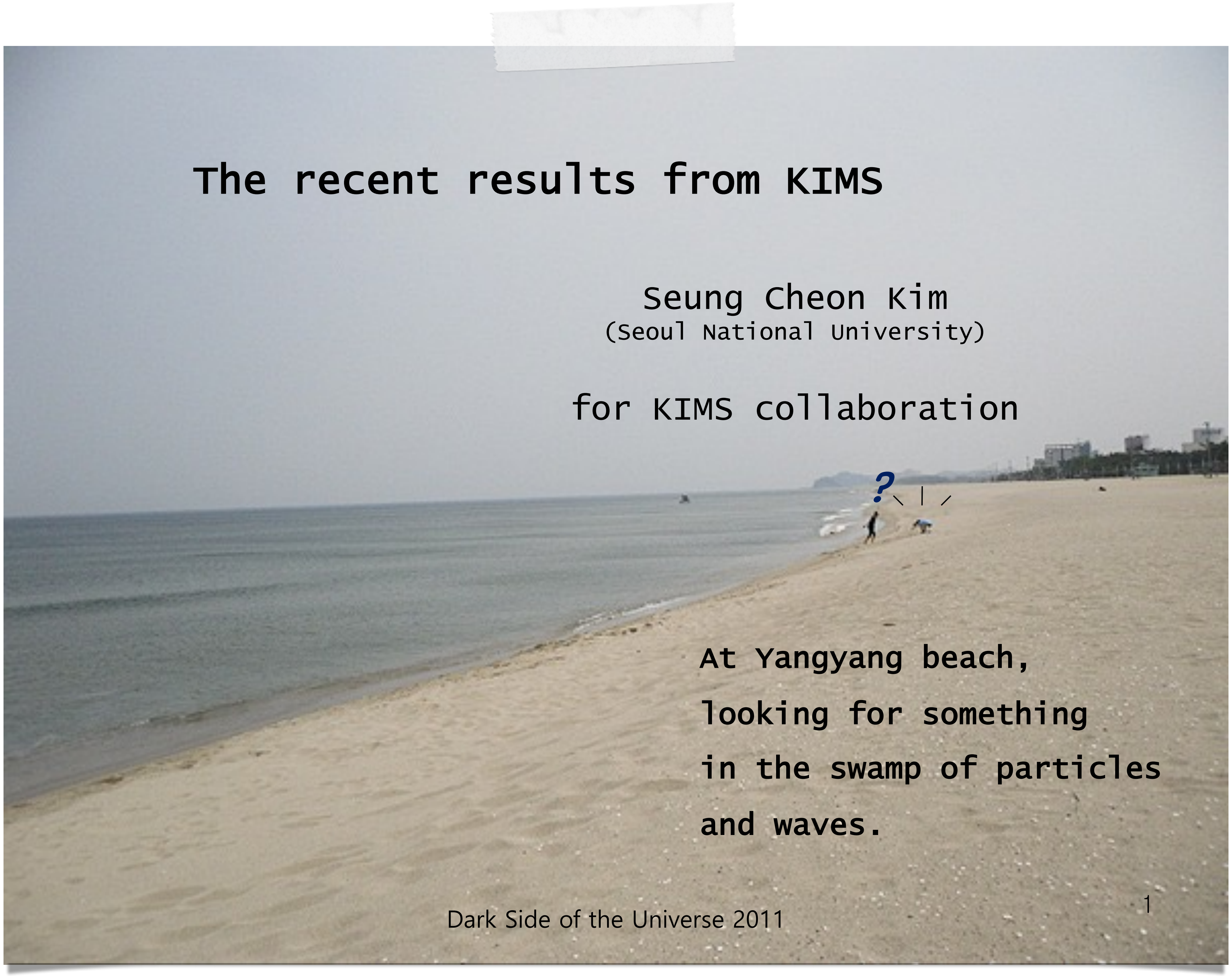
KIMS experiment

Searching for WIMP with CsI crystals

SeungCheon Kim
(CUP, IBS)

Underground Physics Workshop, SNU
15Sep2023

My fond recalling of KIMS



Slide from SeungCheon Kim, DSU 2011

KIMS in wiki

Korea Invisible Mass Search

文A 1 language

Article Talk Read Edit View history Tools

From Wikipedia, the free encyclopedia

The **Korea Invisible Mass Search** (**KIMS**), is a South Korean experiment, led by Sun Kee Kim, searching for weakly interacting massive particles (WIMPs), one of the candidates for dark matter.[1] The experiments use CsI(Tl) crystals at **Yangyang Underground Laboratory (Y2L)**, in tunnels from a preexisting underground power plant.[2] KIMS is supported by the Creative Research Initiative program of the Korea Science and Engineering Foundation. It is the first physics experiment located, and largely built, in Korea.[3]

KIMS in wiki

NOT “Kim’s family”

Korea Invisible Mass Search

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Weakly Interacting Massive Particles (WIMP),
One of the candidates for dark matter :
Particles of ~100 GeV mass from BSM
Nuclear recoil of a few keV
They seemed to be detectible!
But, Never (so WEAK) !!

KIMS in wiki

Korea Invisible Mass Search

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CsI(Tl) :
Experiences from Belle experiments
Higher light yield than NaI of DAMA, Easy handling
What about the background?

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CsI(Tl) :
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What about the background?

DAMA :
Famous early runner in DM hunting race
They believe they already got them!
They used NaI, so similar detector (CsI) should see DM too!?

KIMS in wiki

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Yangyang Underground Lab (Y2L) :
Yangyang, remote (not any more) beautiful country side
Using spaces in Yangyang pumped storage power plant
700 m rock overburden
Reaching the underground lab by car
Muon flux of 3.8×10^{-7}/cm²/s

KIMS in wiki

Korea Invisible Mass Search

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“First physic experiment located, and largely built, in Korea”
Setting an example and a role model for the next generation in Korea
Inspiring young people to be innovative and open to challenge

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$\tilde{\chi}^0_1$-p elastic cross section

Experimental results on the $\tilde{\chi}^0_1$-p elastic cross section are evaluated at $m_{\tilde{\chi}^0_1}$=100 GeV. The experimental results on the cross section are often mass dependent. Therefore, the mass and cross section results are also given where the limit is strongest, when appropriate. Results are quoted separately for spin-dependent interactions (based on an effective 4-Fermi Lagrangian of the form $\overline{\chi}\gamma^\mu\gamma^5\chi\overline{q}\gamma_\mu\gamma^5 q$) and spin-independent interactions ($\overline{\chi}\chi\overline{q}q$). For calculational details see GRIEST 88B, ELLIS 88D, BARBIERI 89C, DREES 93B, ARNOWITT 96, BERGSTROM 96, and BAER 97 in addition to the theory papers listed in the Tables. For a description of the theoretical assumptions and experimental techniques underlying most of the listed papers, see the review on "Dark matter" in this "Review of Particle Physics," and references therein. Most of the following papers use galactic halo and nuclear interaction assumptions from (LEWIN 96).

Spin-dependent interactions

VALUE (pb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<$ 15	90	1 ALNER	07	ZEP2	Xe
$<$ 0.17	90	2 LEE	07A	KIMS	CsI
$<$ 5		3 AKERIB	06	CDMS	Ge
$<$ 2		4 SHIMIZU	06A	CNTR	CaF_2
$<$ 0.4		5 ALNER	05	NAIA	NaI Spin Dep.
$<$ 2		6 BARNABE-HE...	05	PICA	C
$<$ 1.4		7 GIRARD	05	SMPL	F, Cl
$<$ 4		8 KLAPDOR-K...	05	HDMS	Ge

Citation: C. Amsler et al. (Particle Data Group), PL B667, 1 (2008) (URL: http://pdg.lbl.gov)

"First physic experiment locate
Setting an example and a role r
Inspiring young people to be in

World class results
Starting to appear in "The Review of Particle Physics" by PDG since 2008

Brief History of KIMS

- **97 Summer** : First discussion on WIMP search(cryogenic detector)
- **97 Fall** : Started R&D on CsI(Tl) for WIMP search
- **98 Summer** : First result at ICHEP98
- **99 Spring** : Started background measurement at Cheongphyung
- **99 Summer** : Started measurement of intrinsic background from crystal, shielding material
- **99 Fall** : Expanded the collaboration
- **00 Spring** : Prototype shielding structure installed
- **00 Summer** : Approval of the proposal for CRI
- **00 Fall** : DMRC established/ KIMS collab. Expanded
- **01 March** : Taiwan, China joined KIMS collab.

Slide from SunKee Kim,
“WIMP Dark Matter Search”, 2001(?)

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Slide from SunKee Kim,
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2003 : Experiments at Yangyang underground lab

Why CsI(Tl) Crystal ?

Advantage

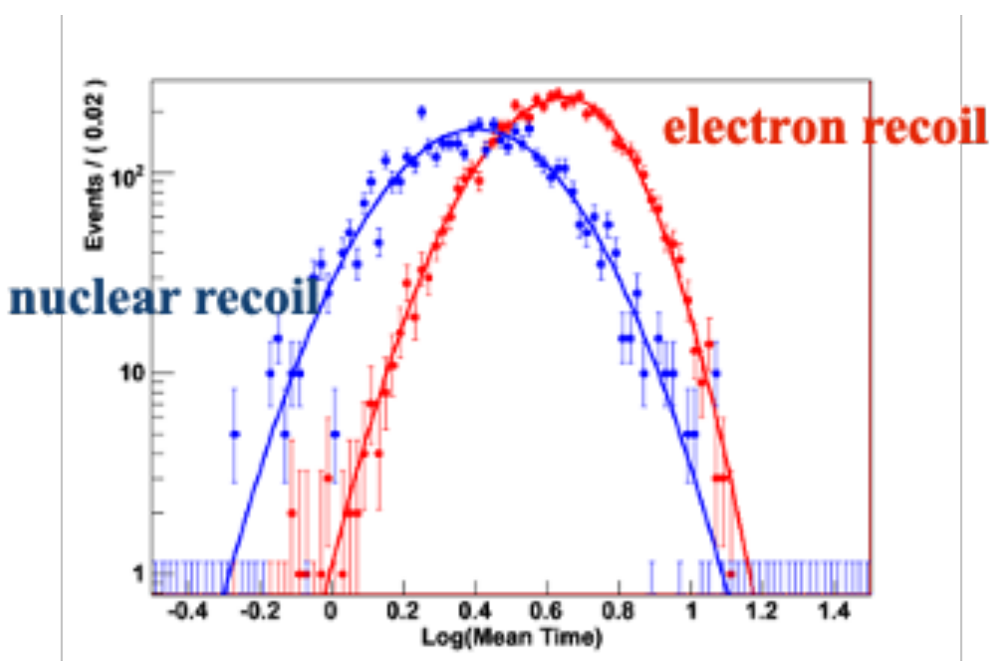
- High light yield ~50,000/MeV
- Pulse shape discrimination
- Easy fabrication and handling
- High mass number(both Cs and I)
- SI + SD

	CsI(Tl)	NaI(Tl)
Density(g/cm3)	4.53	3.67
Decay Time(ns)	~1000	~230
Peak emission(nm)	550	415
Hygroscopicity	**slight**	strong

Disadvantages

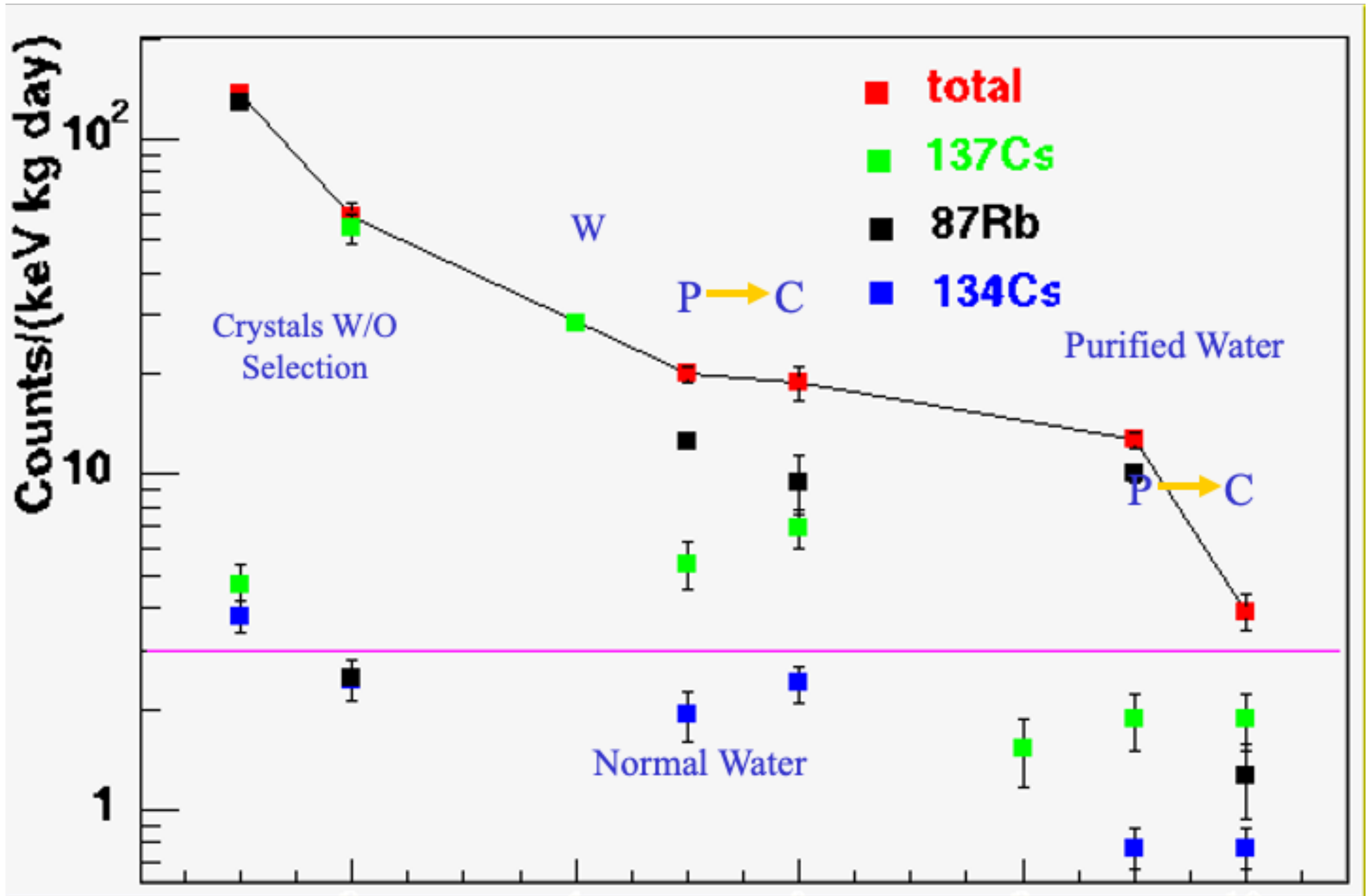
- Emission spectra does not match with normal bi-alkali PMT
- ^{137}Cs($\tau_{1/2}$~30y) ,^{134}Cs($\tau_{1/2}$~2y) may be problematic

