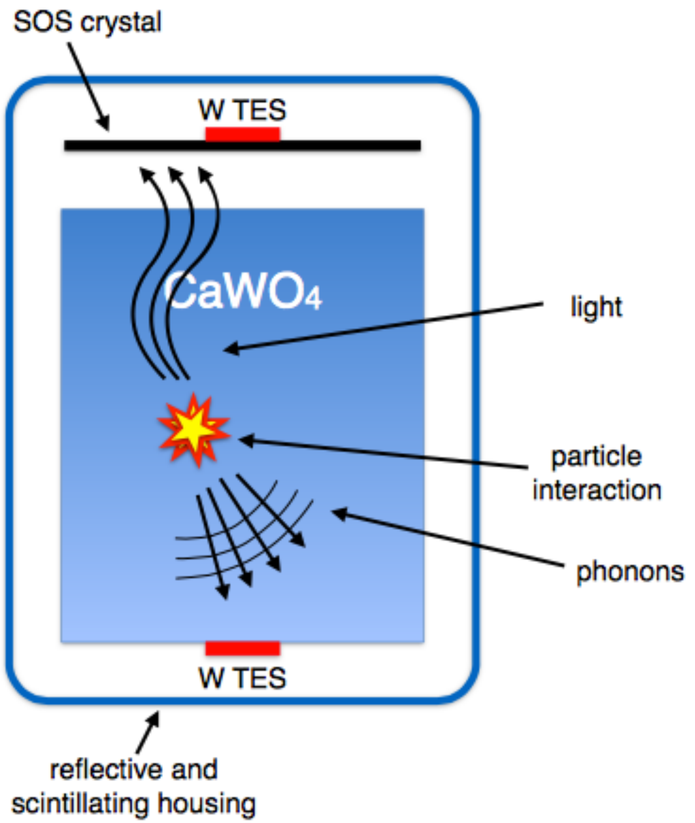
Arxiv:1910.03782

K-40 : 4.3 ppb
Pb-210(Po-210) : 0.34mBq/kg

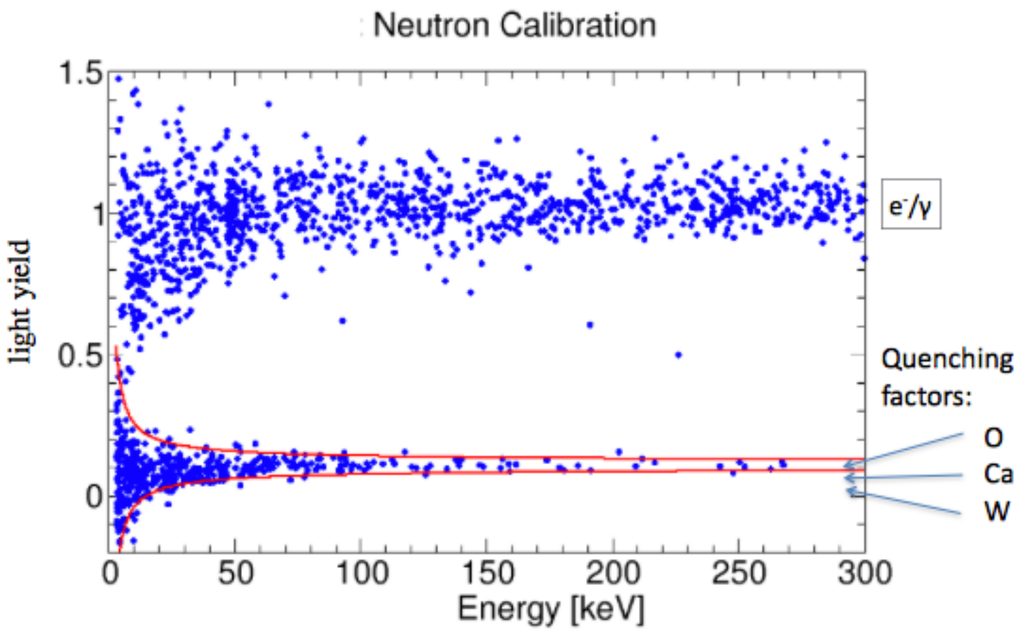
Dark Matter Detection Techniques



Light-Heat Detectors : Crystals



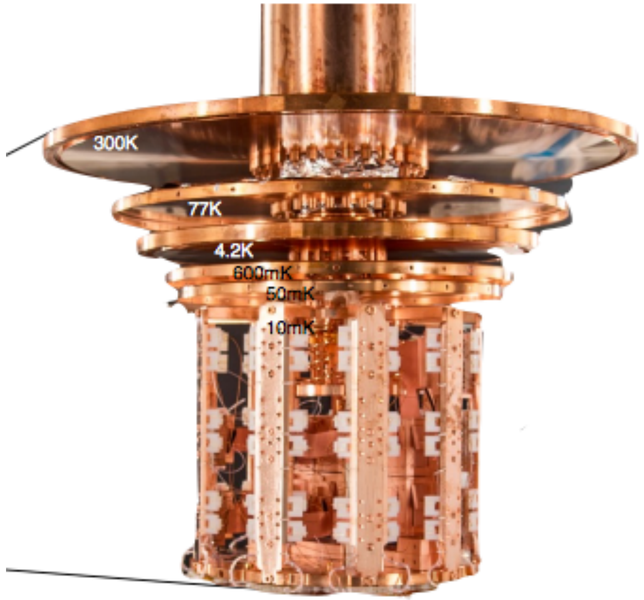
$$\text{light yield} = \frac{\text{energy detected in light channel}}{\text{energy detected in the phonon channel}}$$

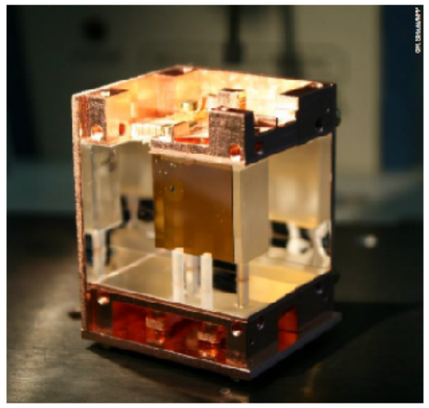


CRESST @ IDM16

Cryogenic measurements (~10mK) both for scintillation light and heat signals from the crystal.

Light-Heat Detectors : CRESST ($CaWO_4$)

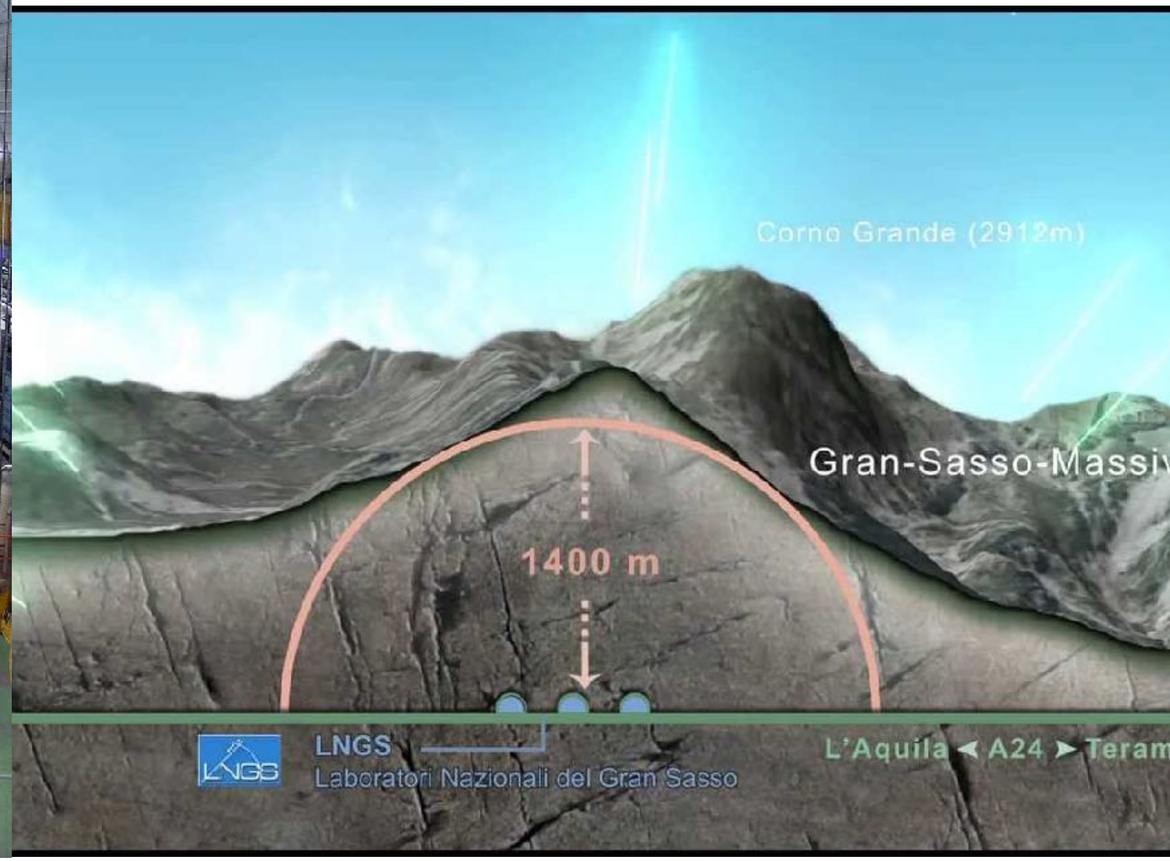




CRESST at LNGS

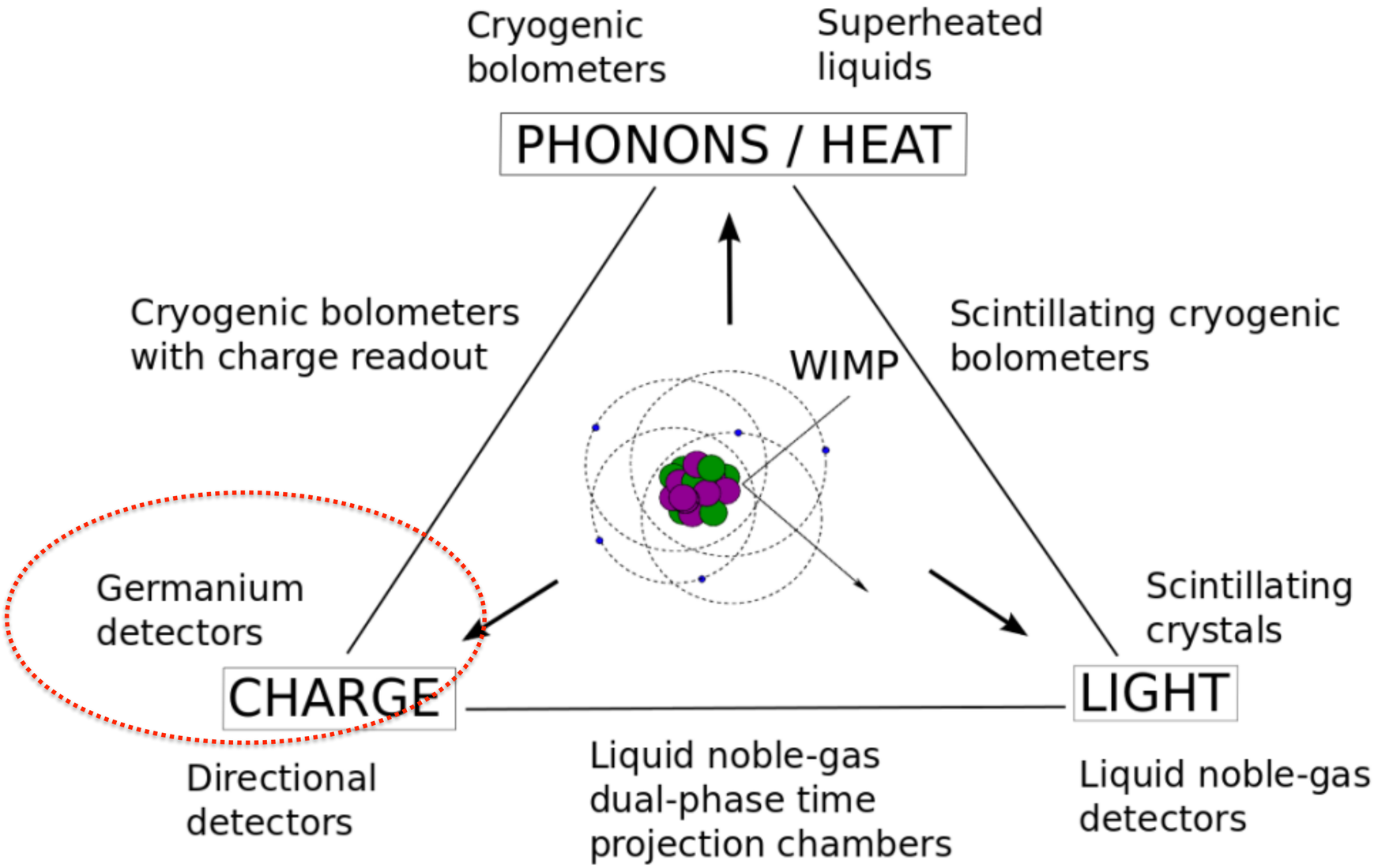


Gran-Sasso National Lab. (Italy)

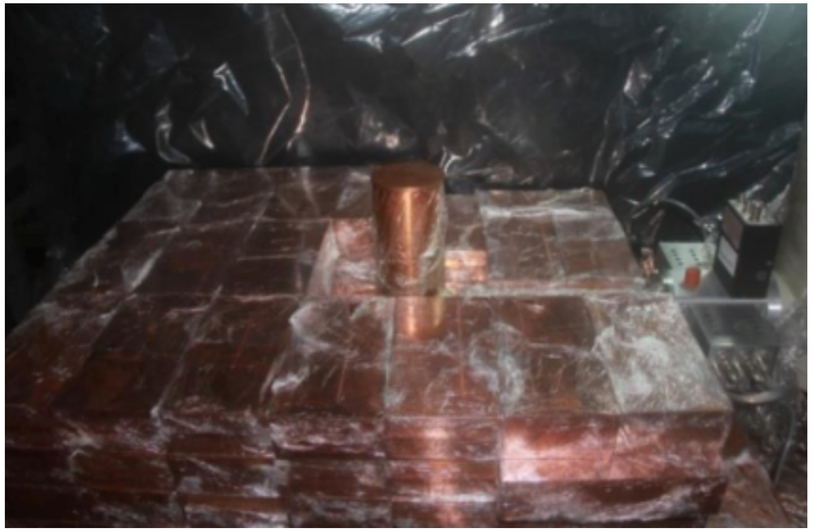


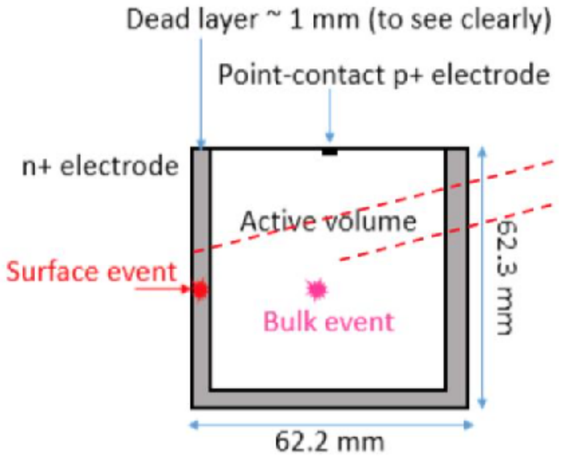
Detector optimized for low mass WIMP search (CRESST-III Phase 1).
Mass of one crystal is reduced by x10. Modular detectors