Slide from Yeongduk Kim, IDM 2002



Isotope	J	Abun	<Sp>	<Sn>
^{133}Cs	7/2	100%	-0.370	0.003
^{127}I	5/2	100%	0.309	0.075
^{73}Ge	9/2	7.8%	0.03	0.38
^{129}Xe	1/2	26%	0.028	0.359
^{131}Xe	3/2	21%	-0.009	-0.227

Summary of Internal Background Reduction



Slide from Yeongduk Kim,
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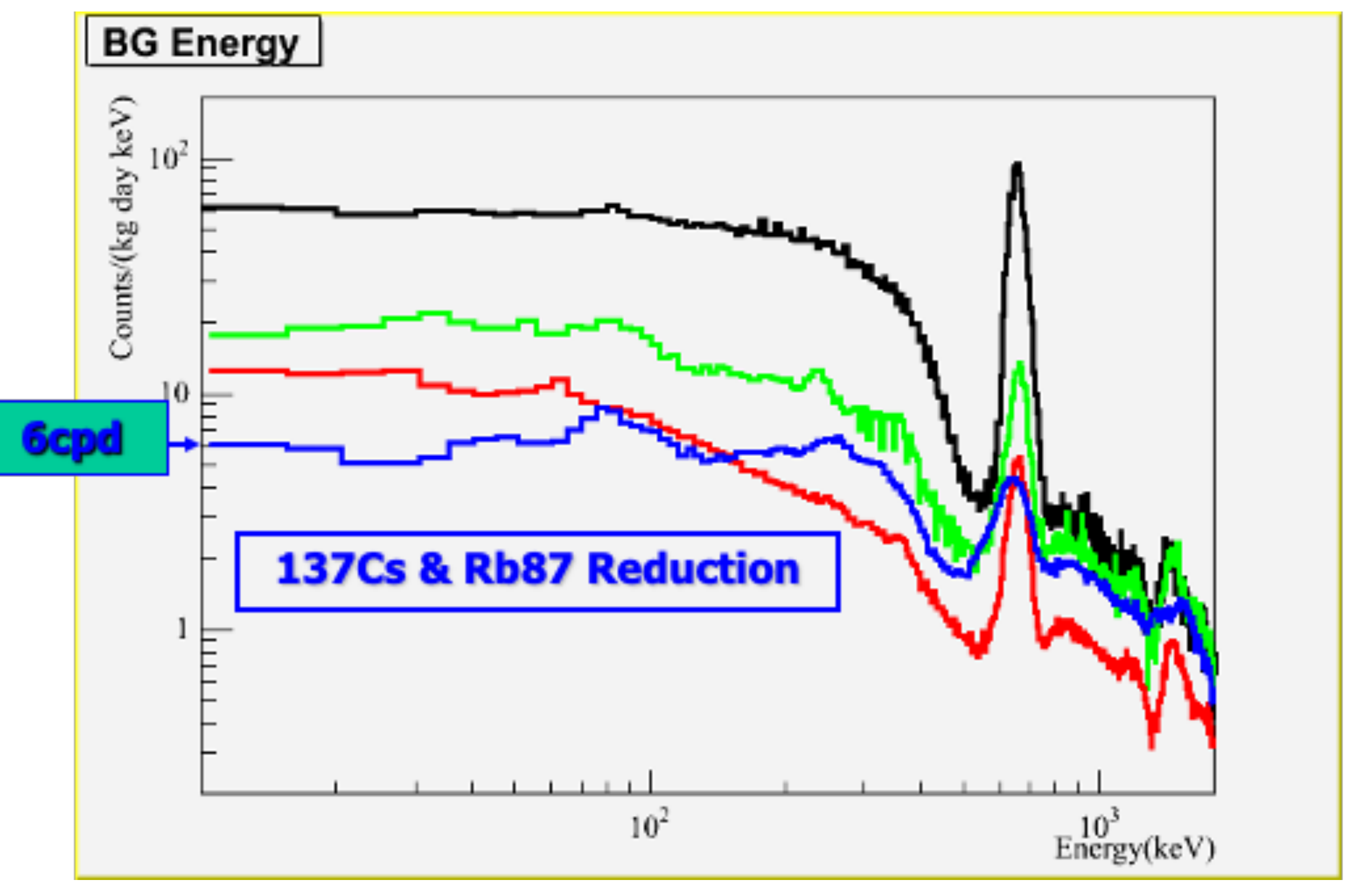


Contributions

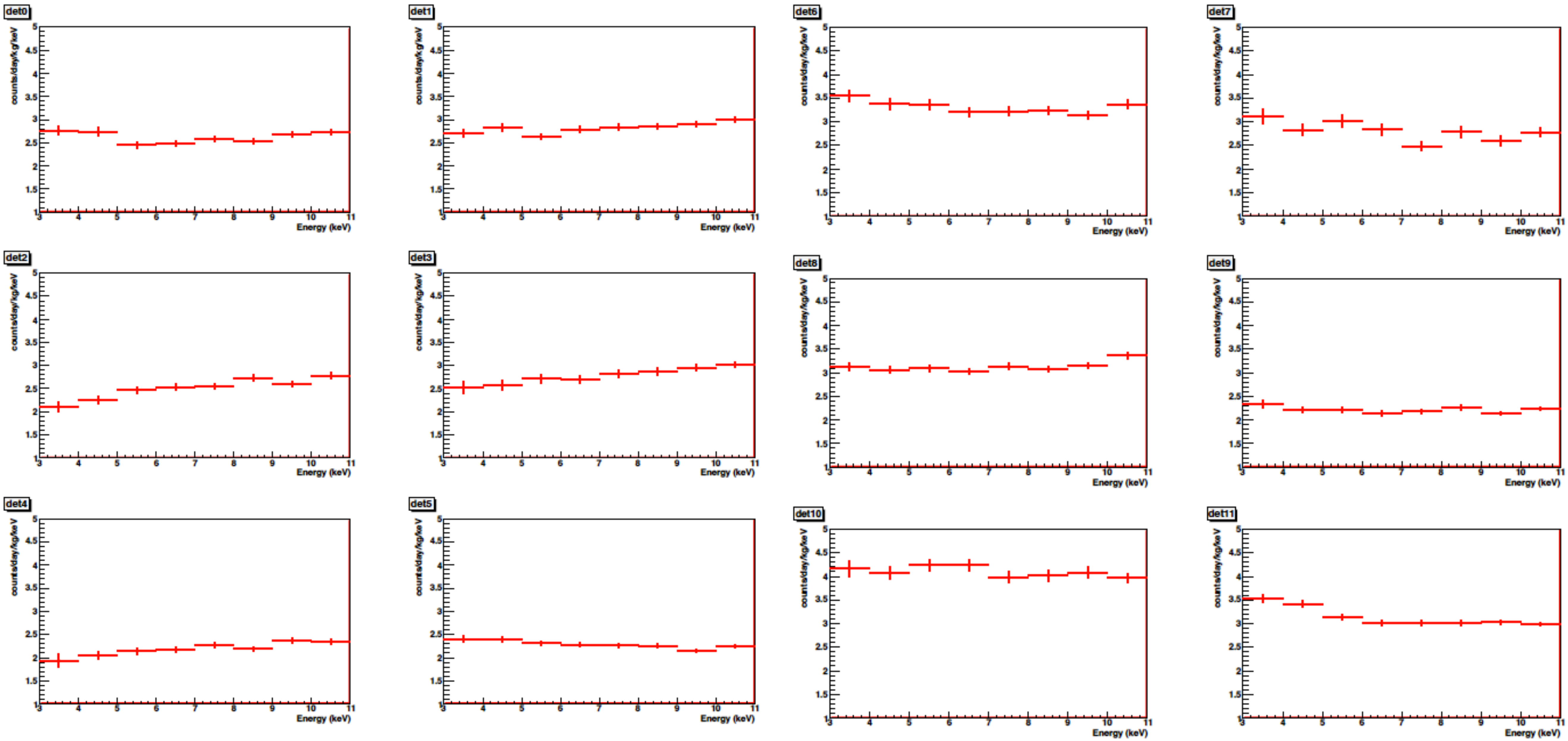
1. **Cs137 ~ 3.0 cpd**
2. **Cs134 ~ 1.8 cpd**
3. **Rb87 ~ 1.0 cpd**

Total ~ 6 cpd @ 10keV

237 kg days data

Slide from Yeongduk Kim,
The Future of Dark Matter Detection 2004 (?)

Background level reached 2~4 cpd, eventually.



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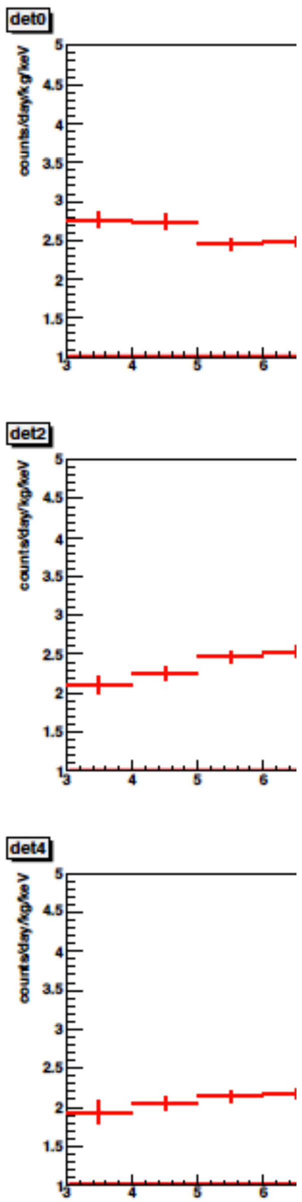
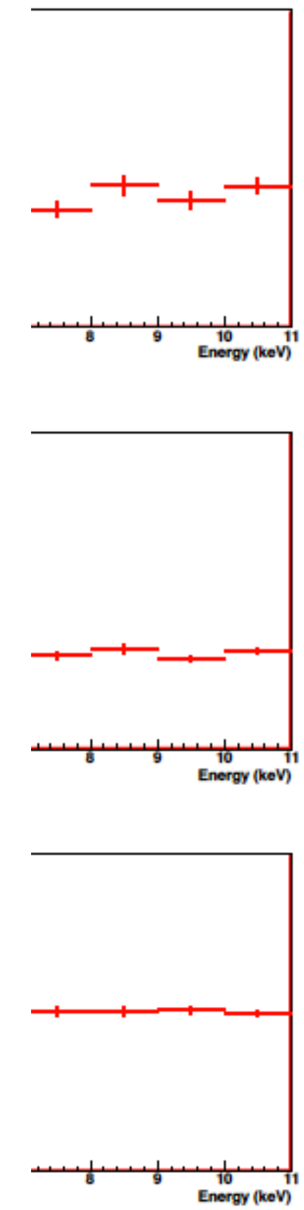


Background at the low energy

A few tens of recoil energy will be measured as a few keV because quenching.
The current background level below 10 keV
: 2.8 counts/keV/kg/day (cpd) + PMT dark current

γ & β background (electron recoil (ER) events) -main background	Background level (cpd) & their origin
Internal source	~ 1 ($^{134,137}Cs$) ~ 0.1 (^{238}U, ^{232}Th) ~ 0.3 (^{87}Rb)
PMT	~ 0.5 (^{238}U, ^{232}Th, ^{40}K)
Crystal surface (progenies of ^{222}Rn)	0.1 – 1 (?) (mainly, ^{210}Pb)
Surface alpha (SA)	~ 0.1
Scintillation at PMT body	< 0.1



Slide from SeungCheon Kim,
"A WIMP dark matter search with CsI(Tl) crystal" 2012 21

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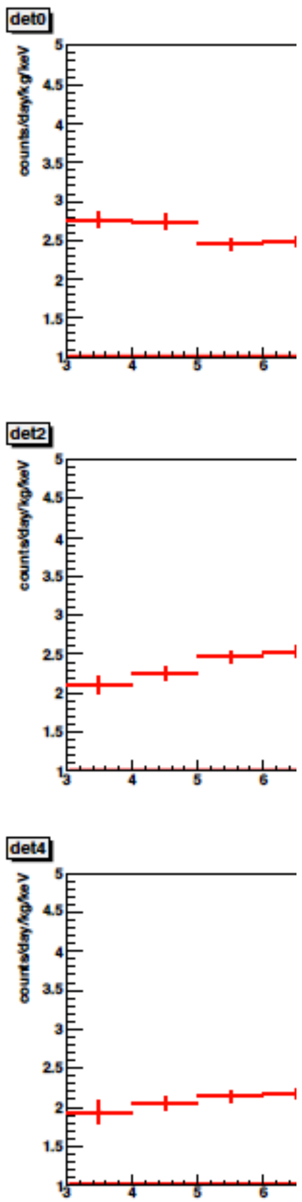

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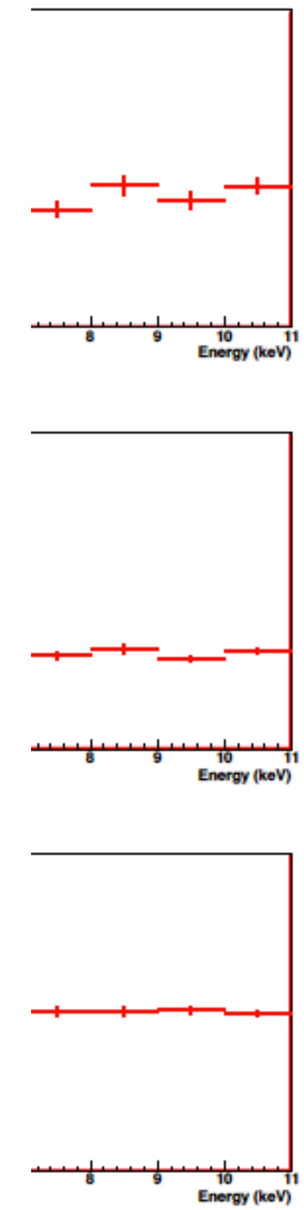


Slide from SeungCheon Kim,
"A WIMP dark matter search with CsI(Tl) crystal" 2012 [21]

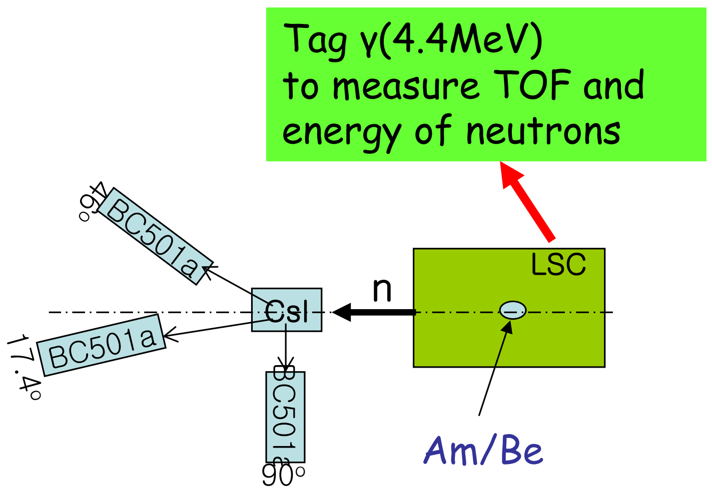
Detector with < 2 cpd possible now?
: good surface cleaning + clean PMT

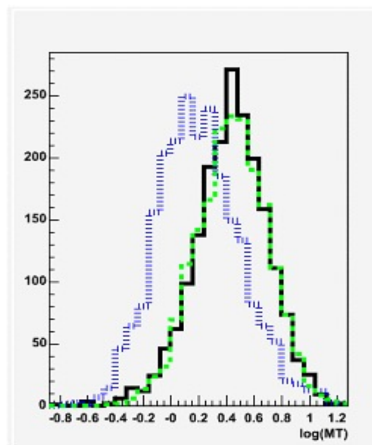
Neutron calibration facility in SNU

300 mCi Am/Be source
- **→ neutron rate 7 x 10^5 neutrons /sec**
- **→ a few 100 neutrons/sec hit 3cmX3cm crystal**
- **→ Quenching factor of Recoil Energy**

Take Neutron calibration data
PSD check - Quality factor

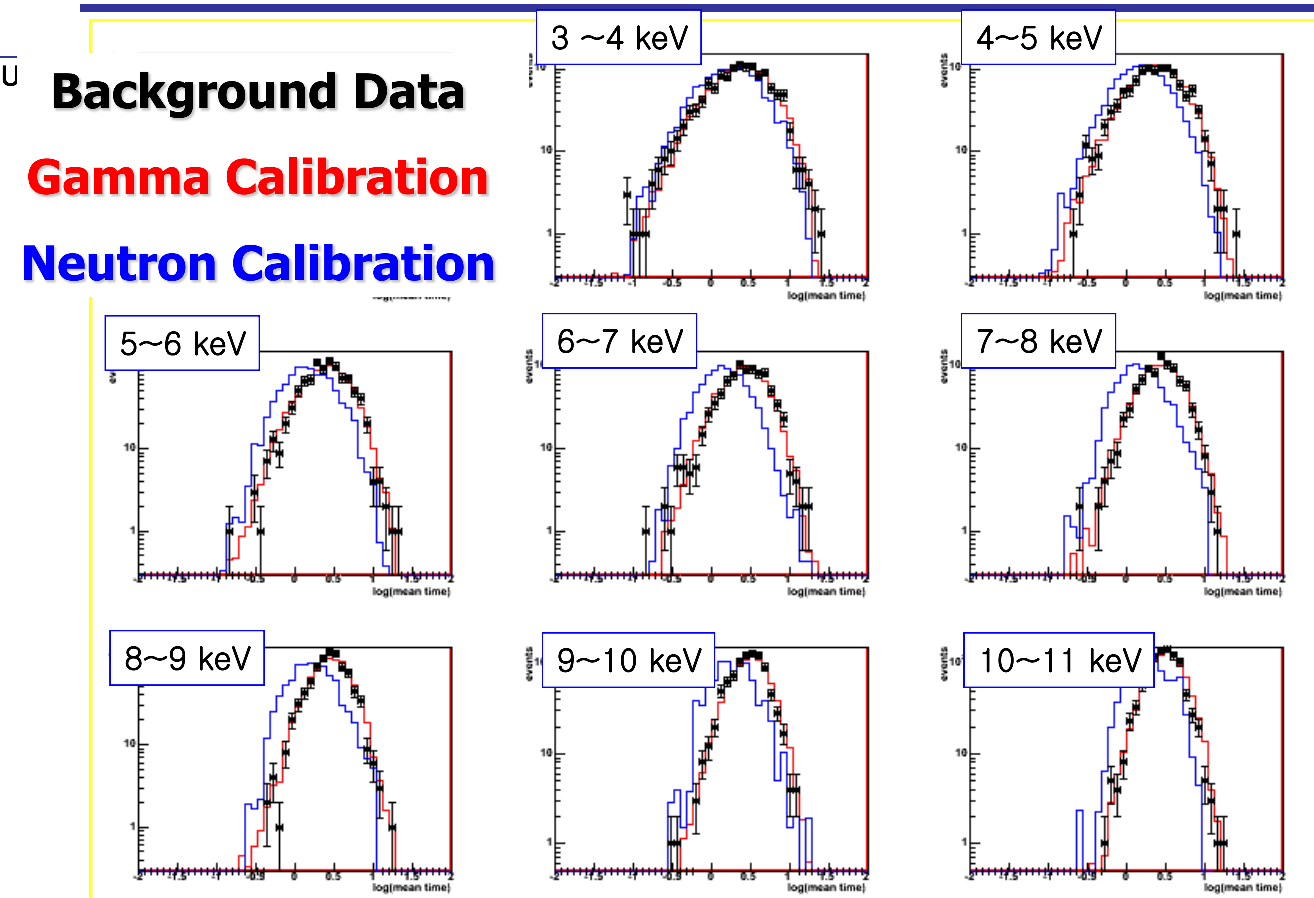
Nuclear recoil





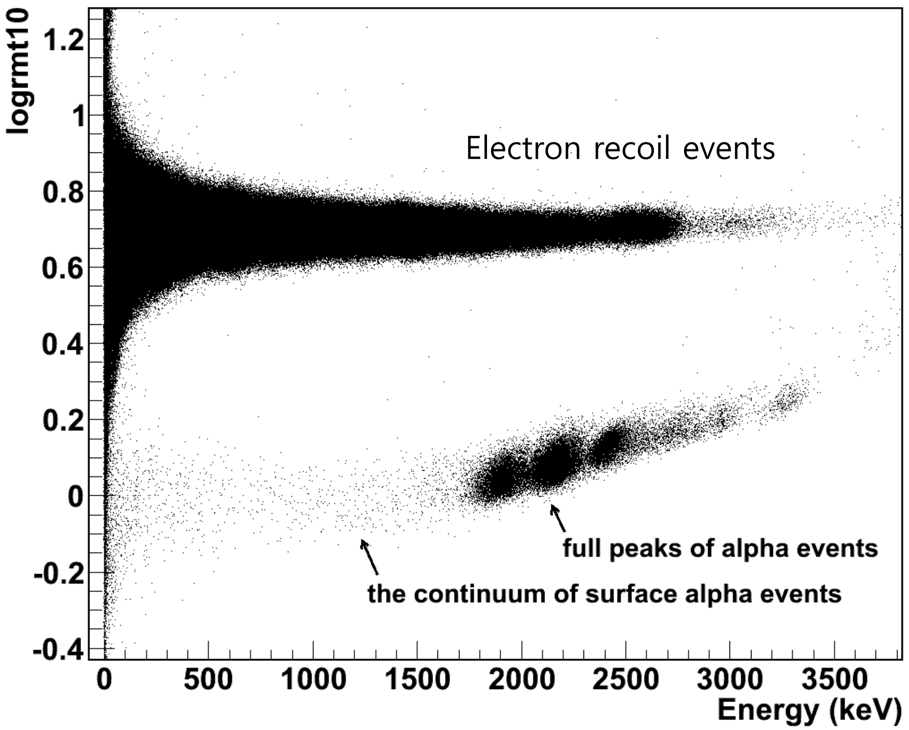
@Energy = 10 keV
137 Cs Compton
Neutron Recoil
Background data

Extraction of Nuclear recoil events

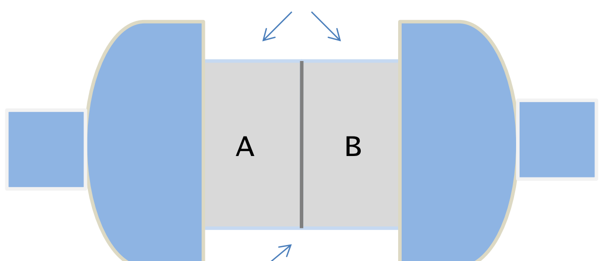


Slide from Hyunsu Lee,
“CsI(Tl) crystals for WIMP search”, 2006

Surface alpha (SA) background

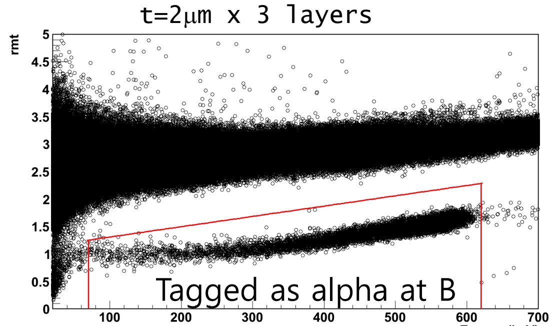


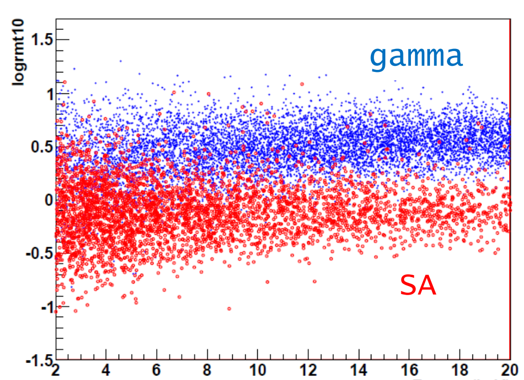
Study of SA events
using Rn progeny contaminated crystal



PMTs

CsI(Tl) crystal
A: Rn progeny contaminated
,exposed to Rn gas for 4 days
B: clean

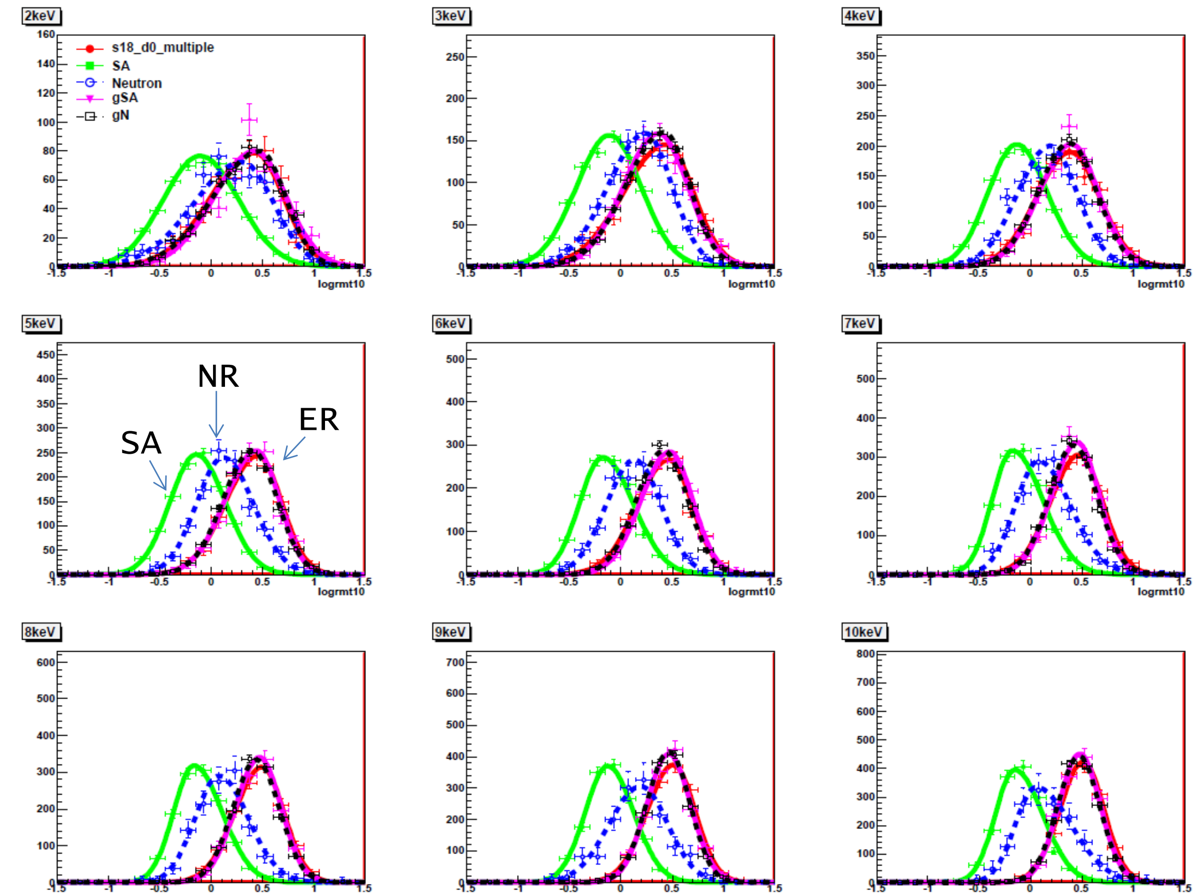




Dark Side of the Universe 2011 11

Surface alpha

Comparison of PSD parameter, logrmt10



Dark Side of the Universe 2011 12

Slide from SeungCheon Kim, DSU 2011

Detector design

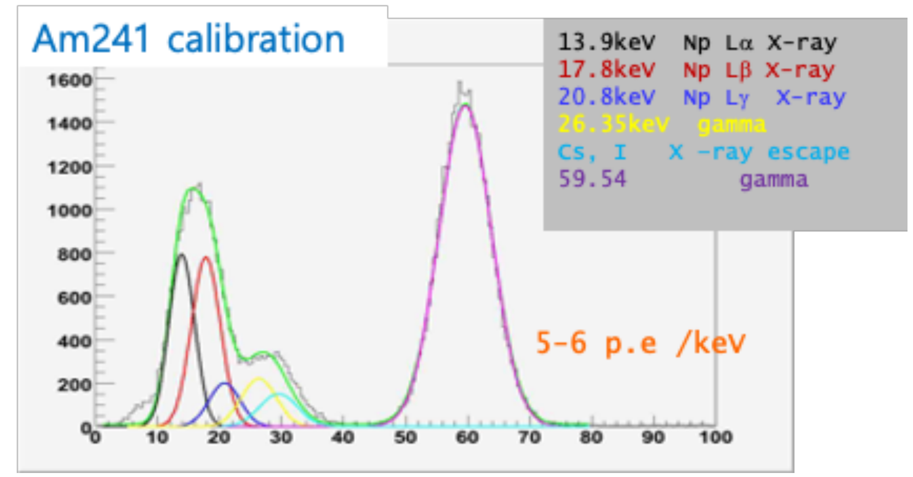
KIMS detector

One detector module : one CsI Crystal + 2 PMTs

Crystal size: 8x8x30 cm³ (8.7 kg)
(Beijing Hamamatsu Photon Techniques Inc.)