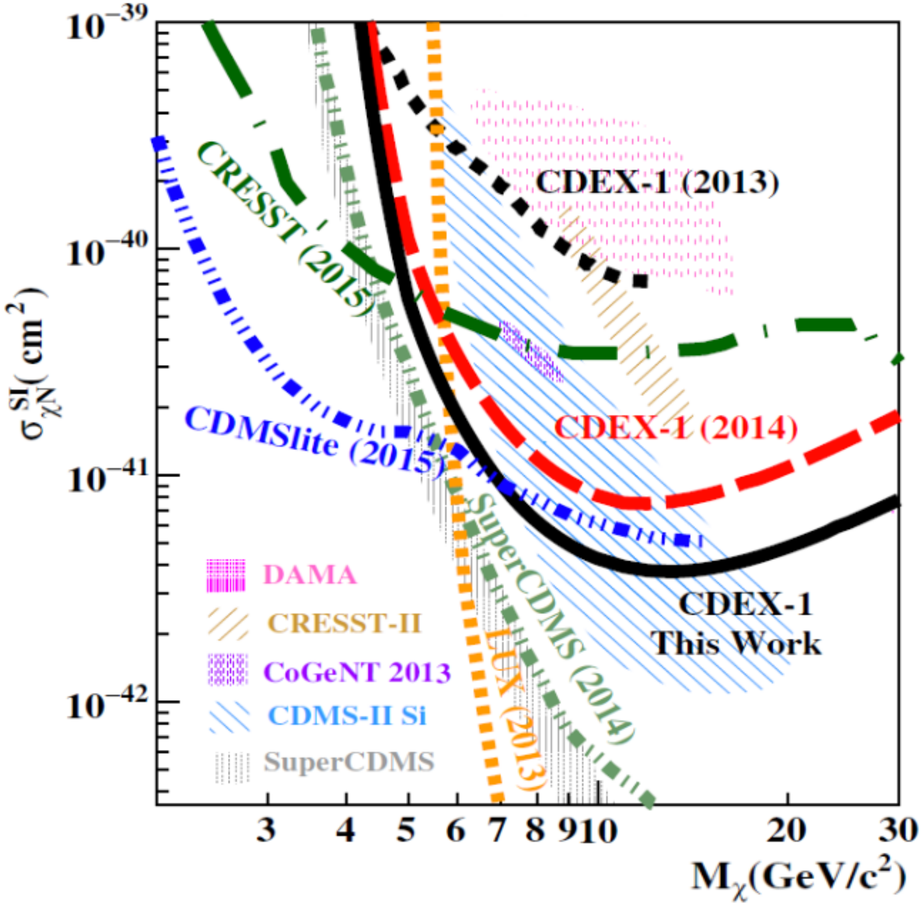
Dark Matter Detection Techniques



Ionization Detectors : HPGe “CDEX”



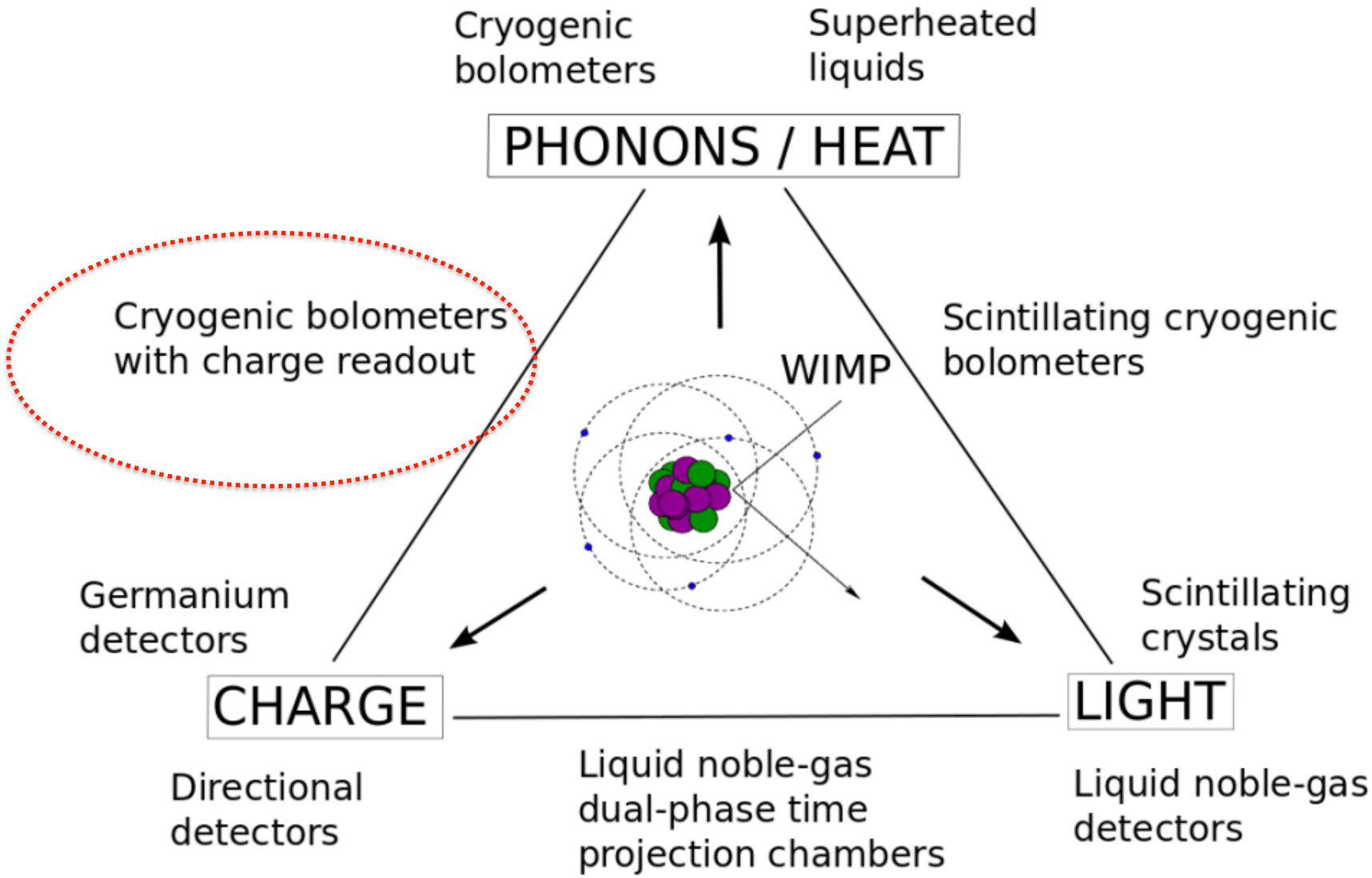




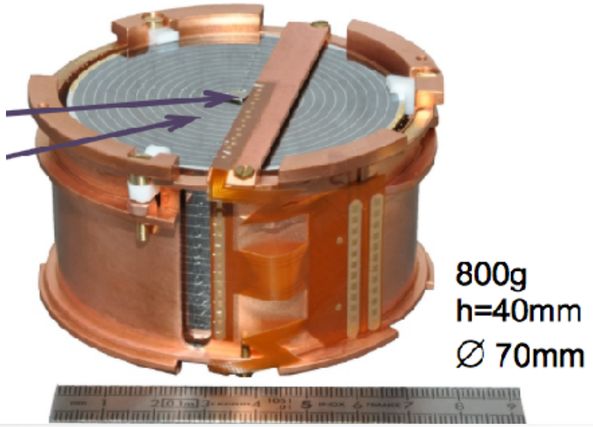
CDEX @ IDM16

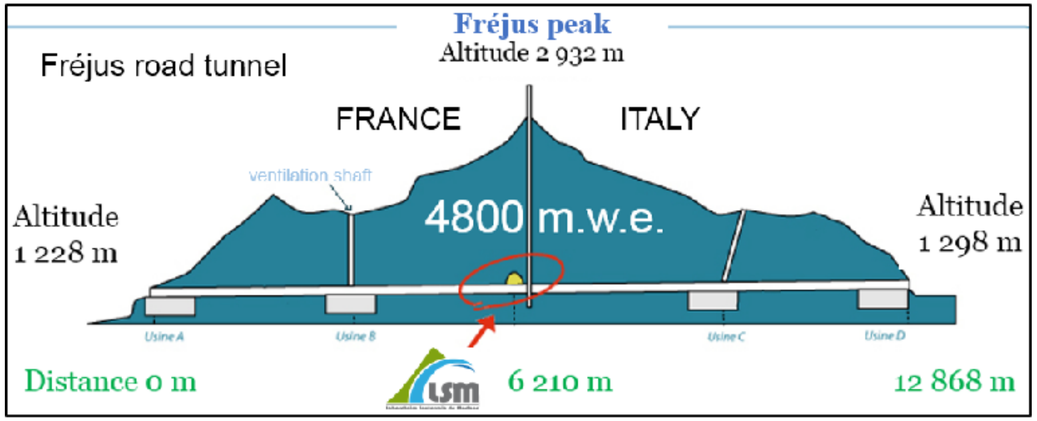
335 kg-days @ CJPL, Fiducial Mass of 915g

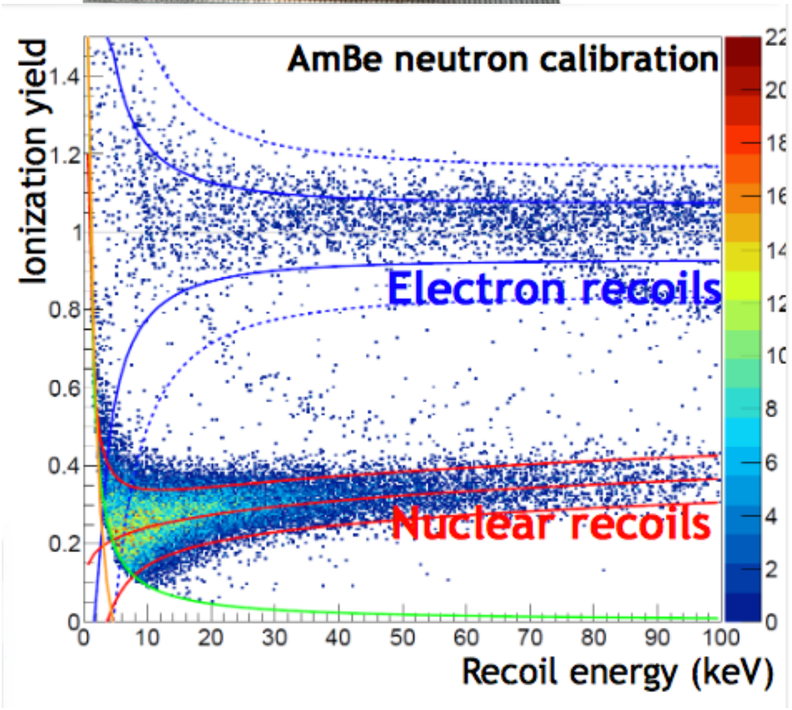
Dark Matter Detection Techniques



Heat-Ionization Detectors : “EDELWEISS”



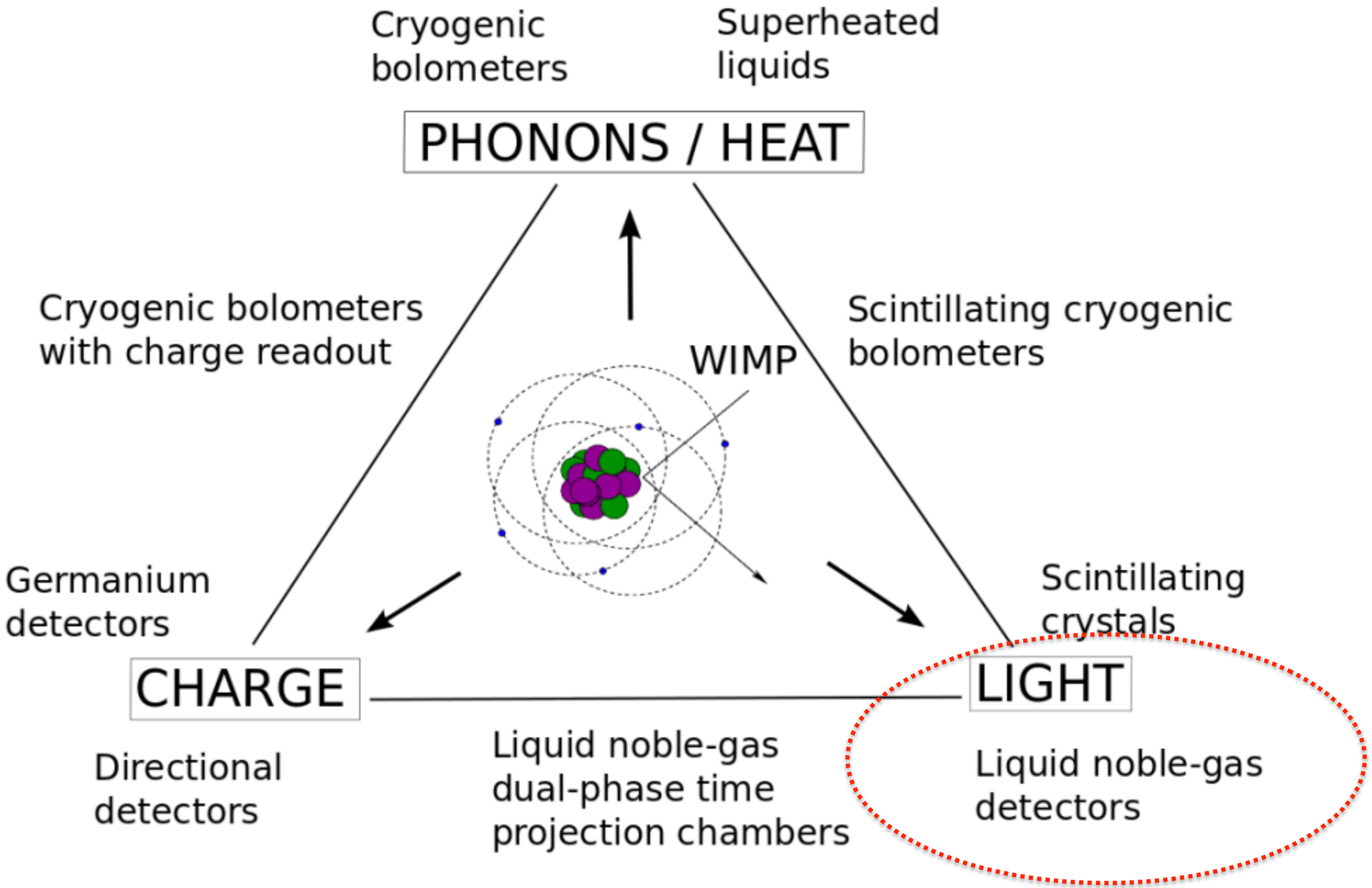




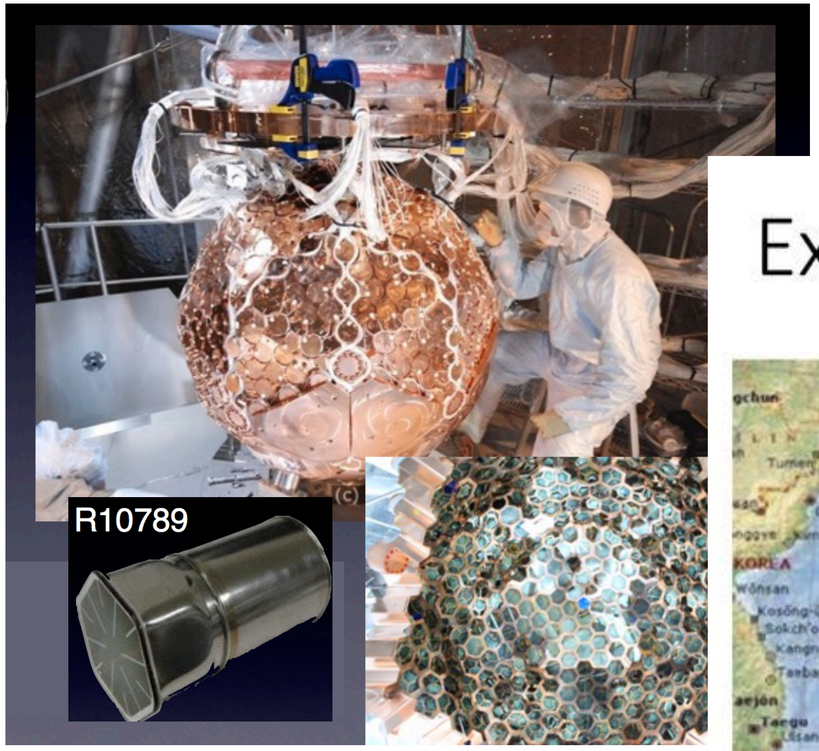
LSM under alps

- 582 kg-day fiducial exposure.
- optimized for lowest energy threshold using 8 detectors.
- BDT analysis

Dark Matter Detection Techniques



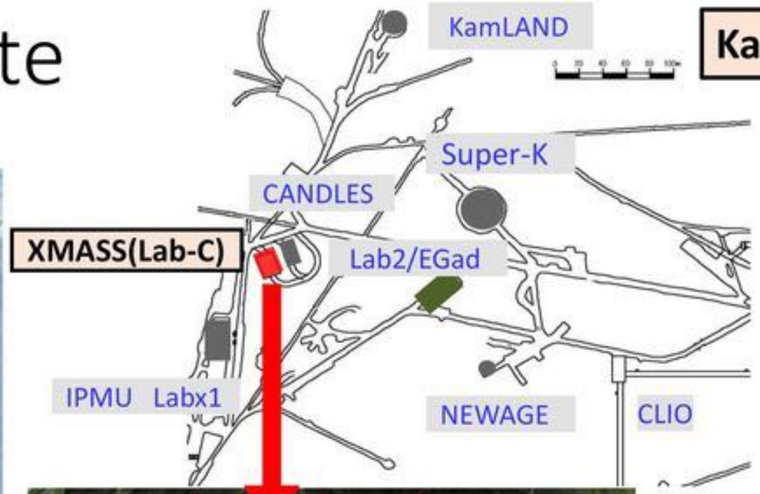
XMASS (1+) single phase LXe scintillation at -100C



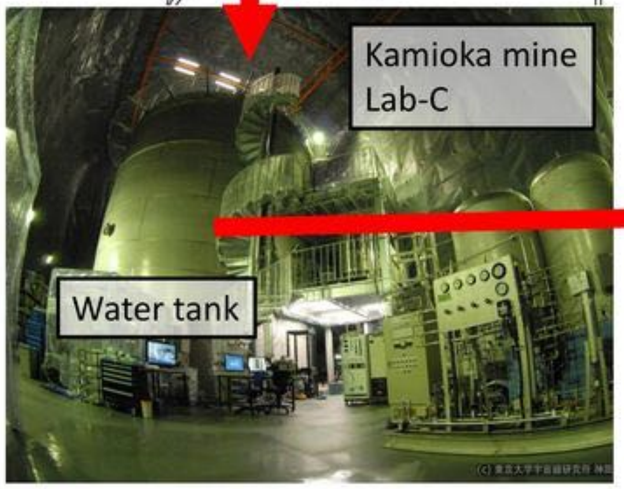
642 ultra-low bkg. PMTs ~830 kg of liquid Xe

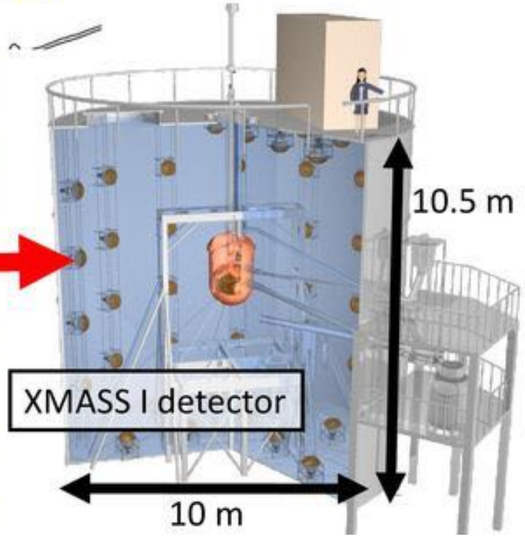
Experimental site



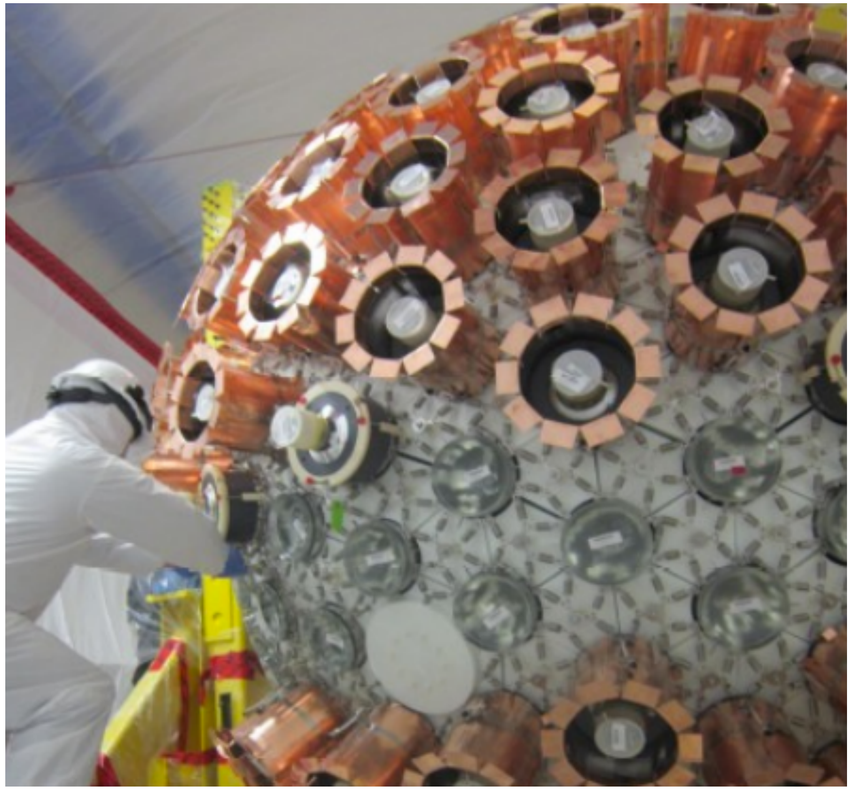


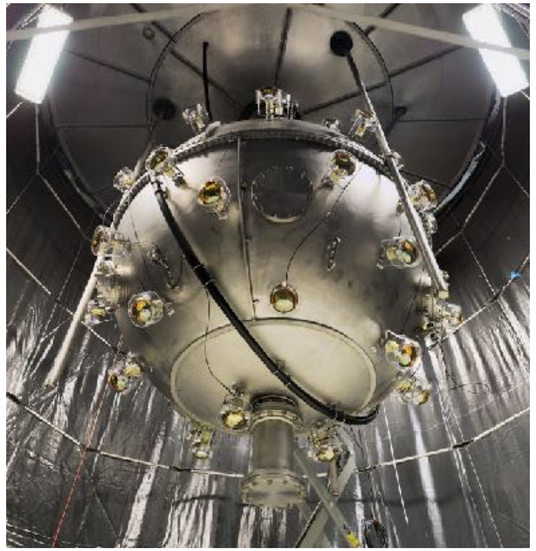
~1000m underneath Mt. Ikenoyama. (2700 m.w.e.)

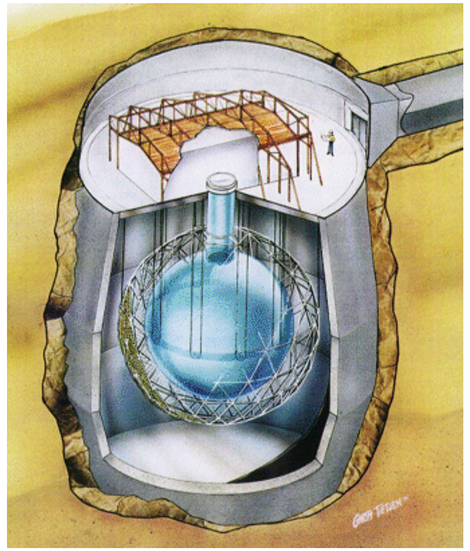




Light Detectors : Single phase LAr “DEAP-3600”





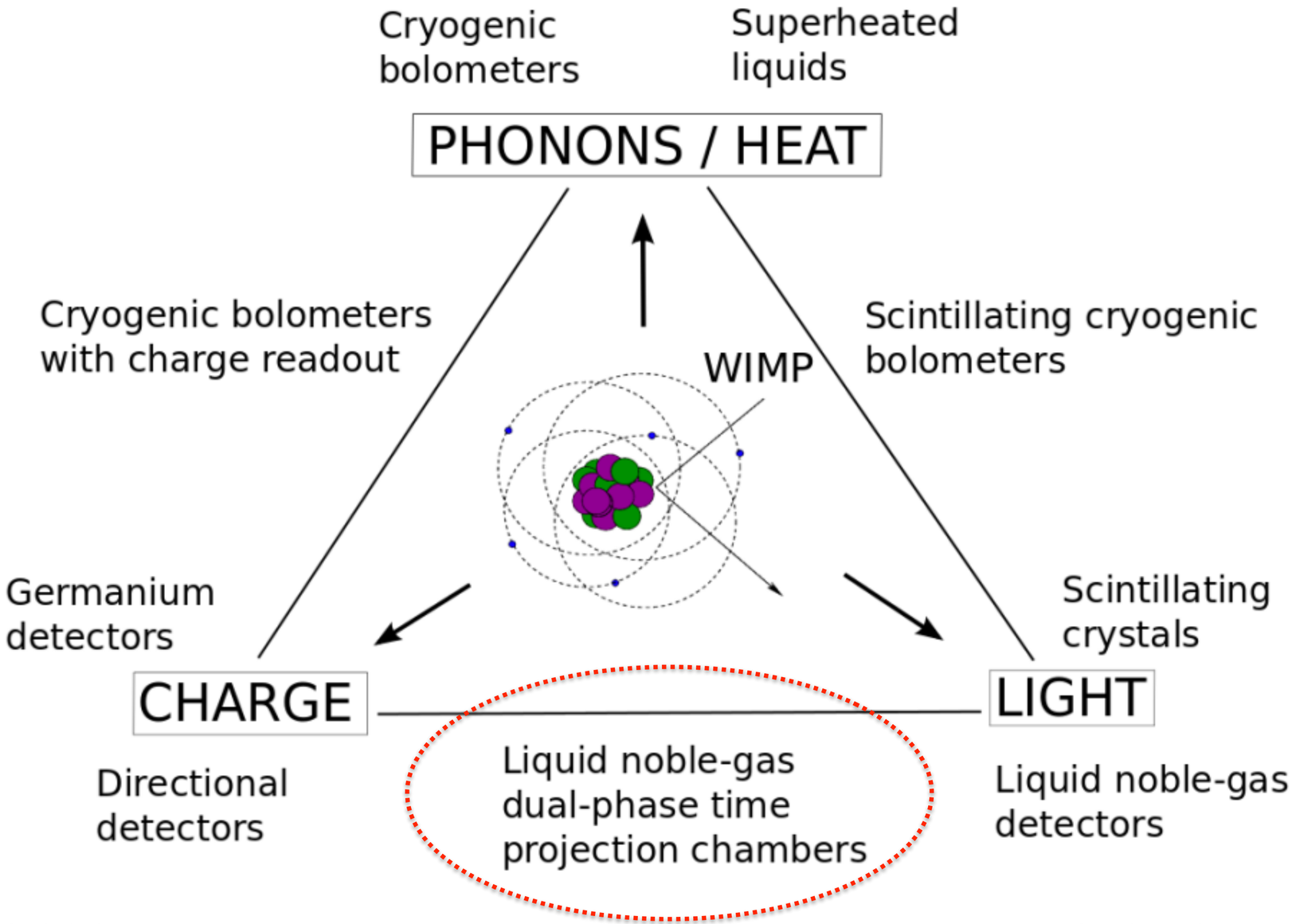


SNO lab, sudbury, CANADA

- ~1000 kg Fiducial mass
- ~3600 kg LAr in active region
- located at SNOLAB

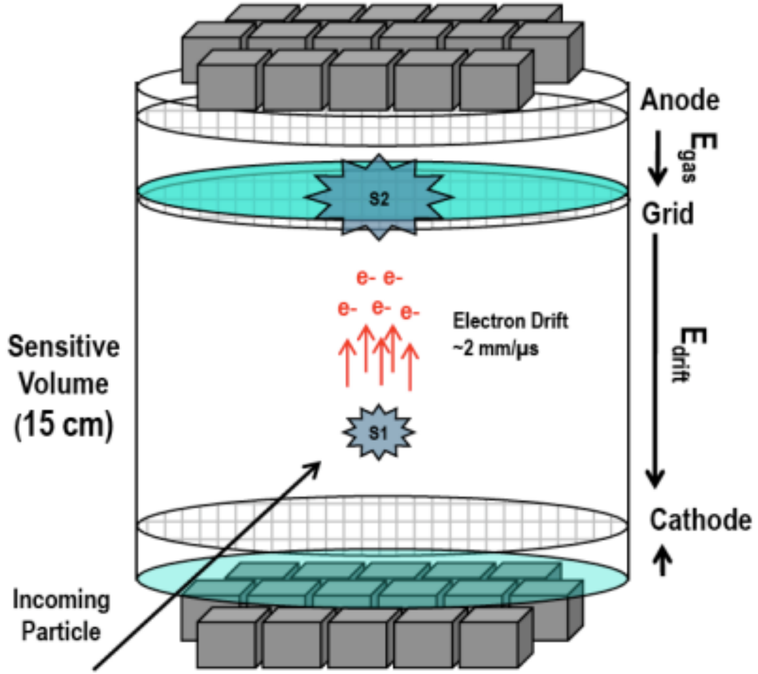
- Ar-39 background in the atmospheric Ar
- LY higher. PSD is good for sufficiently high energy events
- The detector will run soon