PMT : 3” PMT (9269QA),
Quartz window,
RbCs photo cathode
(green extended)

Event window is 40μs.
Digitized with 400MHz FADC



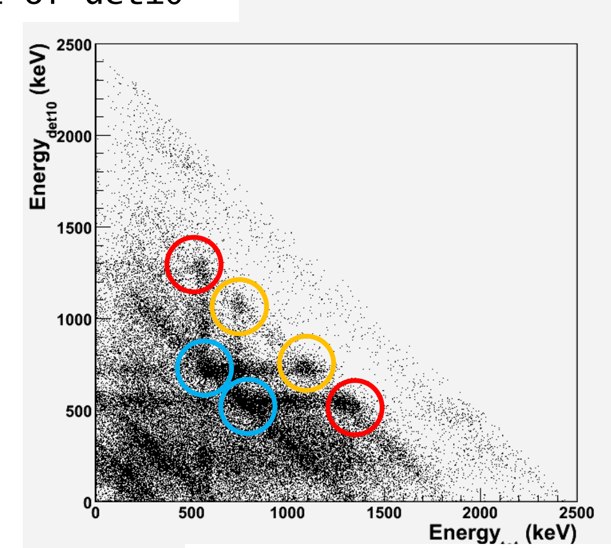
Detector array

3 x 4 detector array

The total mass : 103.4 kg

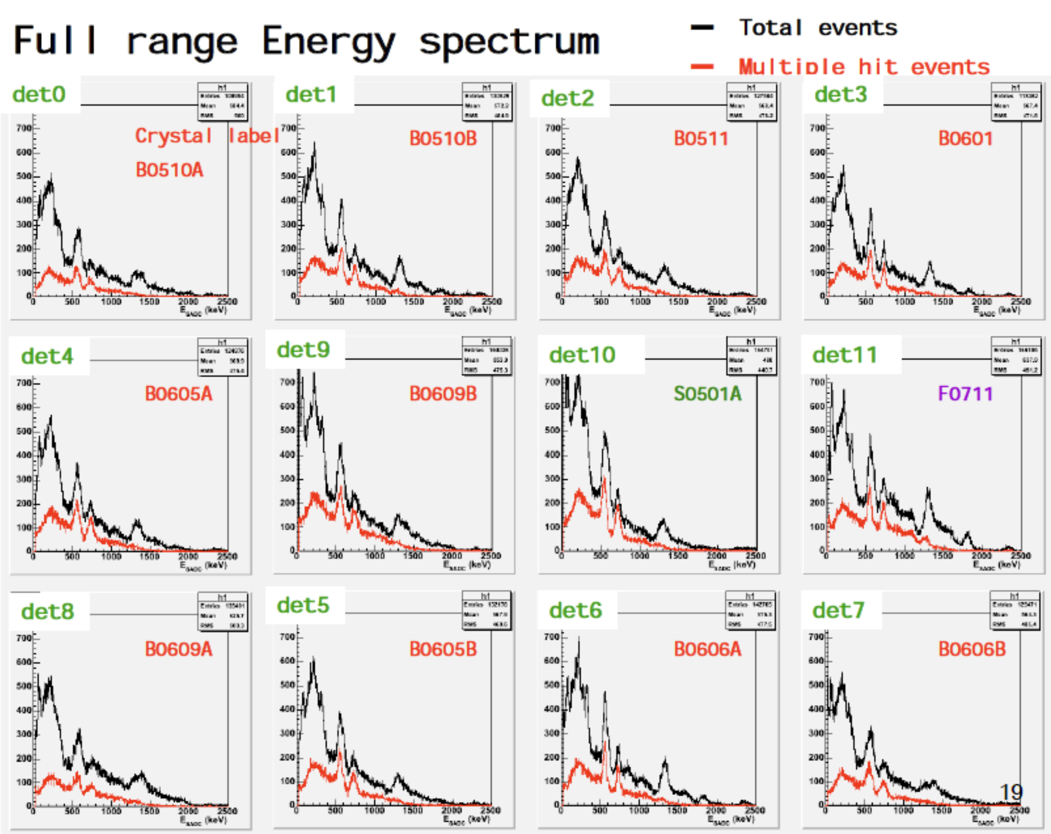
Multiple hit events
=> references for calibration

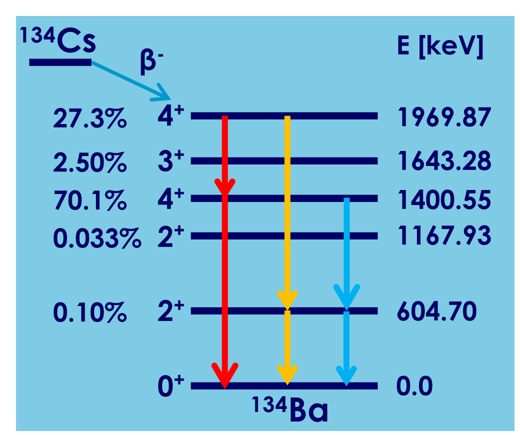
E of det10



Total E except det10

Full range Energy spectrum





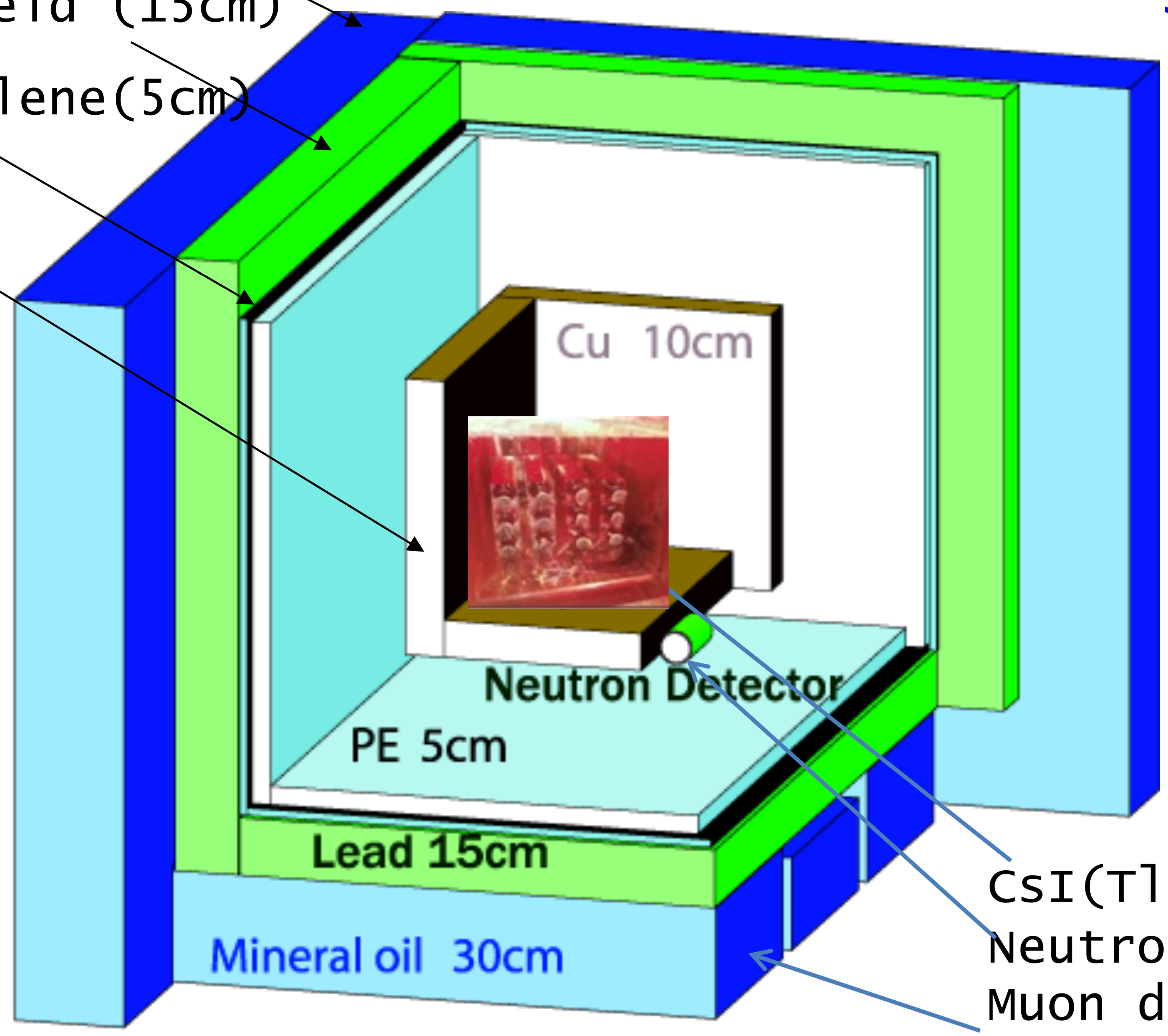
KIMS Detector system

Neutron shield(30cm mineral oil)

Lead shield (15cm)

Polyethylene(5cm)

Copper (10cm)



CsI(Tl) Scintillator

Neutron detector

Muon detector (Neutron sheild)

N_2 gas flow inside the Cu shield

Neutron shield(30cm mineral oil)

KIMS Detector

Lead shi

Polyethy

Copper
(10cm)

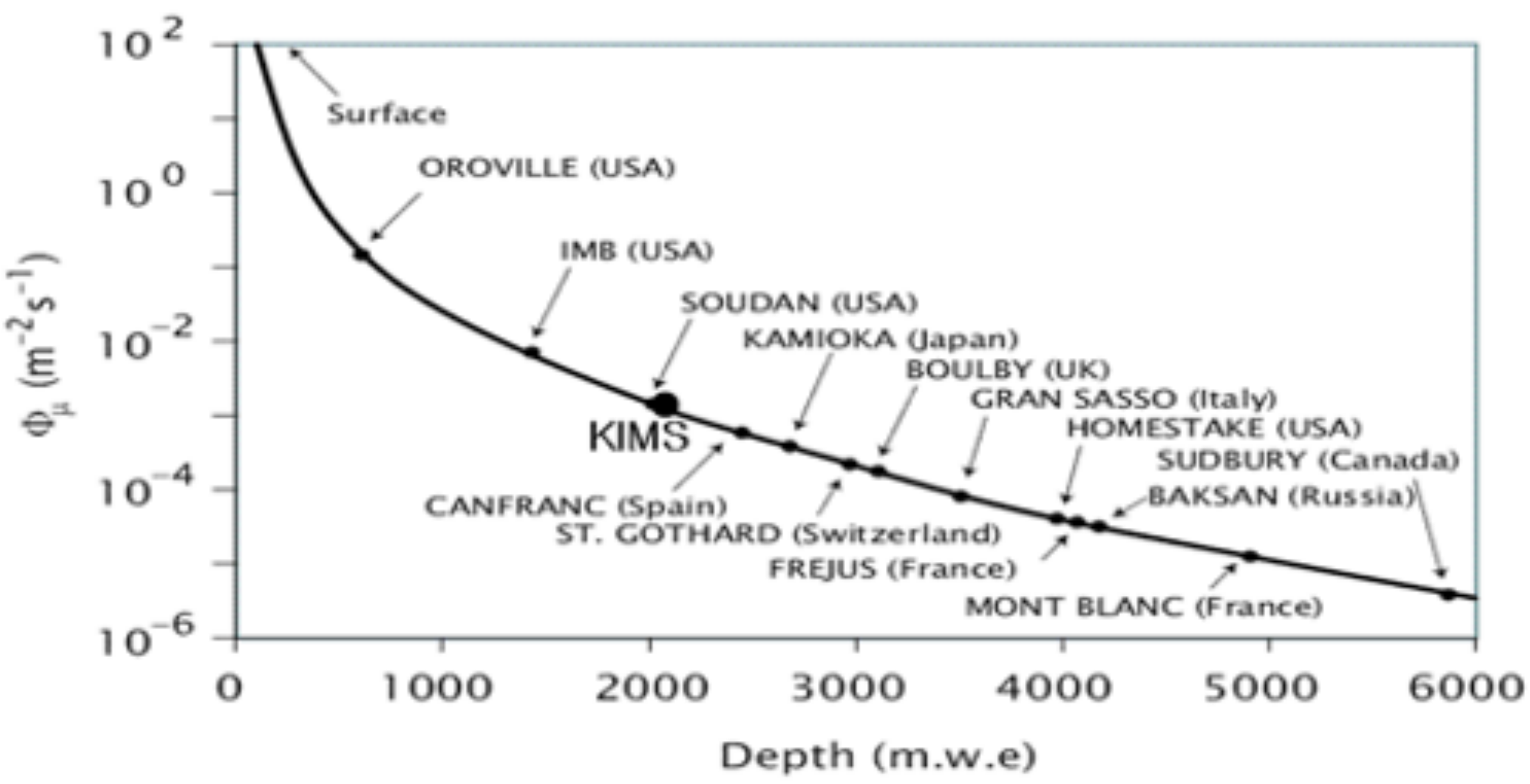
ator

(Neutron shield)

N_2 gas flow inside the Cu shield

Slide from Hongjoo Kim,
Windows on the Universe, 2013

Slide from Hongjoo Kim,
Windows on the Universe, 2013



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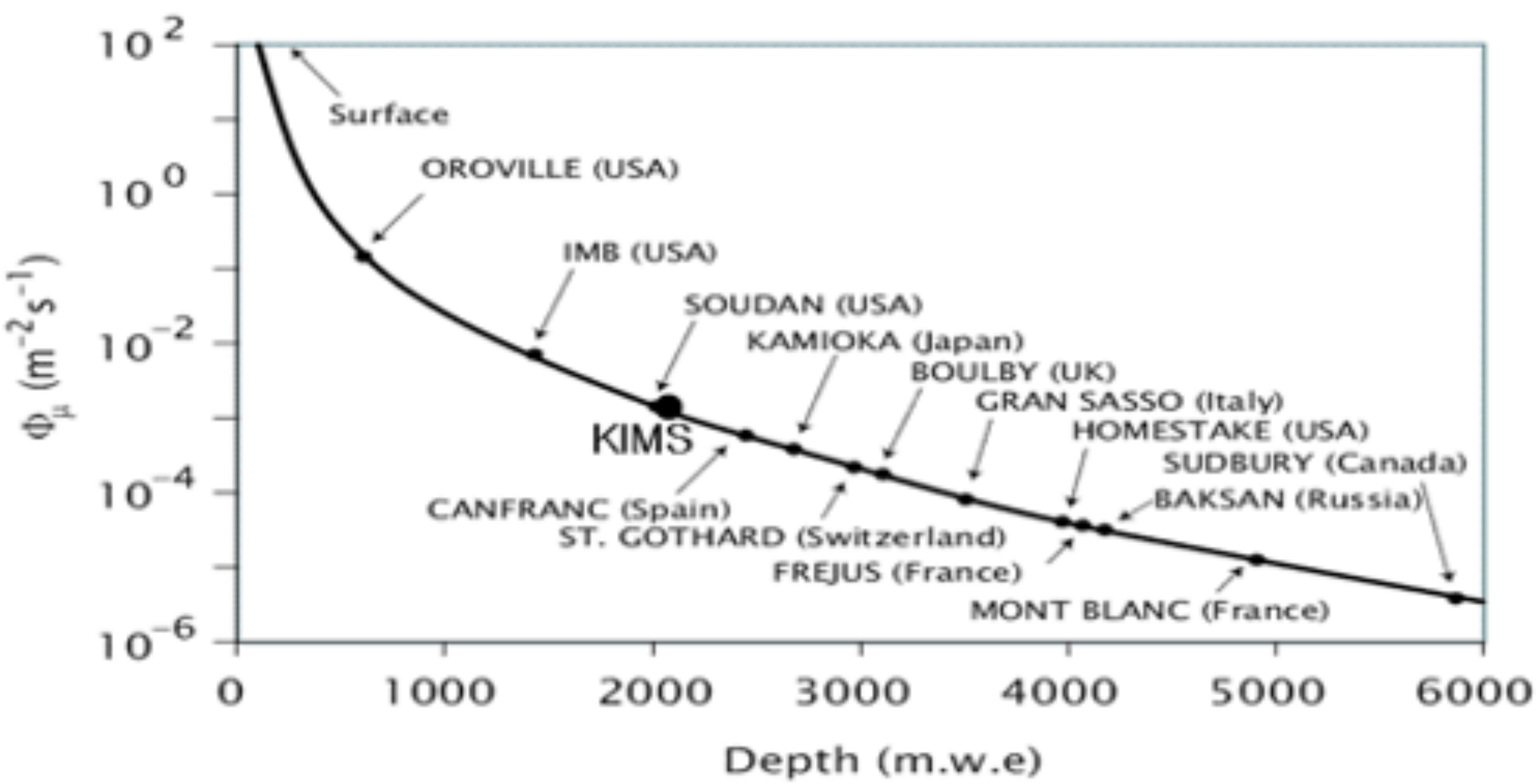
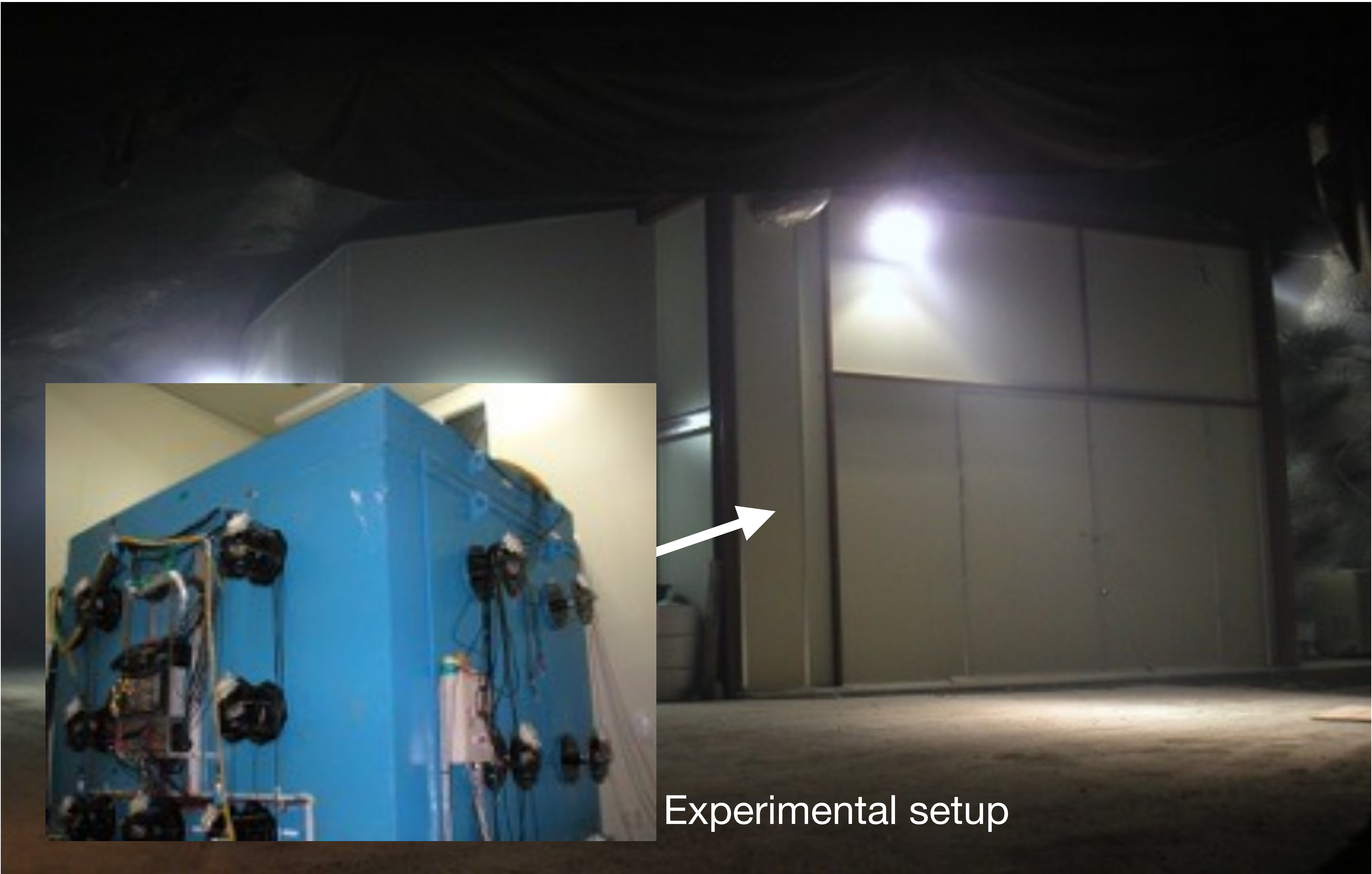


Depth	**Minimum 700 m**
Temperature	**20 ~ 25 °C**
Humidity	**35 ~ 60 %**
Rock contents	**^{238}U less than 0.5 ppm** **^{232}Th 5.6 ± 2.6 ppm**
Muon flux	**2.7 x 10^{-7} /cm^2/s**
Neutron flux	**8 x 10^{-7} /cm^2/s**
^{222}Rn in air	**1~2 pCi/liter**