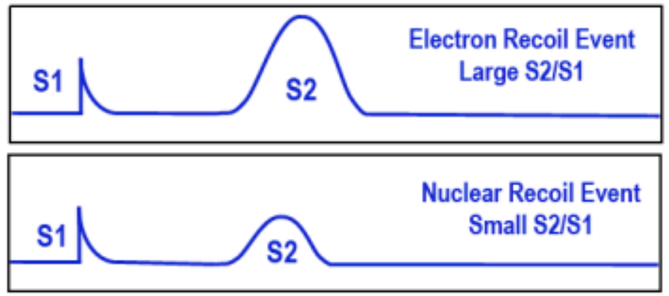
Dark Matter Detection Techniques



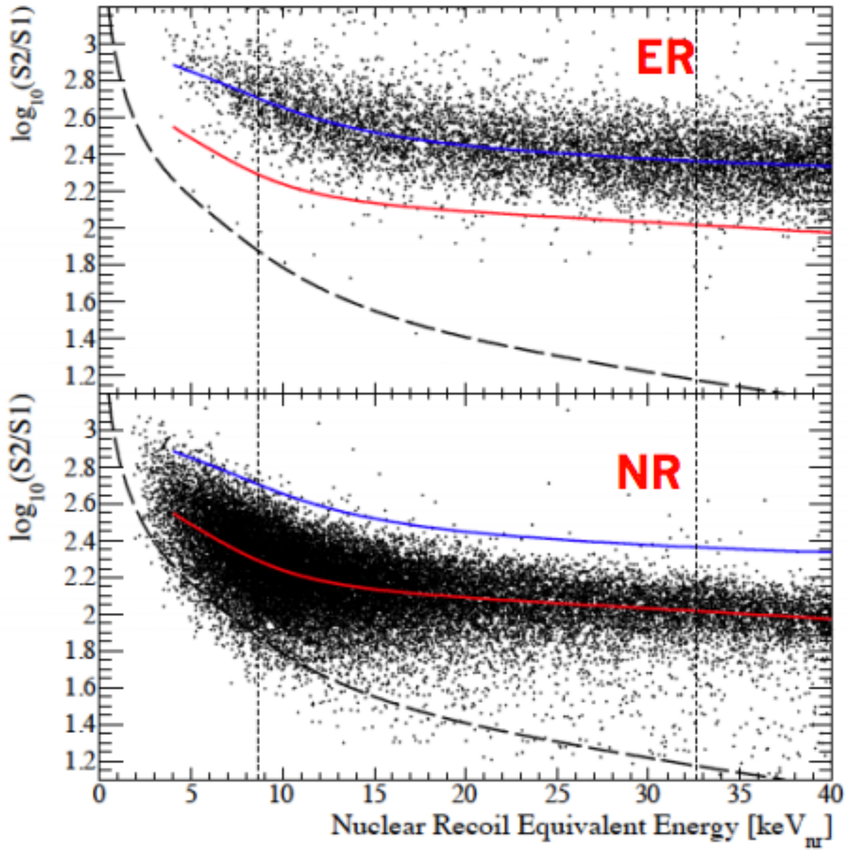
Light-Ionization Detectors : two phase Noble liquid

Time Projection Chamber technology



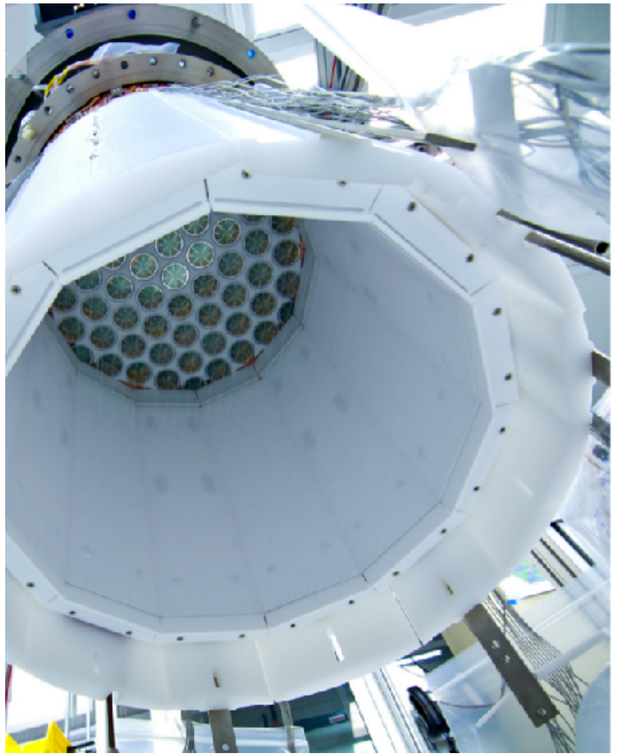


^{60}Co and ^{241}AmBe calibration data



XENON100: Aprile et al. arXiv:1005.0380v3

Light-Ionization Detectors : LXe two phase “LUX”

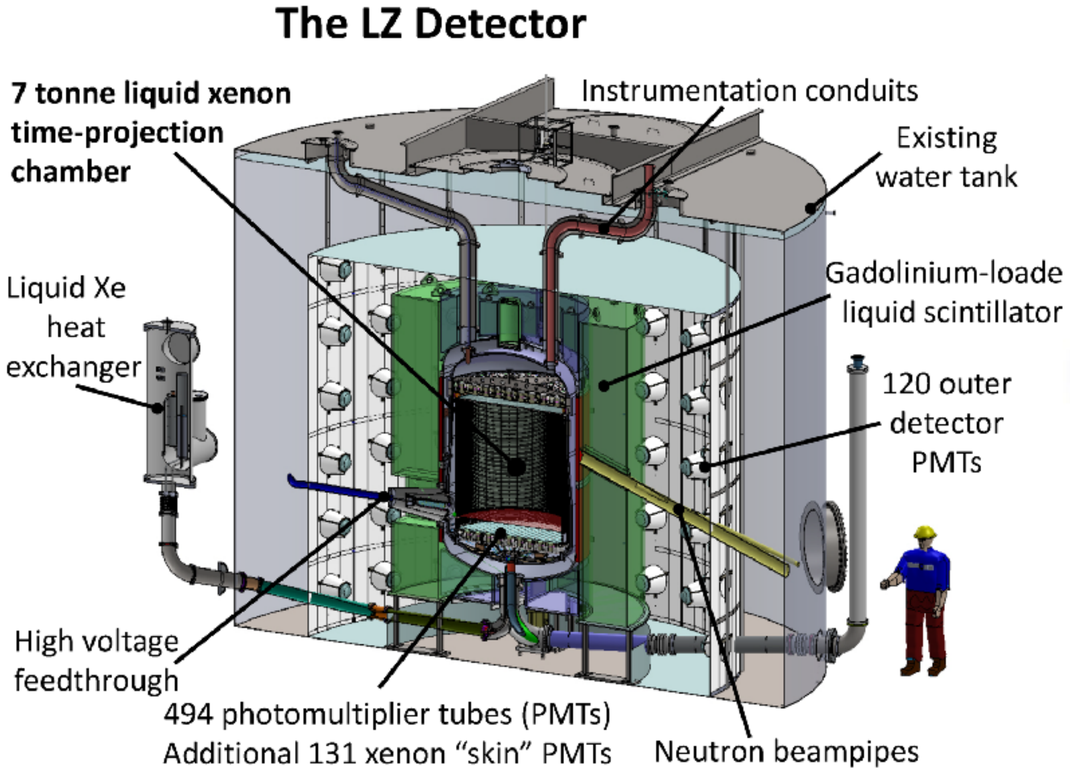




Sanford lab. at South Dakota

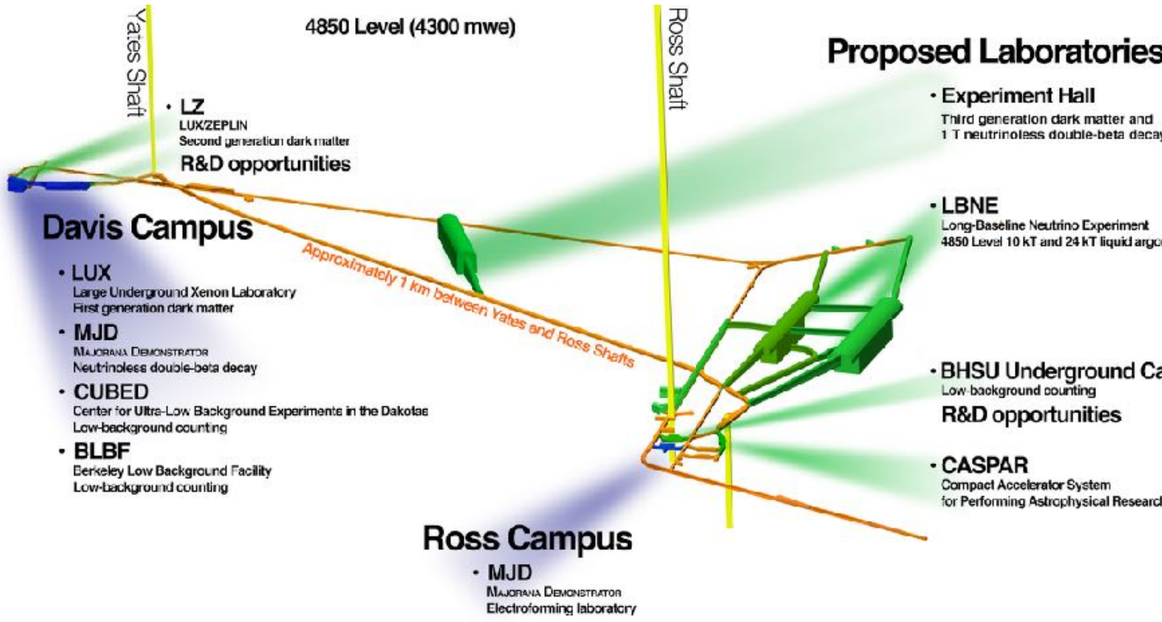
- 332 days of live time (~100 kg fiducial mass)
- ~250 kg LXe in active region
- Scaleable detector
- Profile Likelihood Analysis
- fake signal injection analysis
- Fiducial volume cut to reject background

Light-Ionization Detectors : LXe two phase “LZ” LUX+Zeppelin



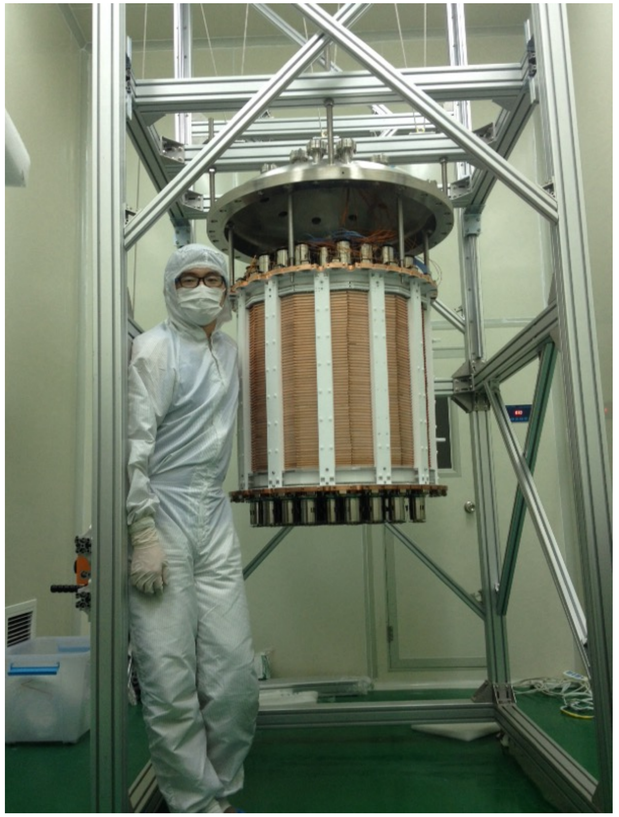
7 ton LXe

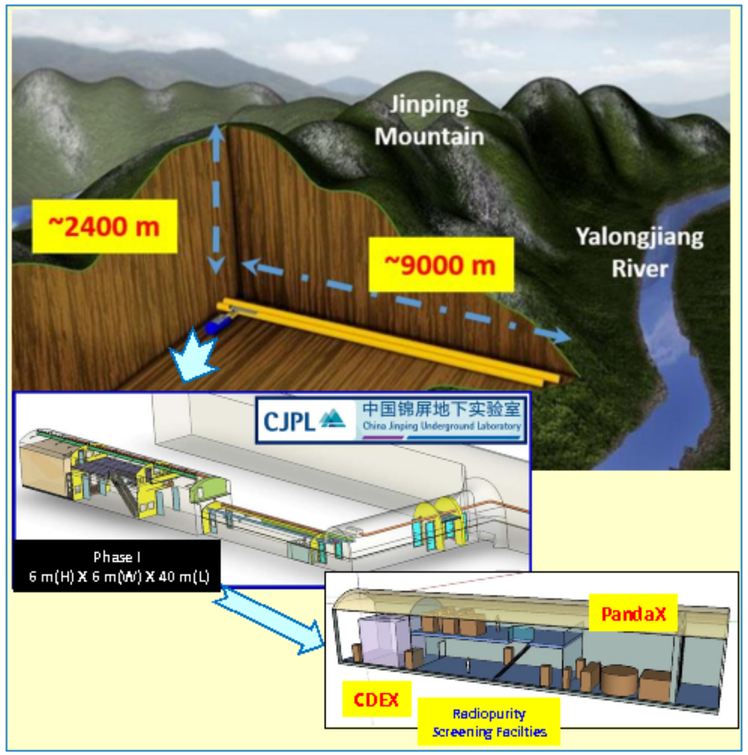
Data taking…



Sanford lab. at South Dakota

Light-Ionization Detectors : LXe two phase “PandaX”

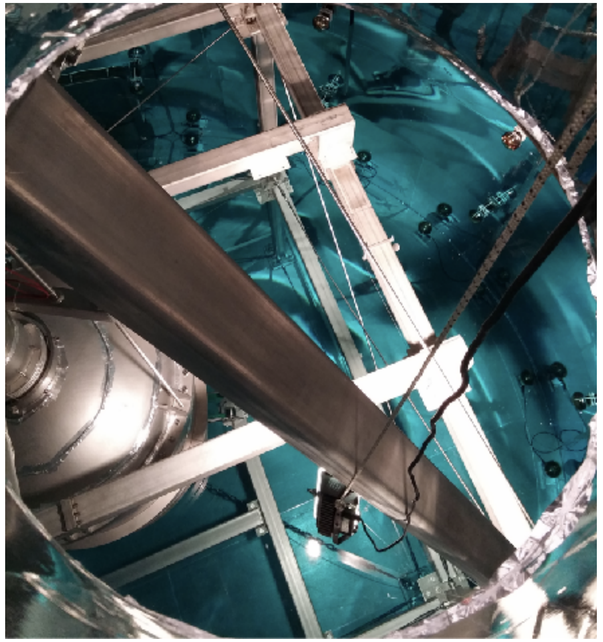




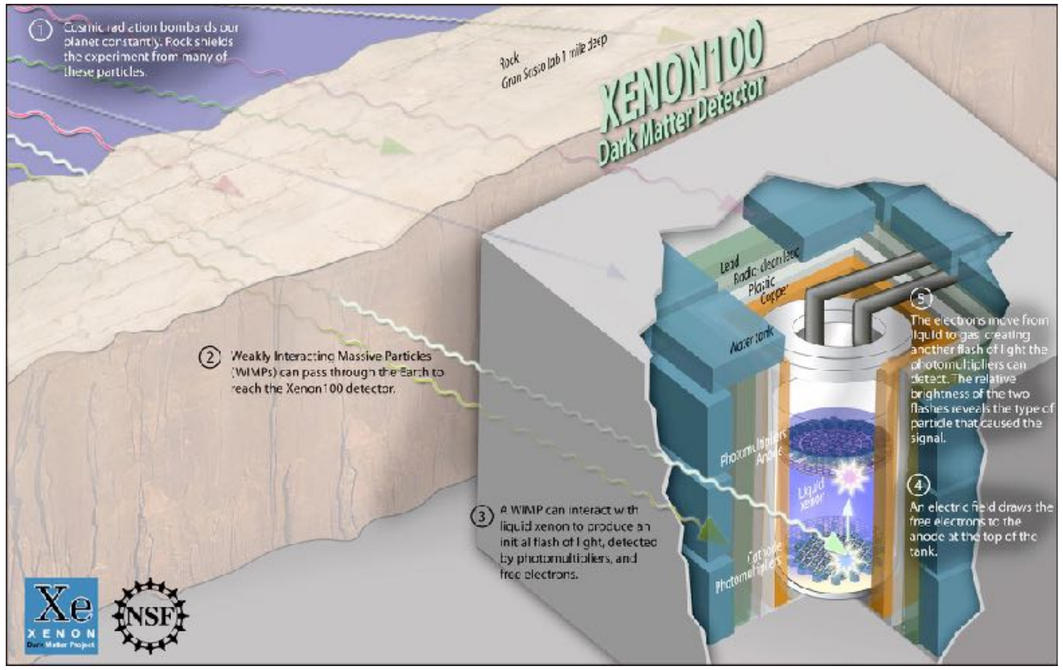
CJPL underground lab in China

- ~99 days of live time (~300 kg fiducial mass)
- 500 kg active region
- Run8 (bkg. ~15 mDRU)+Run9 (~2 mDRU)
- Kr background removal campaign
- BDT analysis with improved reconstruction
- 1 event in the final sample

Light-Ionization Detectors : LXe two phase “XENON”





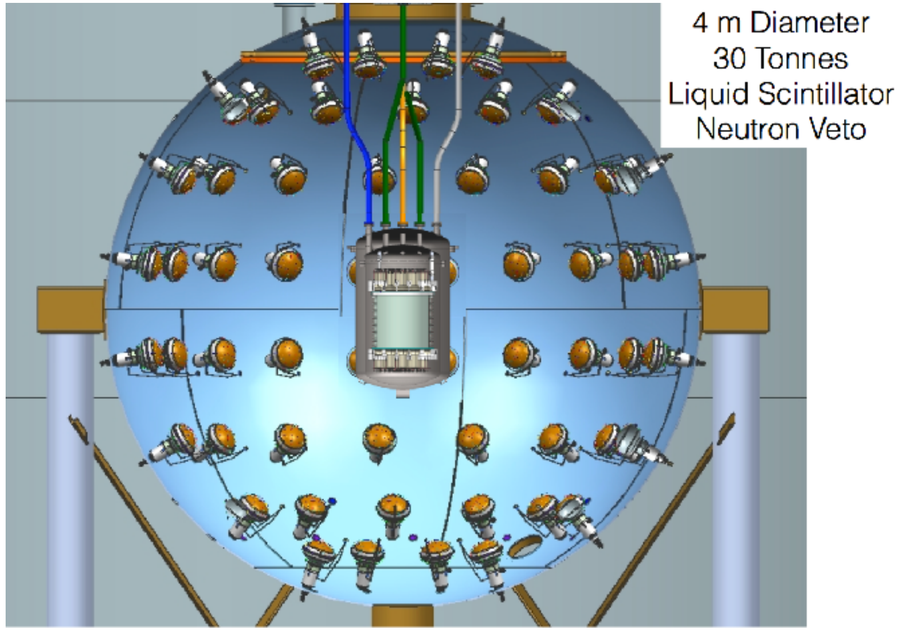


- ~1000 kg Fiducial mass
- ~2000 kg LXe in active region
- Scaleable to nTon detector

XENON experiment at LNGS

- XENON-1T finished
- XENON-nT starting

Light-Ionization Detectors : two phase LAr “DarkSide-50”





LNGS

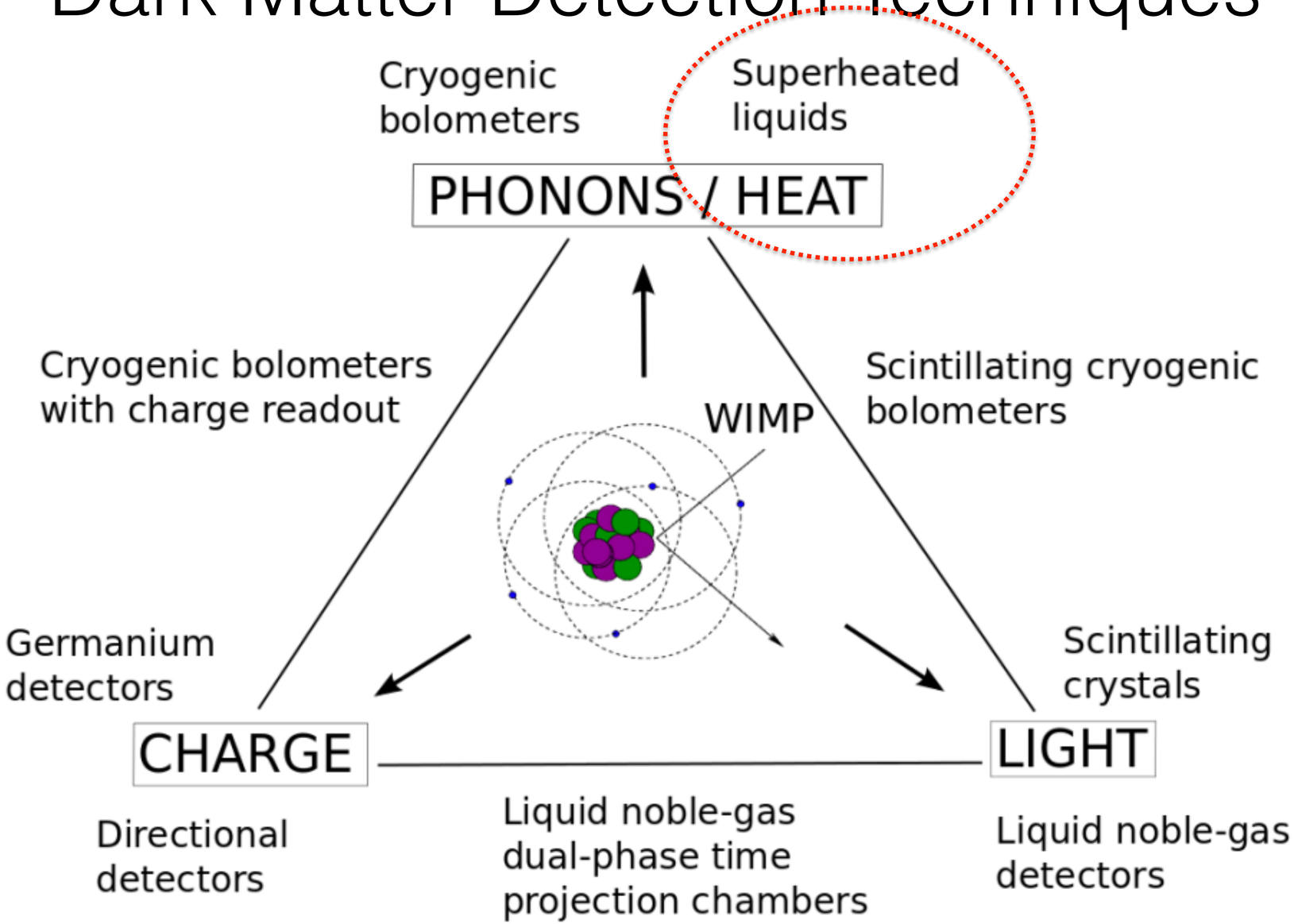
- Similar technology as 2phase LXe
- 50 kg fiducial mass (153 kg Active)
- Underground Ar is used

- Ar-39 background in the atmospheric Ar
- Relatively abundant, easy to purify.

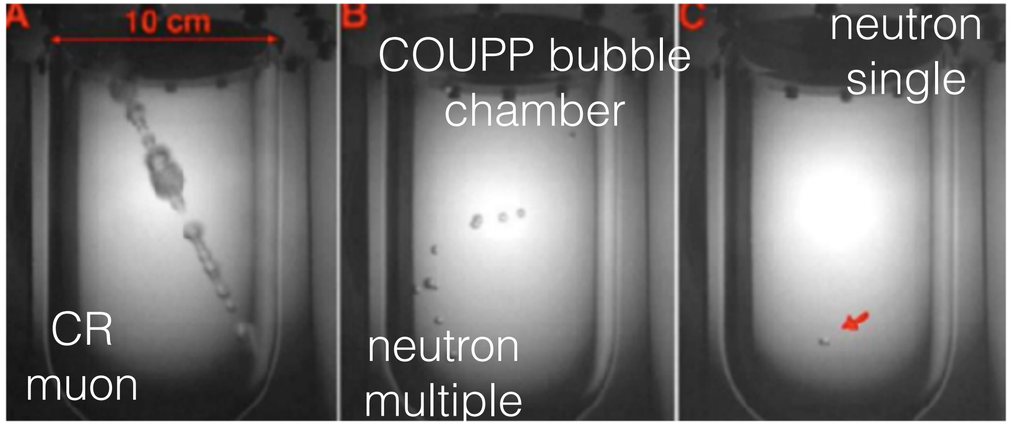
Light-Ionization Detectors : Liquid Noble future detector

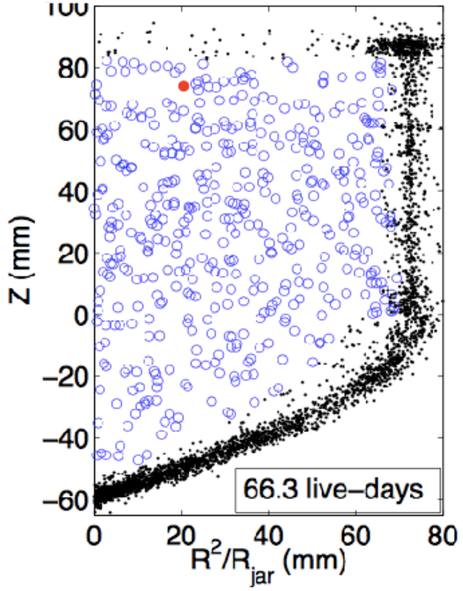
	Single/Dual	Target	Current	Fiducial V.	Future
XMASS	Single	LXe	finished	100kg	
DEAP	Single	LAr	running	1000kg	DEAP-50T
XENON	Dual	LXe	commission	a few tons	XENONnT
PandaX	Dual	LXe	planning	1000kg	PandaX-xT
LUX	Dual	LXe	finished	100kg	LZ (5.6 ton FV)
DarkSide	Dual	LAr	running	50kg	DarkSide-20k

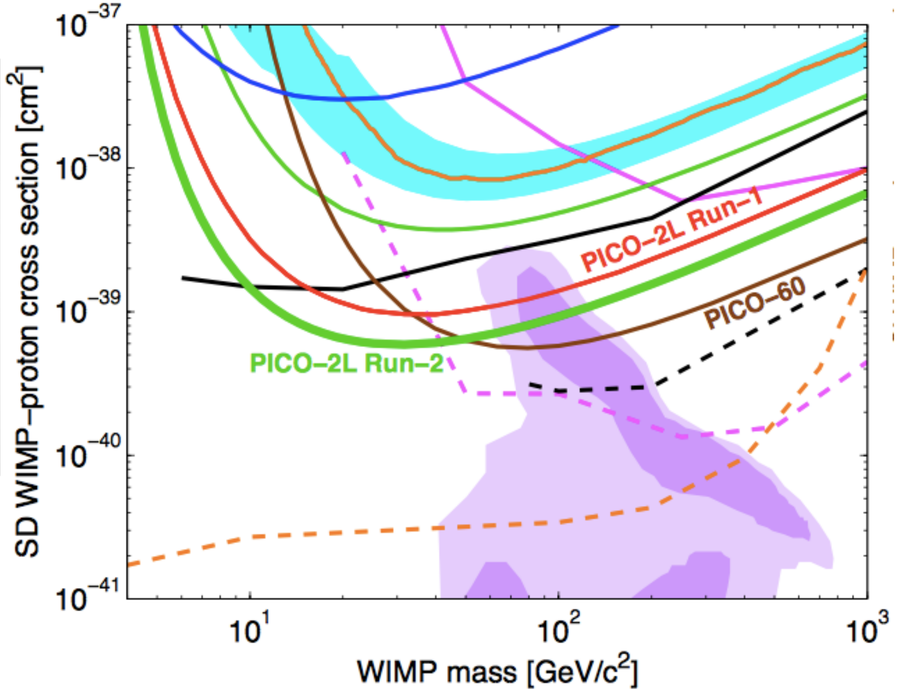
Dark Matter Detection Techniques



Superheated Liquid Detectors : PICO (COUPP + PICASSO)