Slide from Hongjoo Kim, Windows on the Universe, 2013

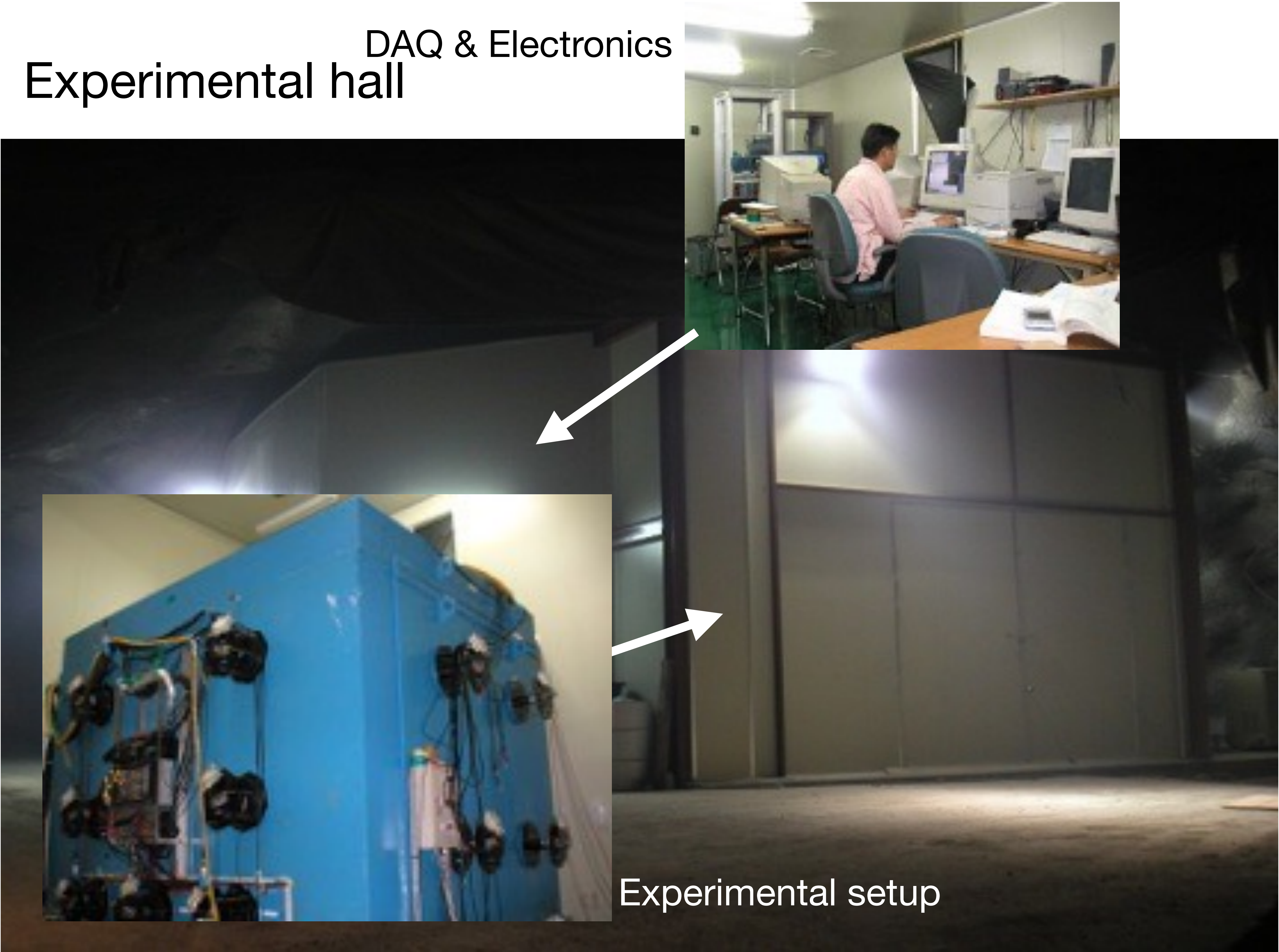
Experimental hall

Experimental hall



Experimental hall

DAQ & Electronics



Experimental setup

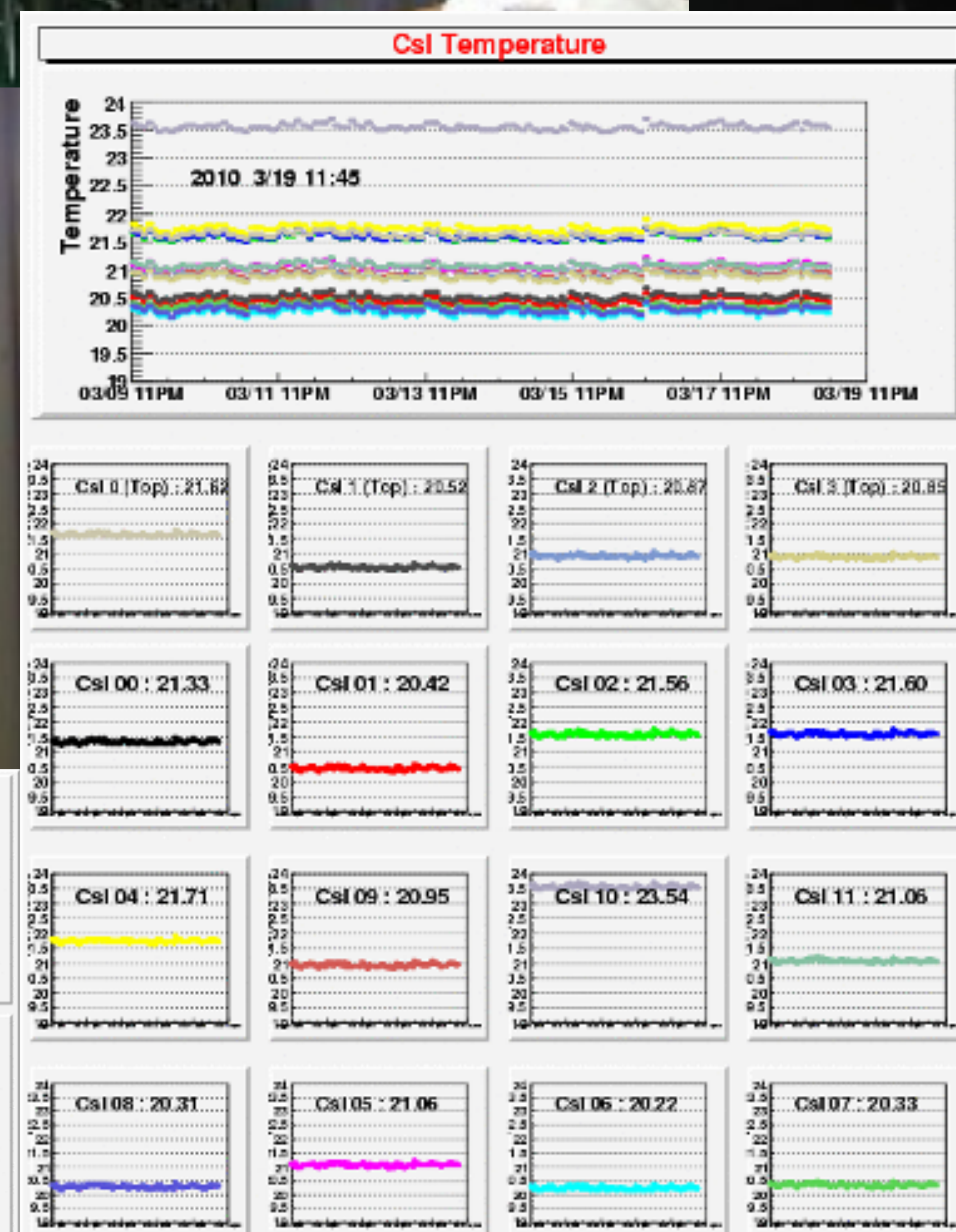
Experimental hall

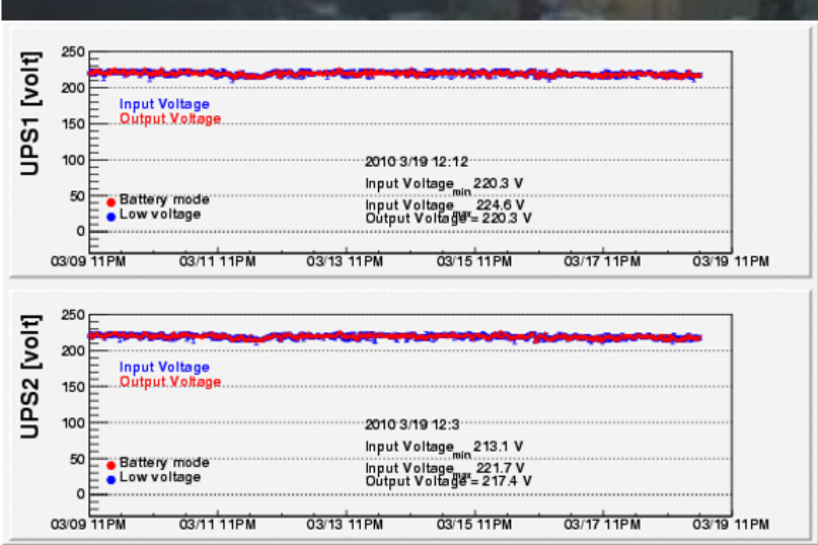
DAQ & Electronics

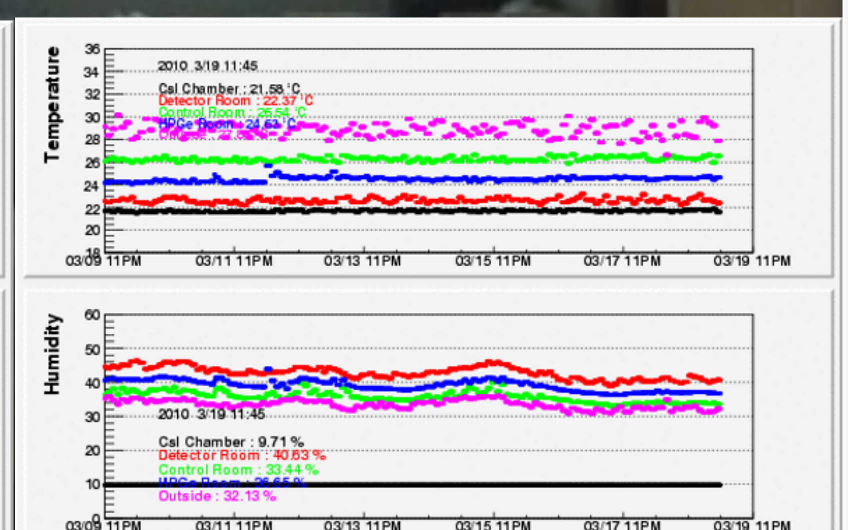
DAQ & Electronics

Experimental hall

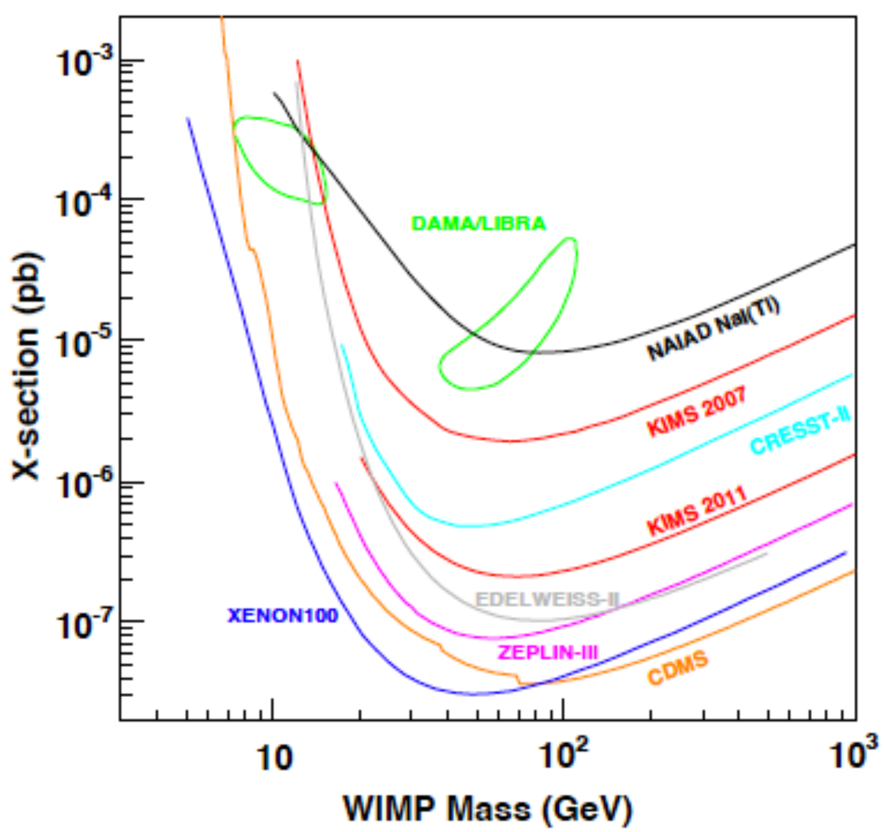
Online monitoring of temperature, humidity, power, Rn level

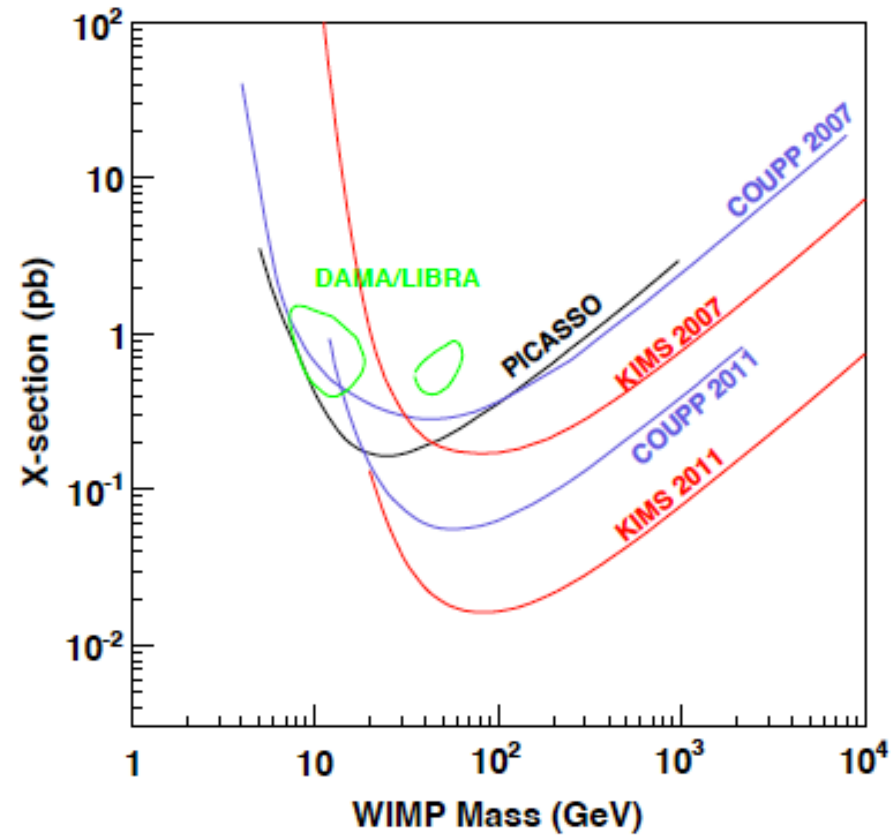




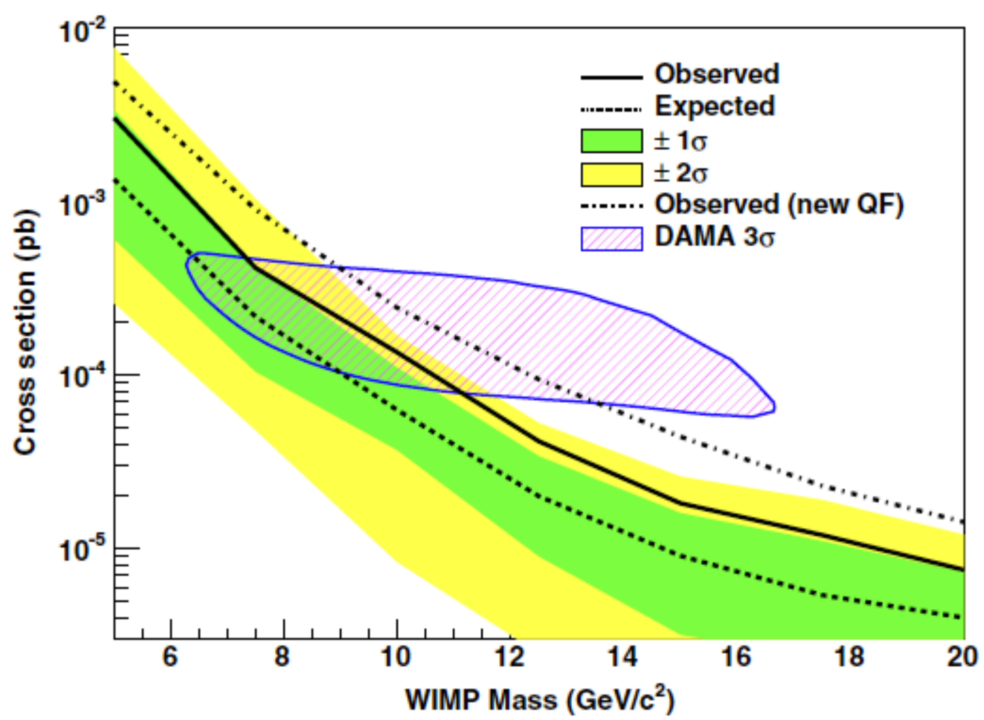


Exclusion limits for WIMP search





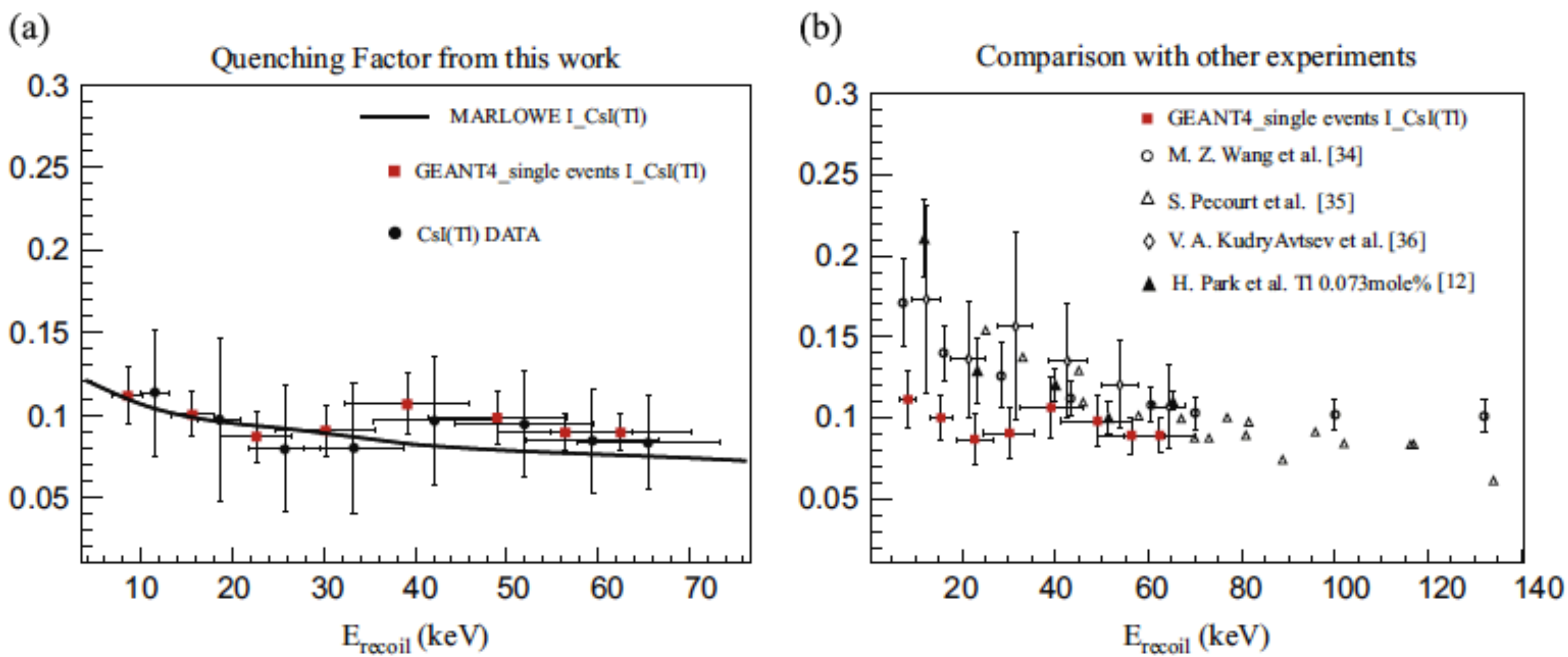
World best limit for spin dependent WIMP-proton interaction



KIMS 2007: H.S.Lee et al. PRL 99, 091301 (2007)
KIMS 2011: S.C.Kim et al. PRL 108, 181301 (2012)