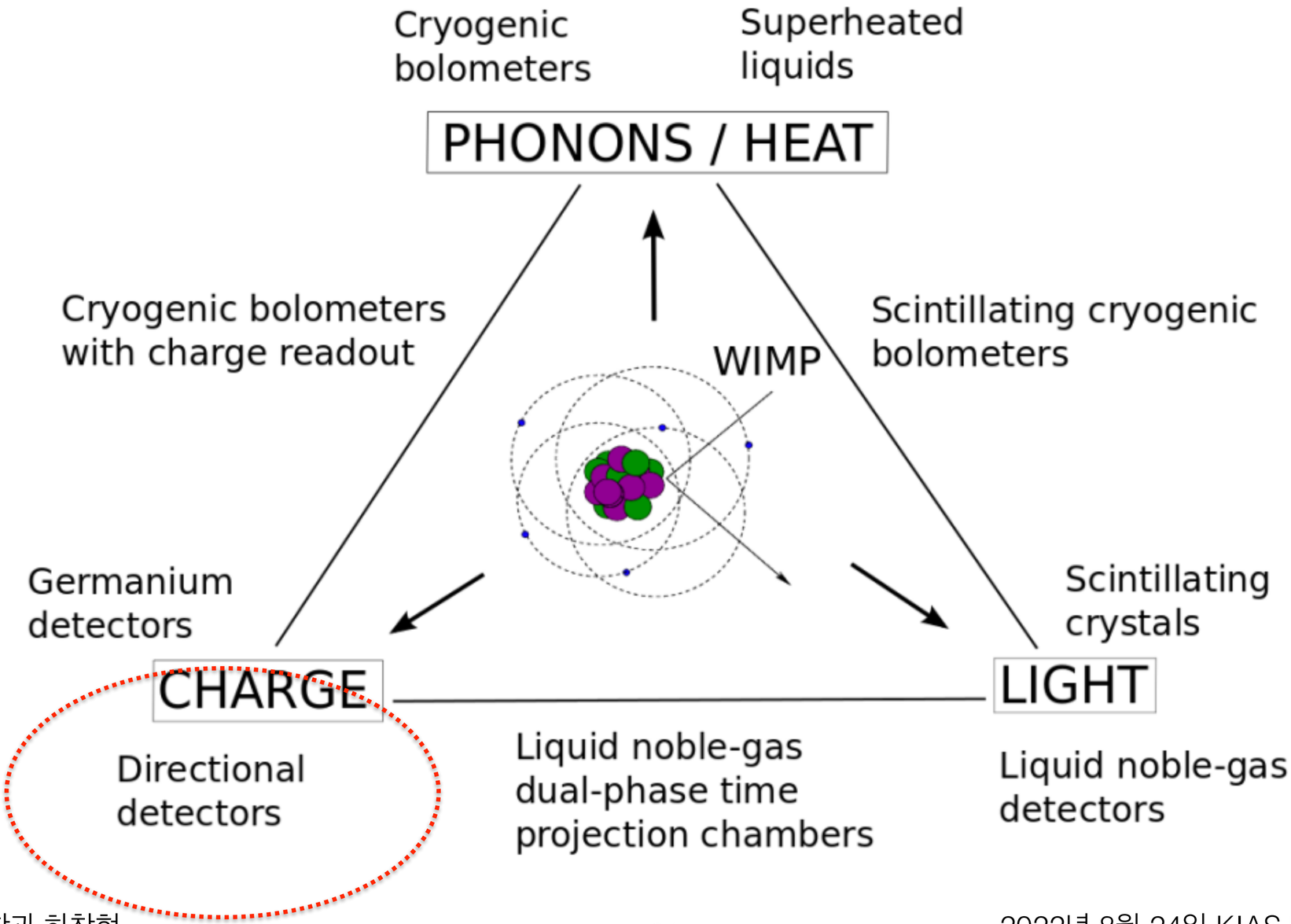




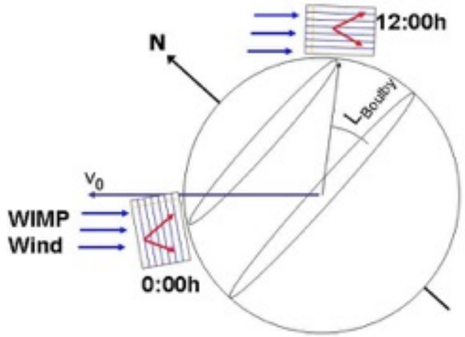
- PICO-2L Run 2
- Exposure: 129 kg-days
- C3F8 as target liquid

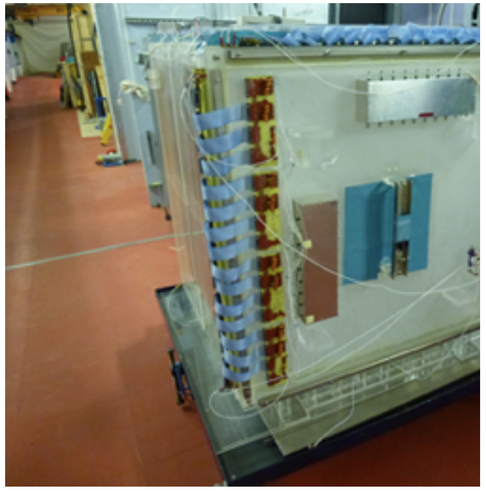
- PICO-60 with C3F8
- Active filteration

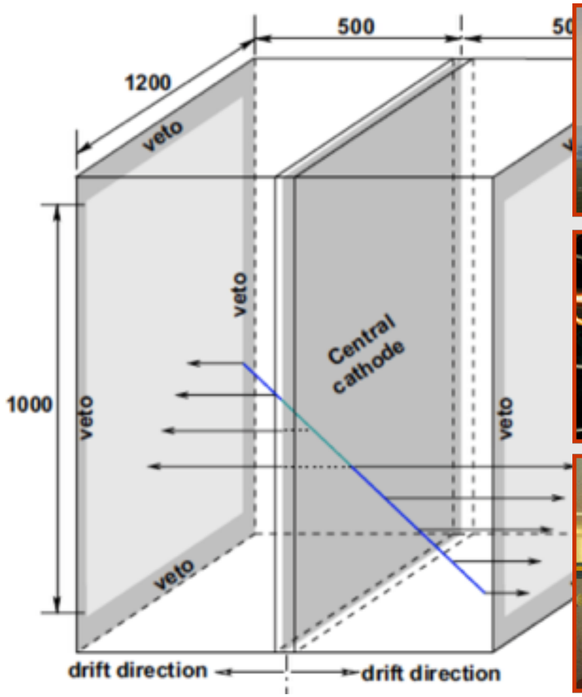
Dark Matter Detection Techniques



DRIFT



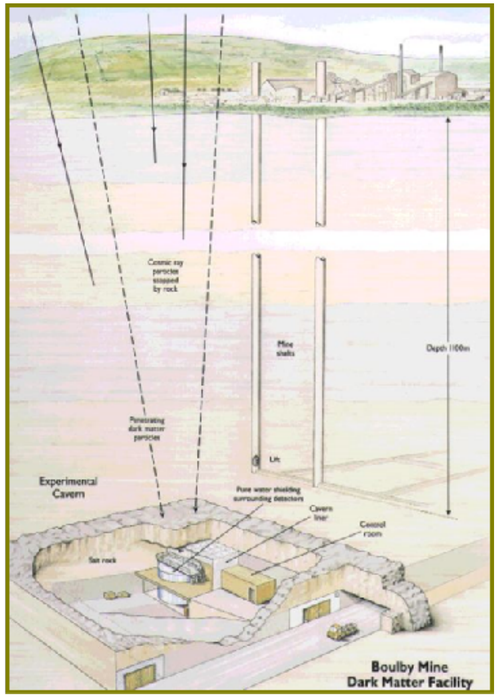








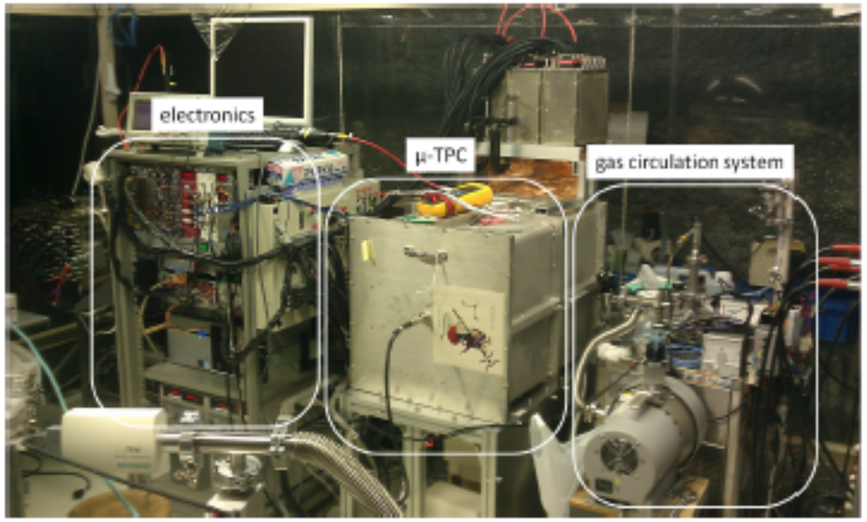


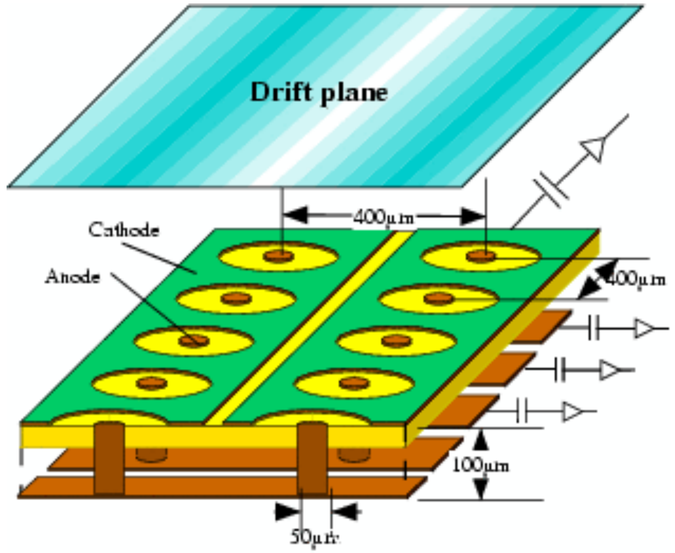


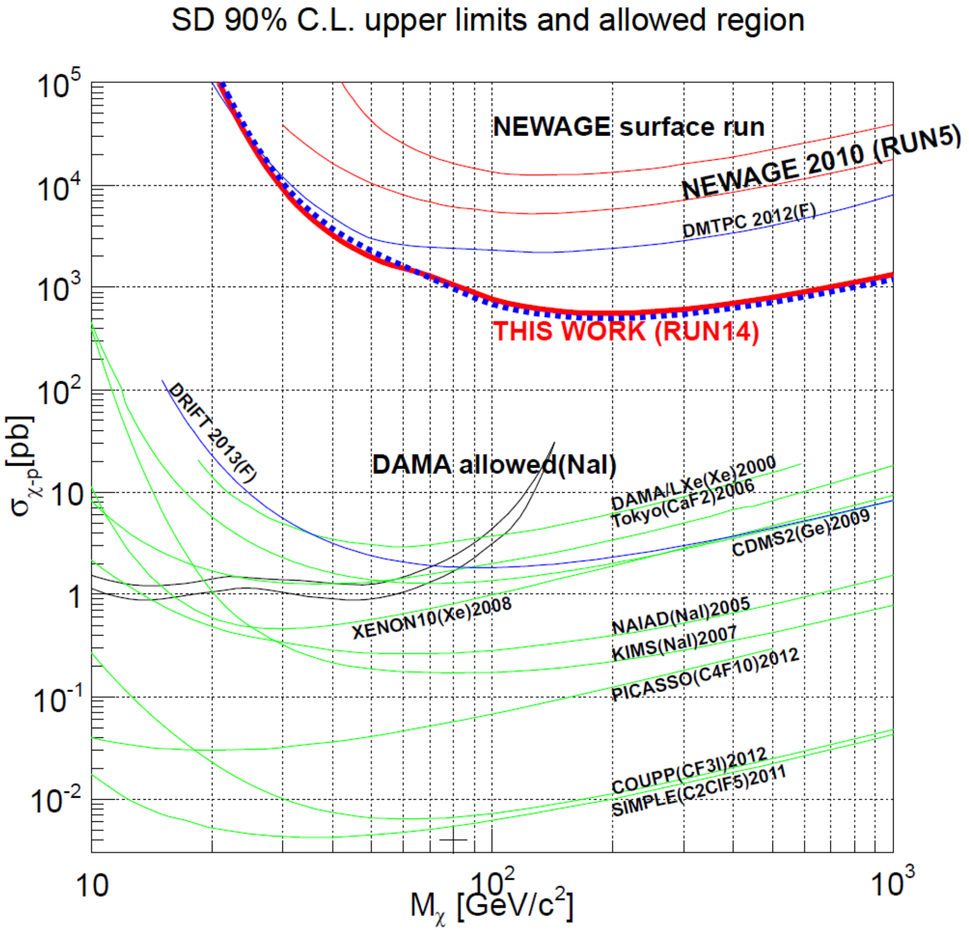
- WIMP wind towards Cygnus
- reconstruct energy and direction
- MWPC with CS_2, CF_4, and O_2 target

- New Neutron background measured.
- Gamma background rejection improved

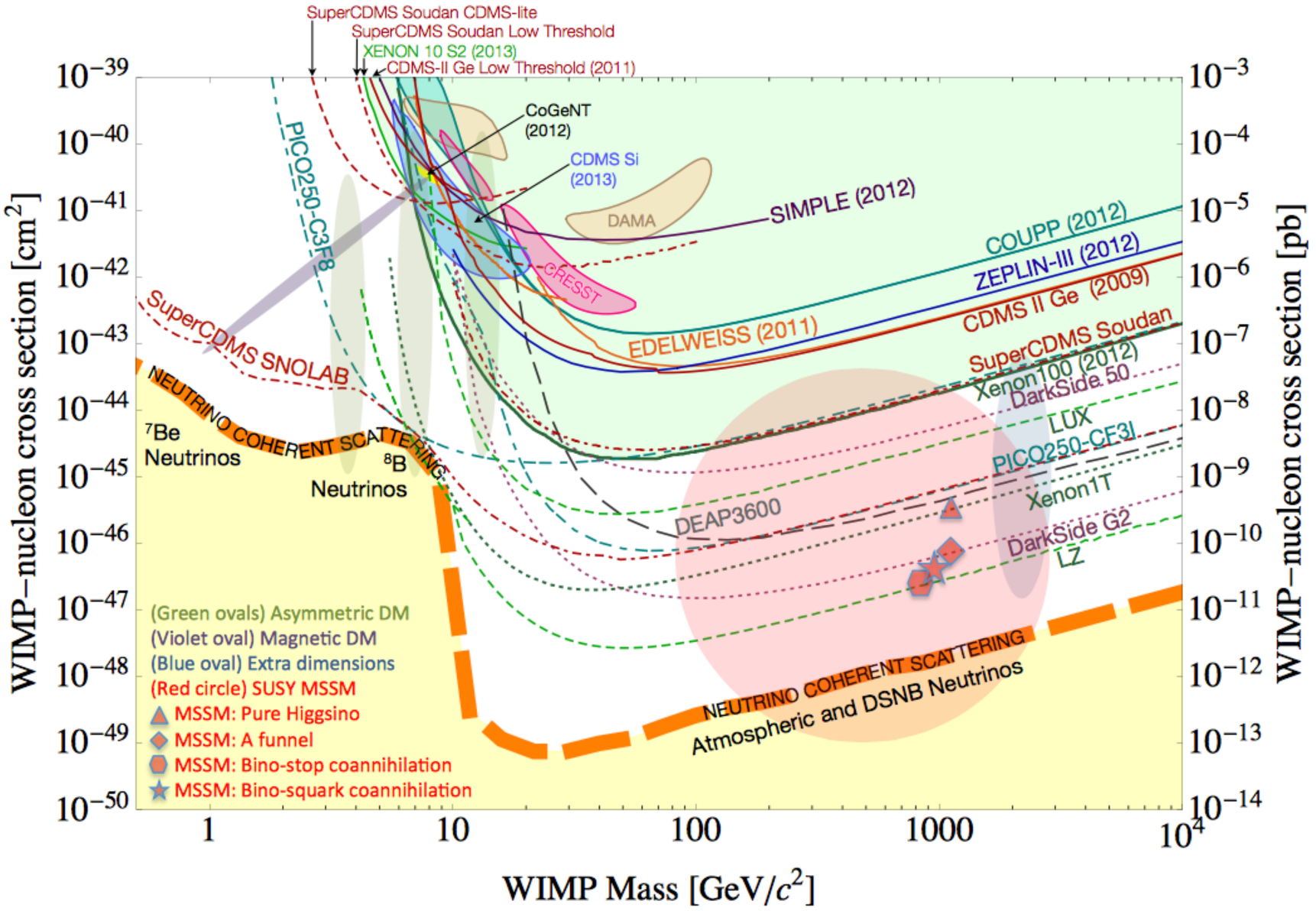
NEWAGE


electronics
μ-TPC
gas circulation system

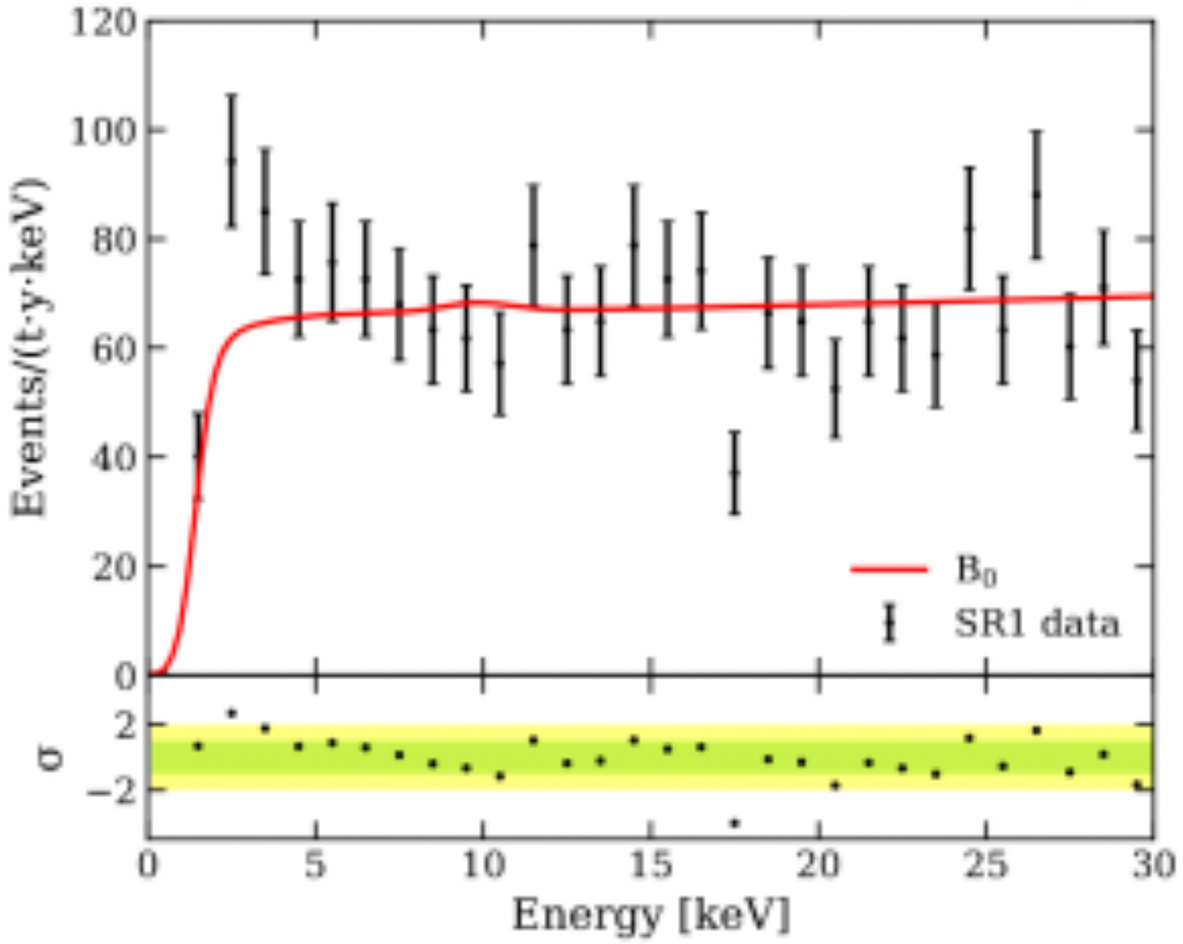

Drift plane
400μm
Cathode
Anode
400μm
100μm
50μm


SD 90% C.L. upper limits and allowed region
NEWAGE surface run
NEWAGE 2010 (RUN5)
DMTPC 2012(F)
THIS WORK (RUN14)
DRIFT 2013(F)
DAMA allowed(NaI)
DAMA/LXe(Xe)2000
Tokyo(CaF2)2006
CDMS2(Ge)2009
XENON10(Xe)2008
NAIAD(NaI)2005
KIMS(NaI)2007
PICASSO(C4F10)2012
COUPP(CF3I)2012
SIMPLE(C2ClF5)2011
$\sigma_{\chi\text{-}p}$[pb]
M_χ [GeV/c^2]

Snowmass 2013

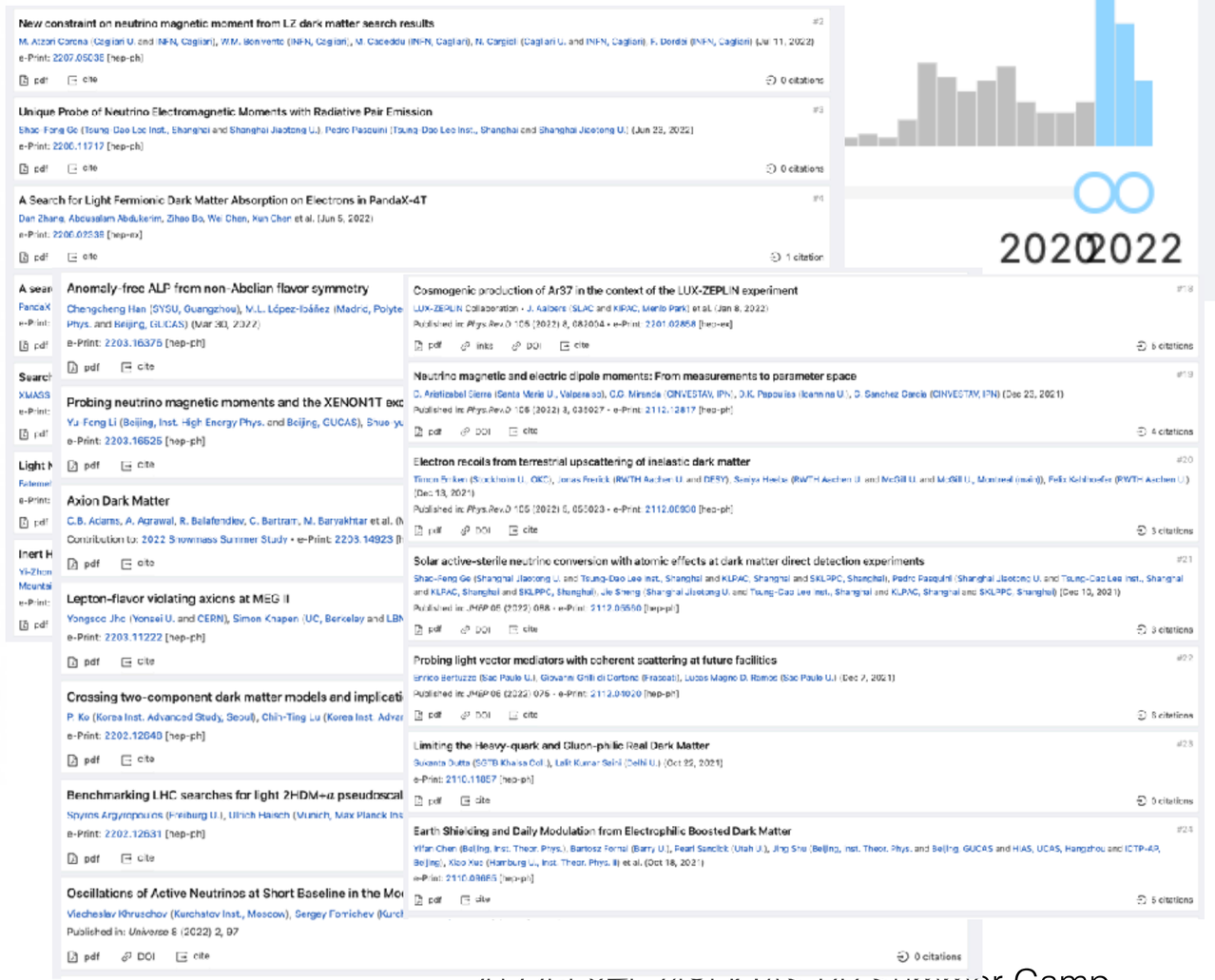


XENON 1t excess

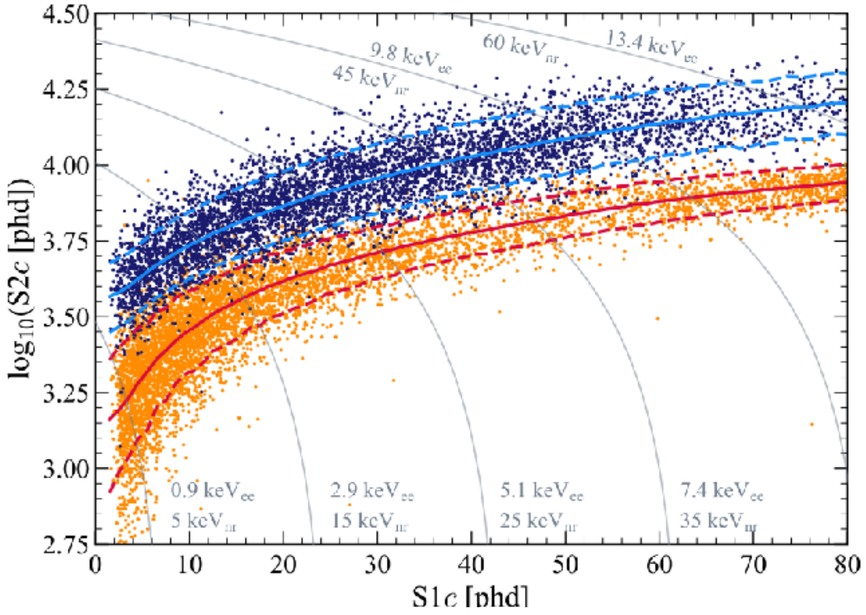


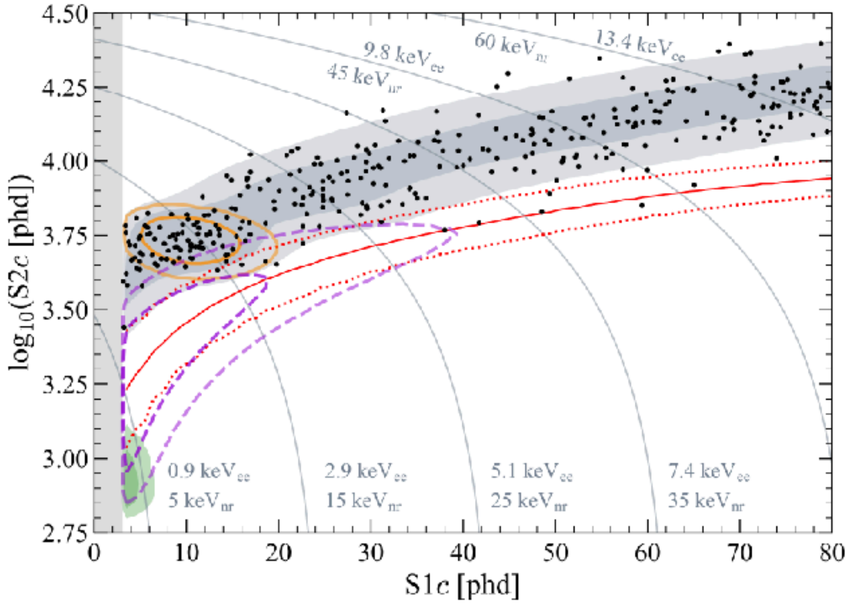
E. Aprile *et al.* (XENON Collaboration)
Phys. Rev. D **102**, 072004