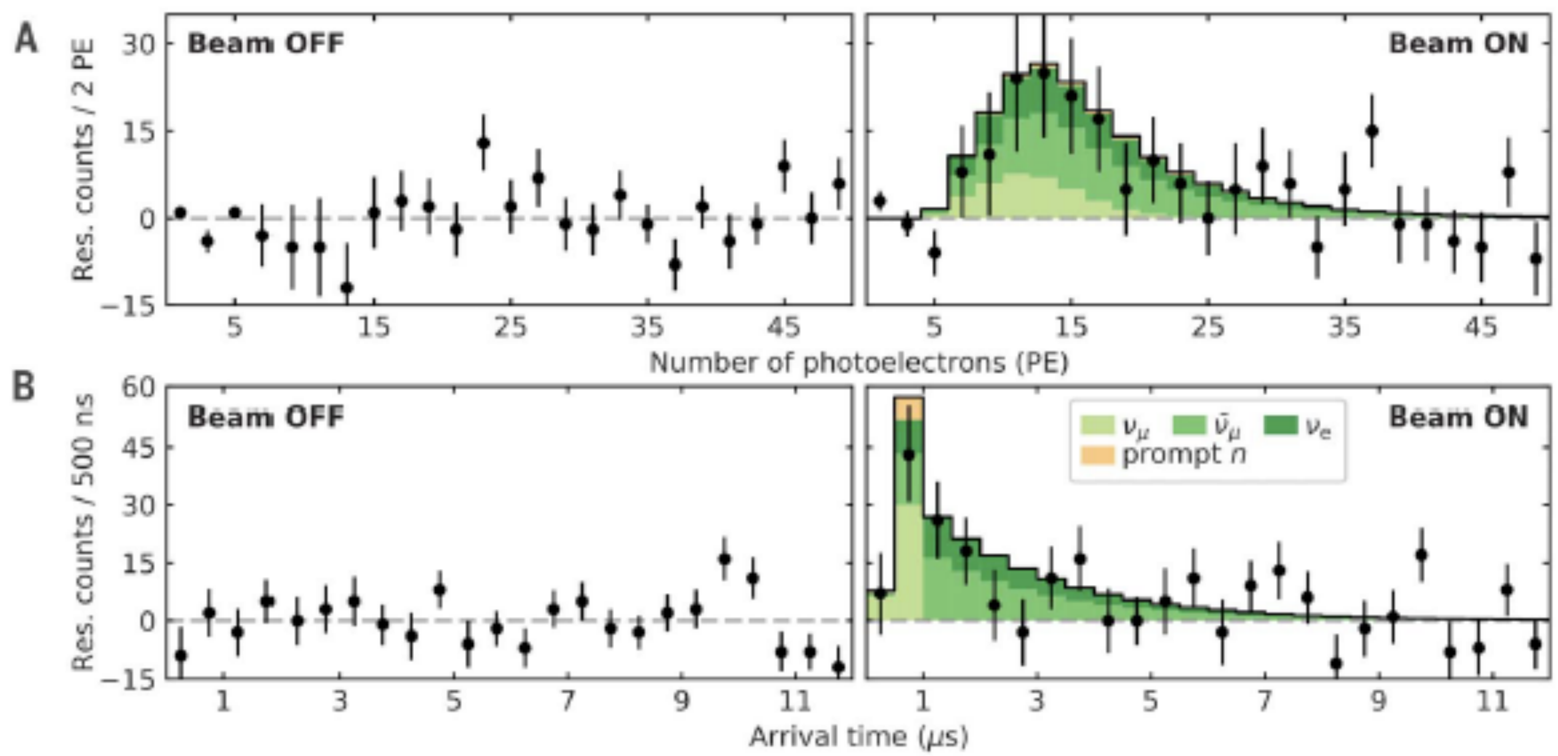
Low mass DM
H.S.Lee et al. PRD 90, 052006 (2014)

Quenching factor measurement for nuclear recoil events
QF = E_{meas}/E_{recoil}

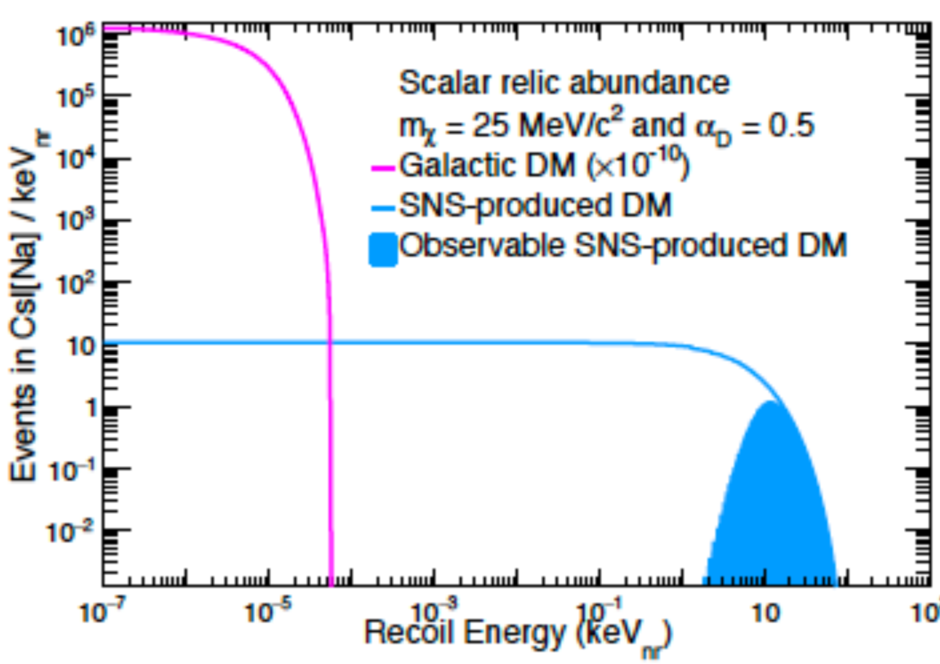


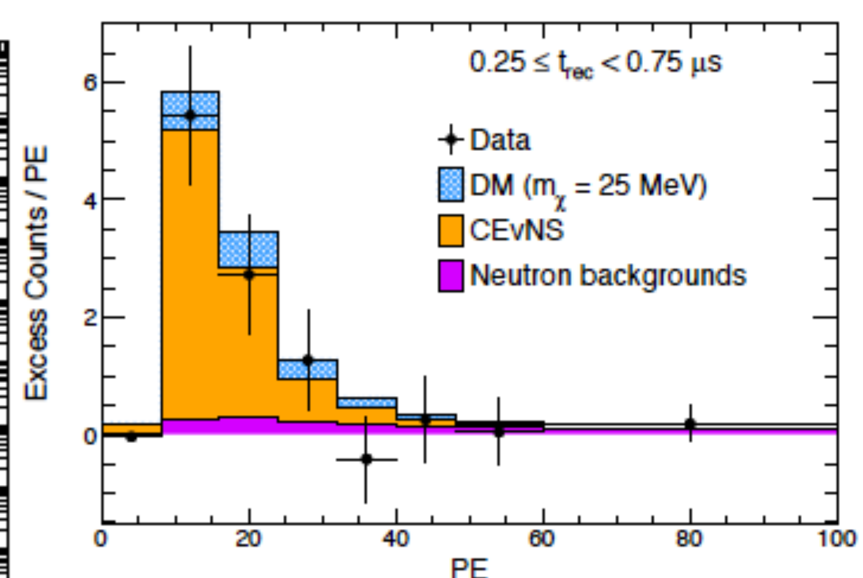
H. Park et al. NIMA 491, 460 (2002)
J. H. Lee at al. NIMA 782, 133 (2015)

Other CsI experiments for rare phenomena search?



Coherent elastic neutrino nucleus scattering
Science 357, 1123 (2017)
14.6 kg of CsI (Na), 1.17 PE/keV for NR
Neutrinos of tens of GeV from SNS