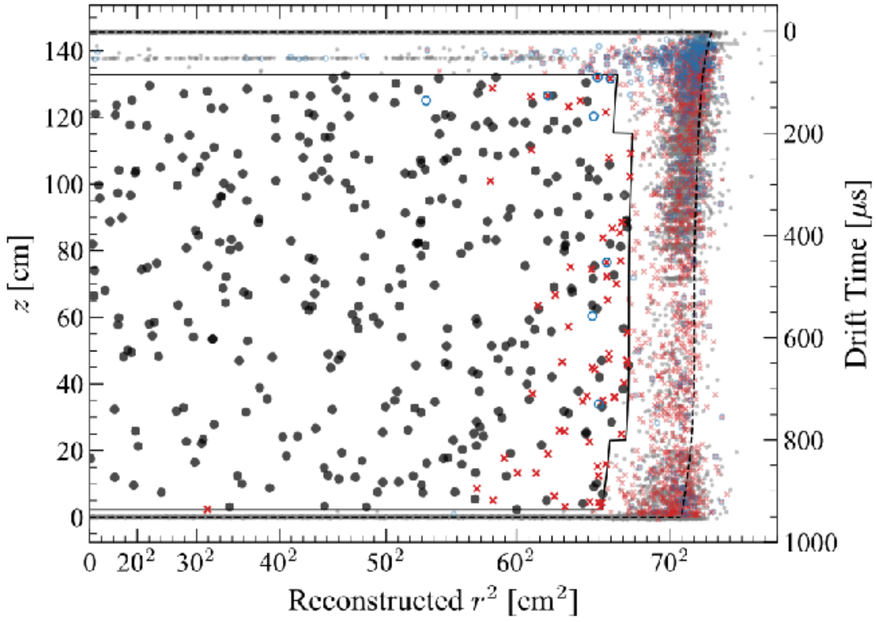
Oct. 2020

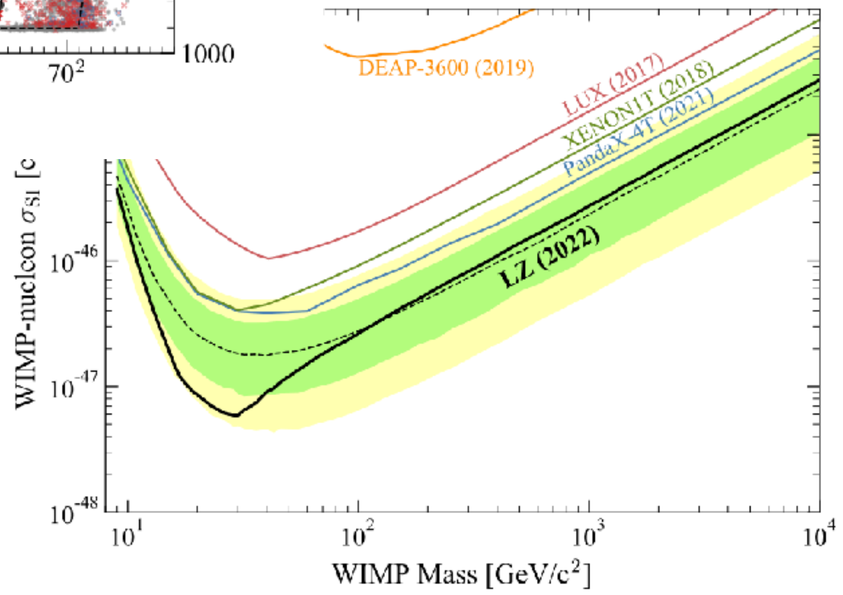


LZ experiment recent results





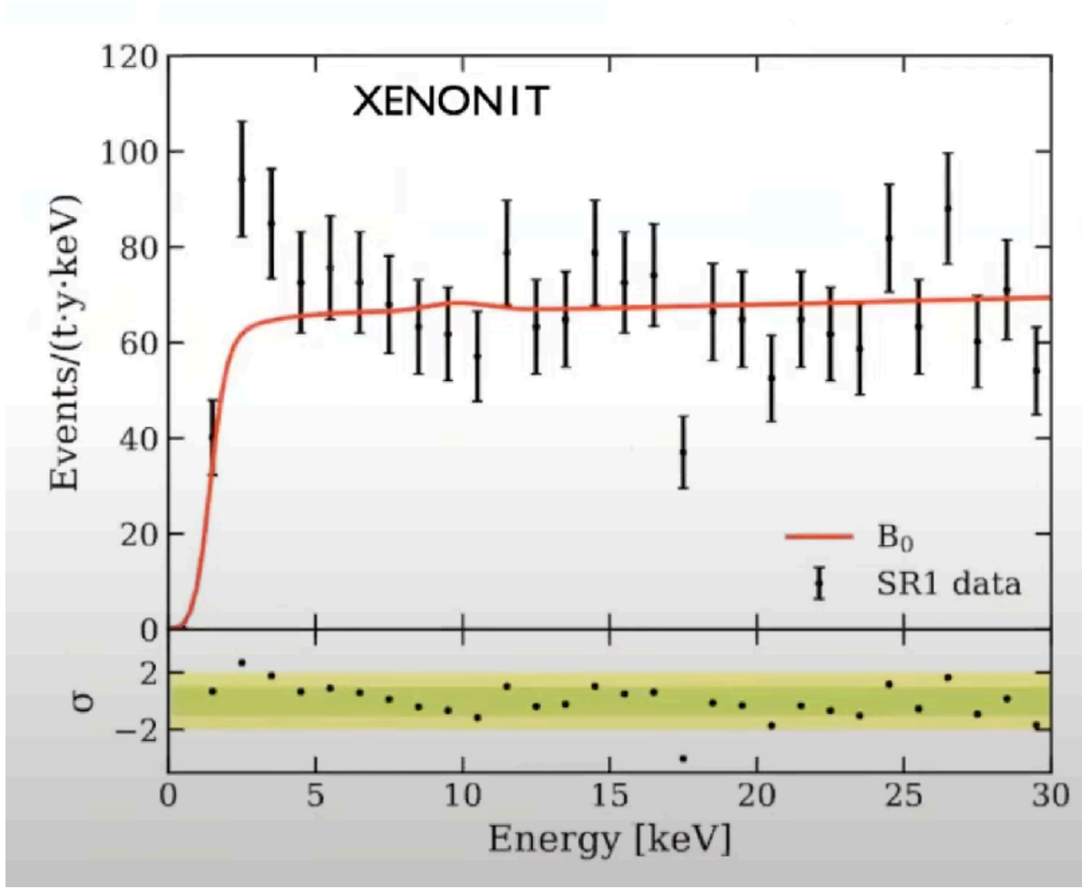


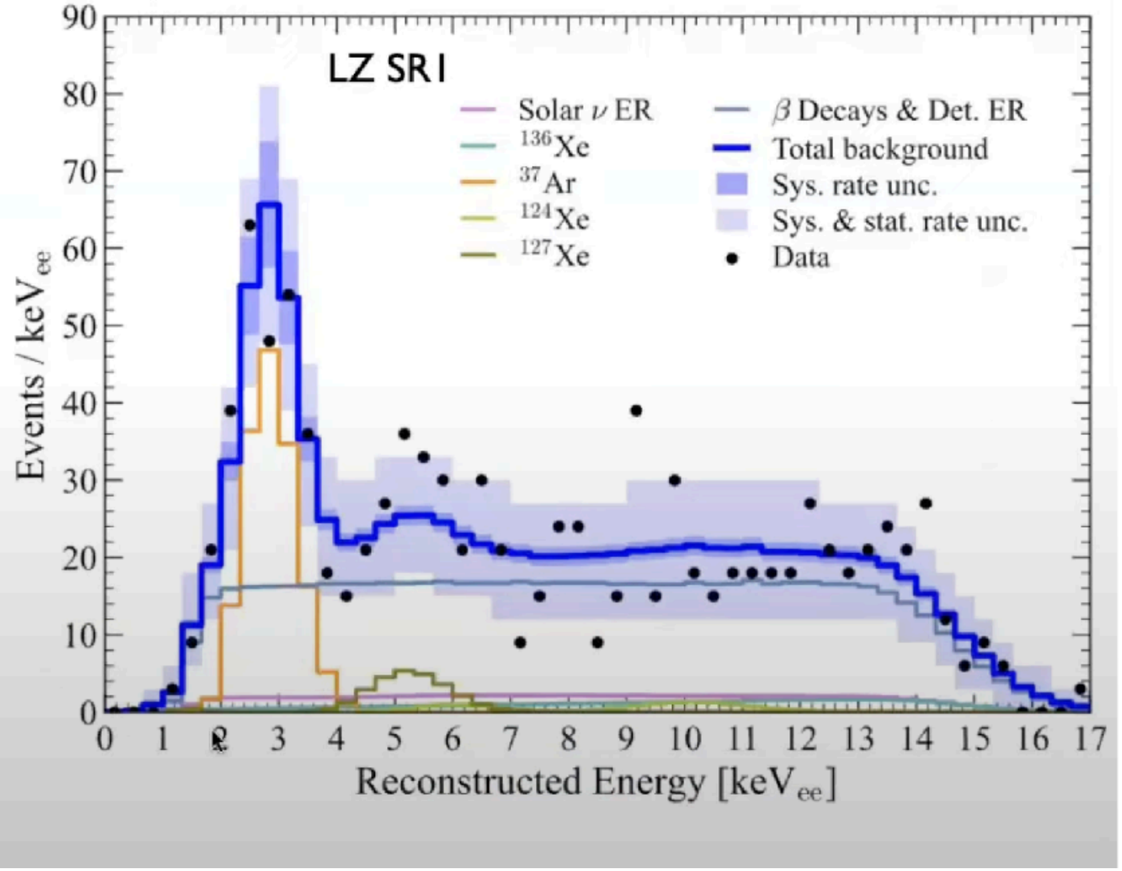


July 2022

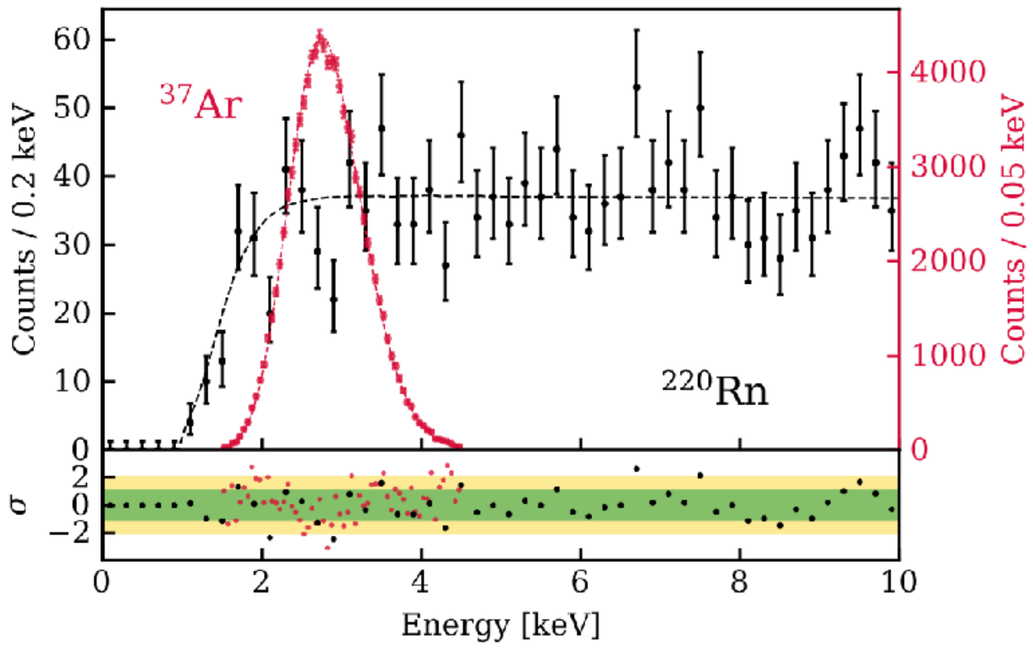
arXiv:2207.03764

LZ results indicate this might be ^{37}Ar



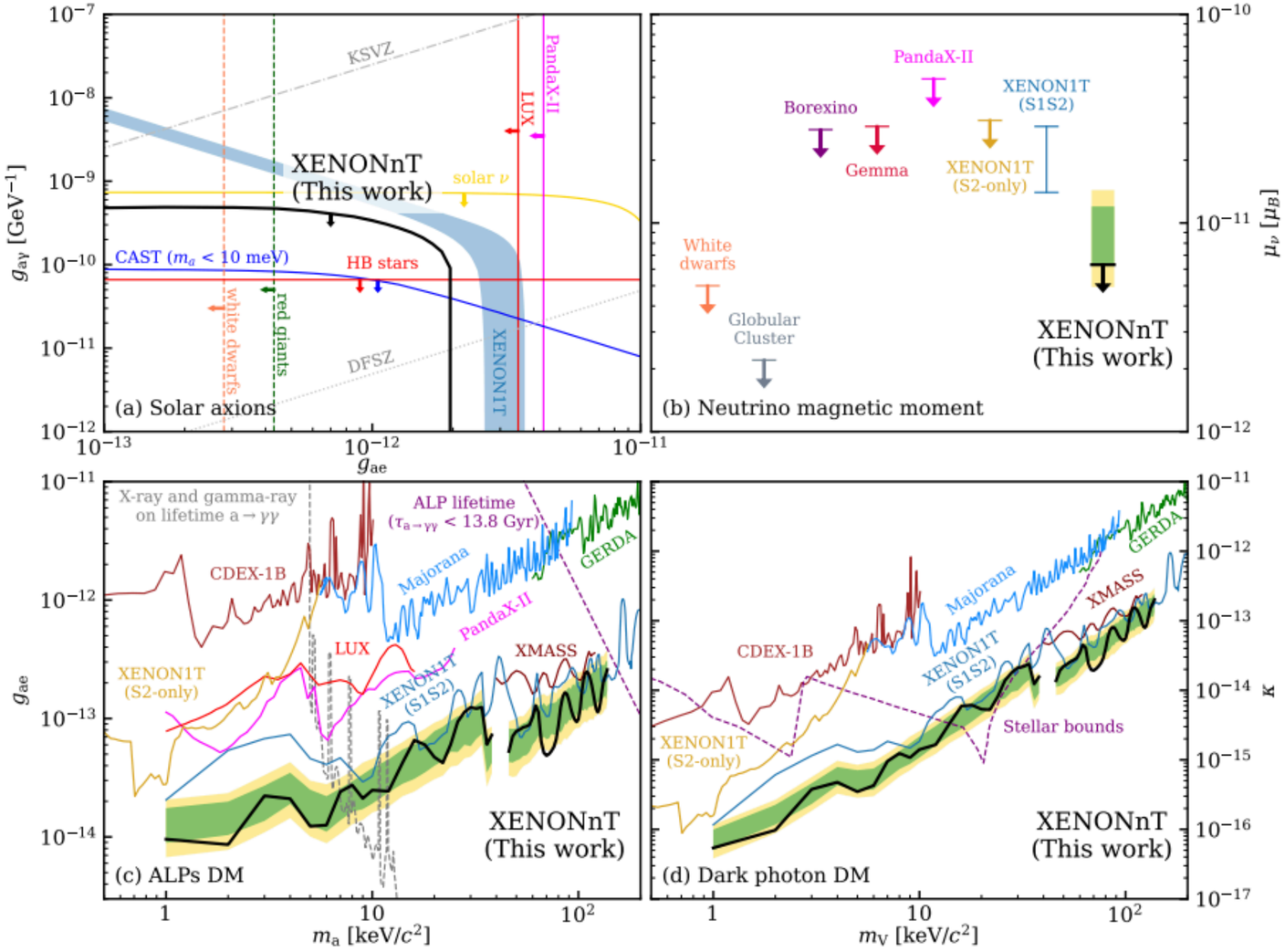


XENONnT recent results (new physics)



July 2022

arXiv:2207.11330



Summary and Outlook

- Universe is made of 27% dark matter that we do not know very well.
- Scientists are trying to detect particle dark matter candidate called WIMP.
- The tiny WIMP signal detection requires quiet environment with low-radioactivity and low-cosmic ray rate.
- There is one claimed detection of WIMP from the DAMA experiment that uses annual variation phenomenon.
- Among various efforts, Korea is specialized in using the crystal scintillator target with the same material as DAMA. So, the reproduction of the experiment is possible.
- We have ruled out a theory that explains the DAMA signal as a dark matter particle but we, then, need to figure out where the modulation comes from with better detection sensitivity. Coming soon.
- Experiments using Xe are leading the field and their results are coming out at the moments.
- Why do we dig? We dig deeper we come closer to the heart of Universe.

희귀반응입자검출실험실 : Rare Event Search Laboratory (RESL)

- 중성미자 실험 관련 연구 및 검출기 개발, 데이터 분석
- 암흑물질 입자 탐색 연구
- IceCube - 중성미자 진동 데이터 분석 (남극점)
- COSINE - 암흑물질 실험 하드웨어 R&D 및 데이터 분석 (양양)
- NEON - 핵발전소 중성미자 검출 (영광)
- AMoRE - 중성미자 미방출 이중베타붕괴 실험 (정선)