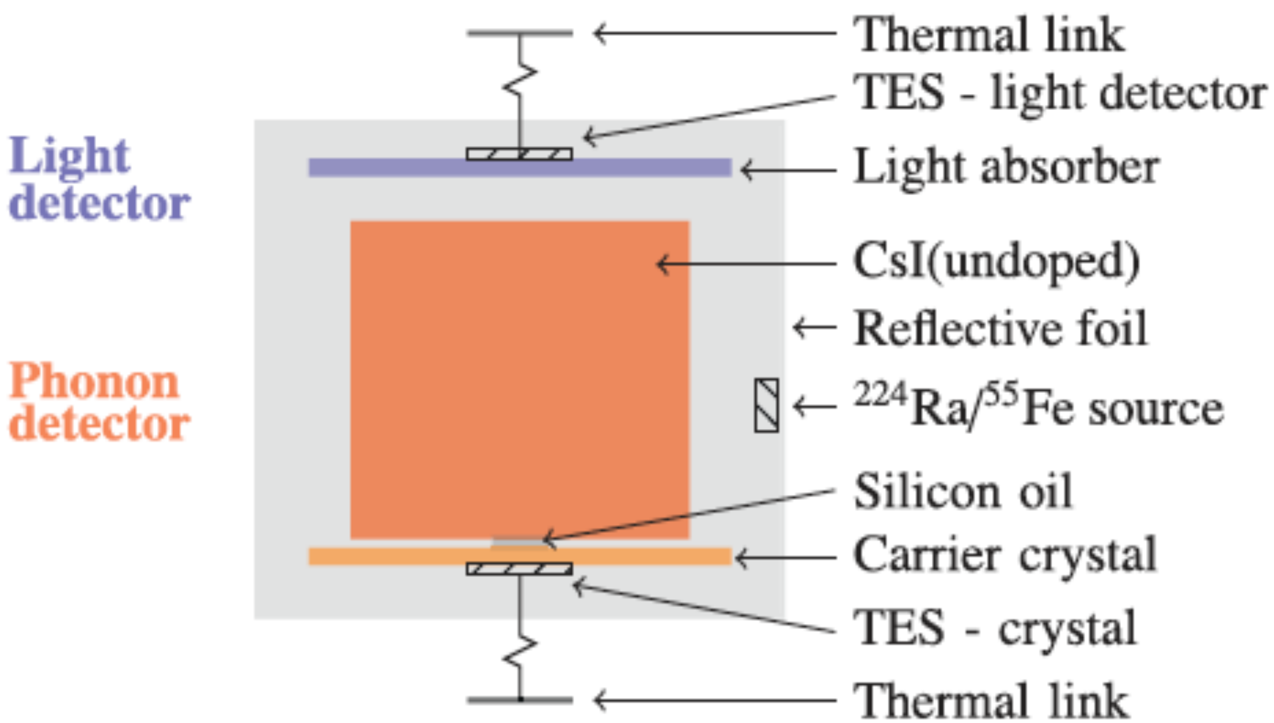


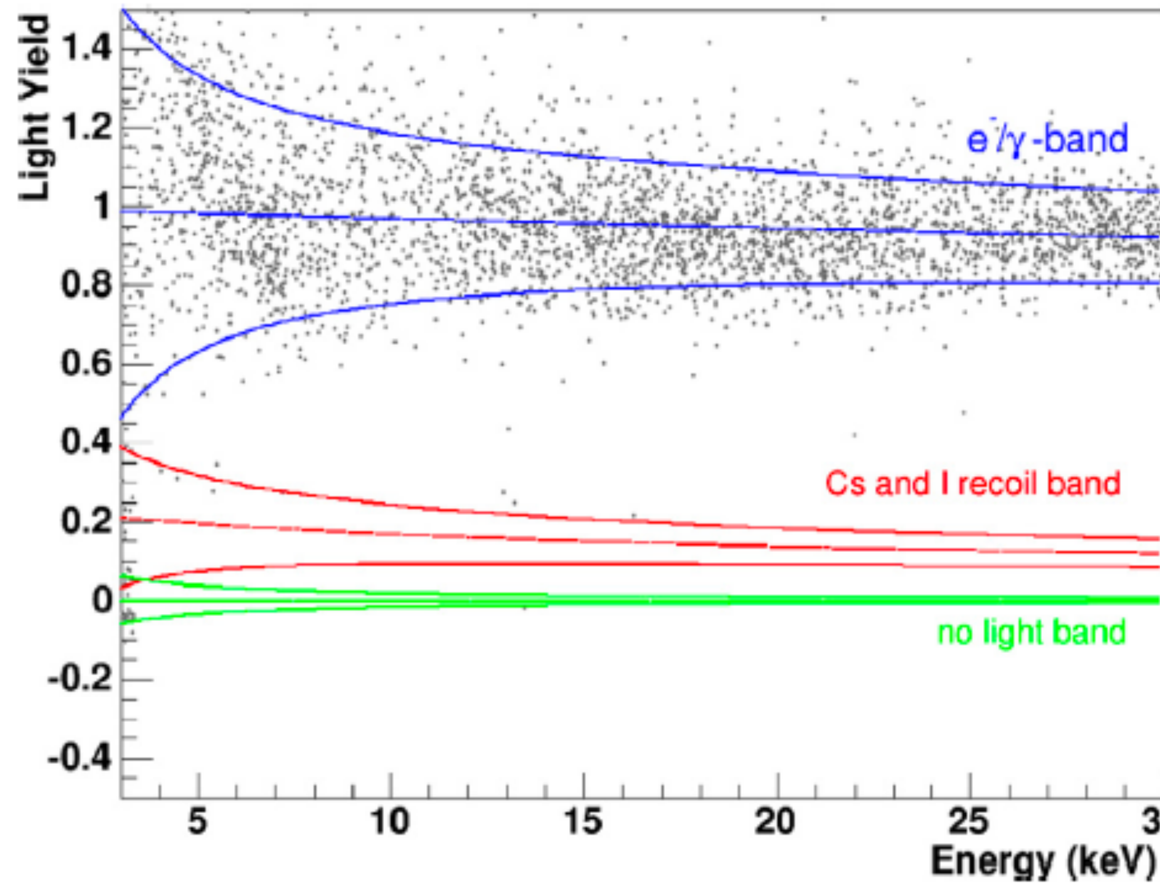


Testing sub-GeV DM produced by SNS

scalar DM mediated by a vector portal

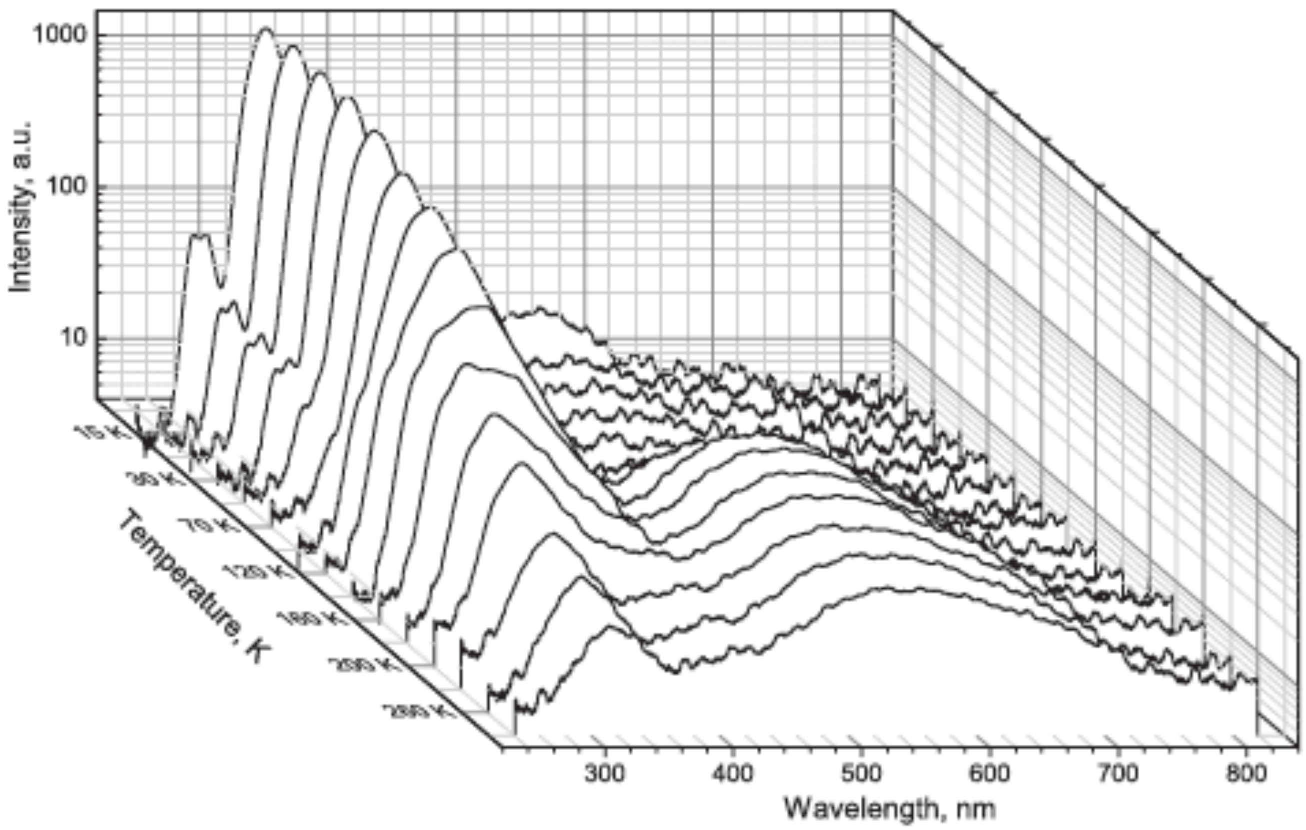
PRL 130, 051803 (2023)
E_{NR}> 9keV, 13 PE/keV



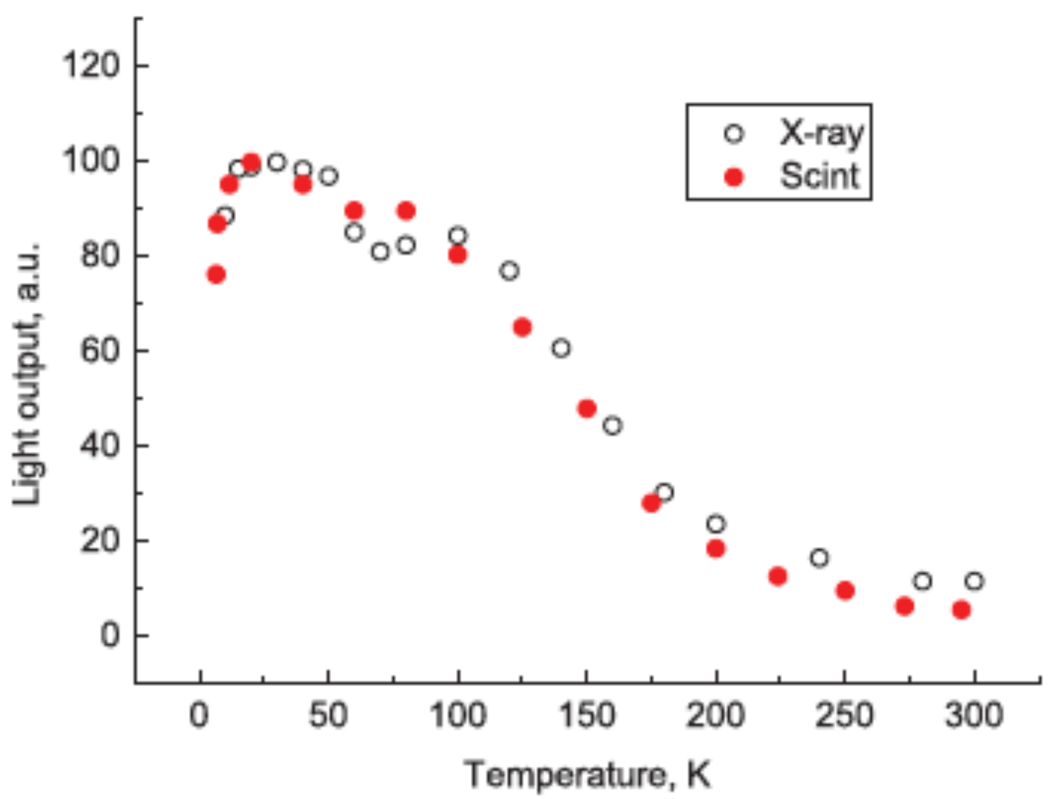


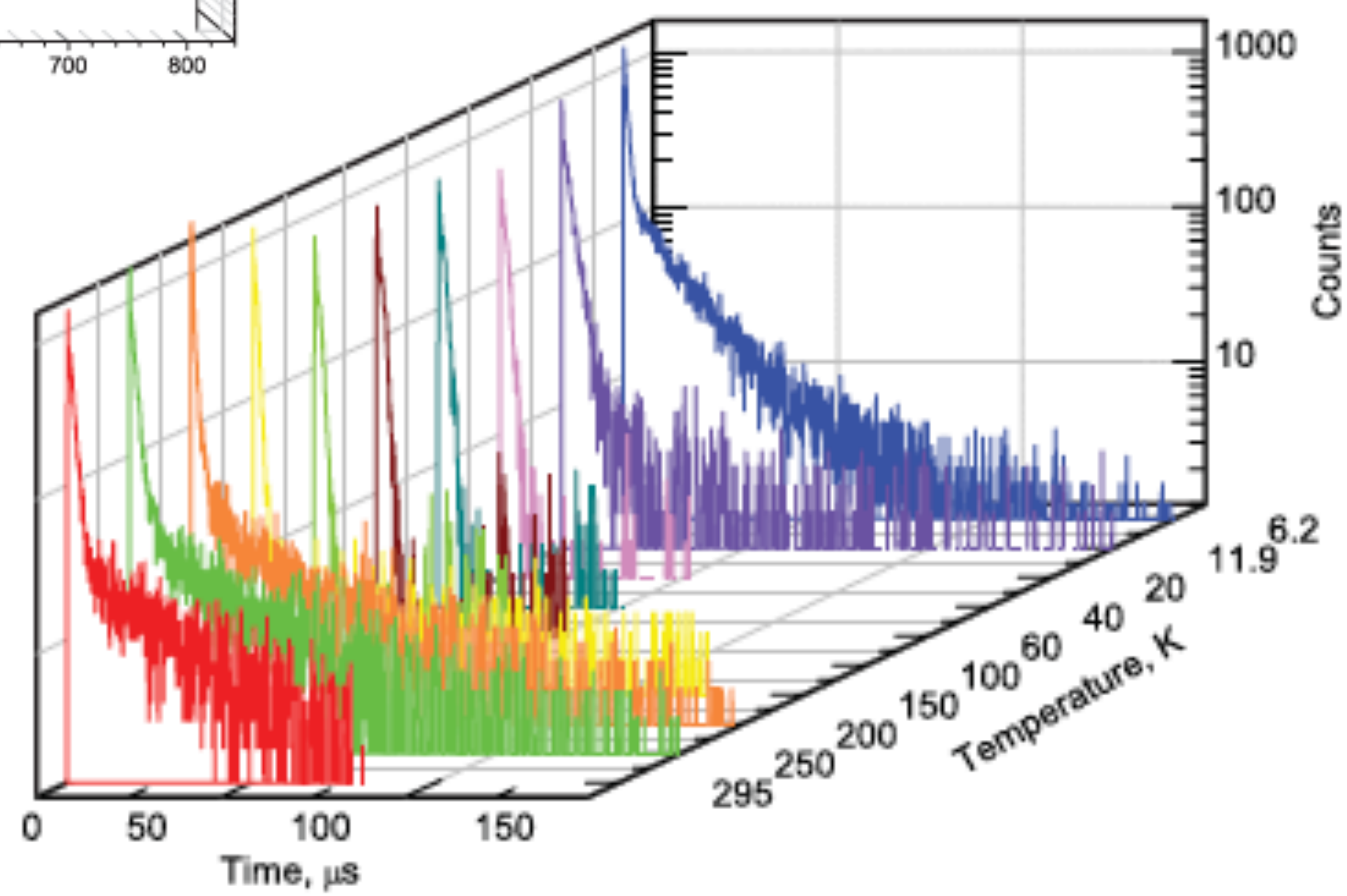
CsI LTD for DM, Astro. Phys. 84. 70 (2016)

σ = 3 keV @ 60 keV



Pontential cryogenic calorimeter
Phys. Status. Solidi B 252, 804 (2015)





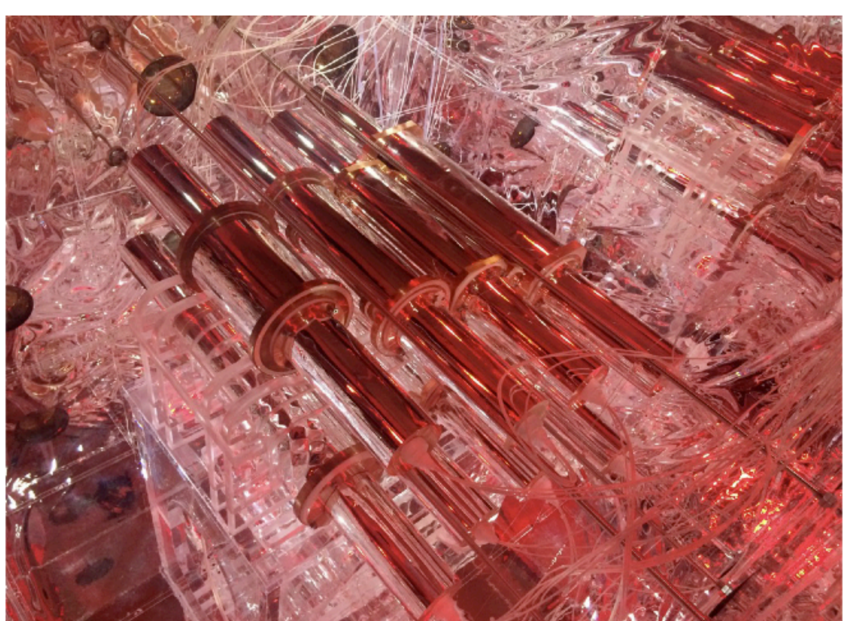
How KIMS has developed today!

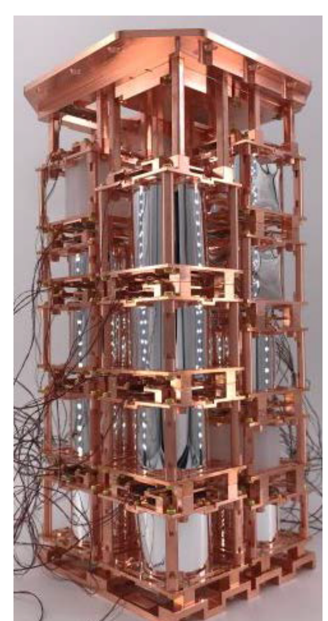
Low background assay & purification & simulation:
Approaching
~ 1 cnts/keV/kg/day @ ~ 1keV for COSINE
~ 10^{-4} cnts/keV/kg/year @ ~ 3MeV for AMoRE-II

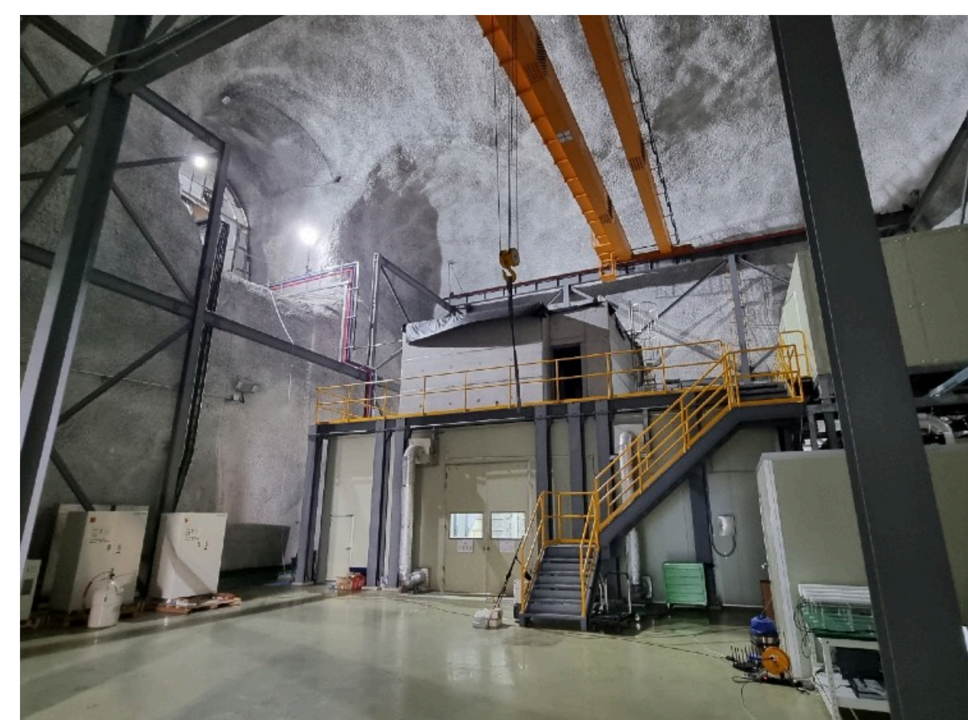
Low background facility:
Yemilab,1000 m deep, Rn-free air, clean room, large space, utilities

Strong research core:
Center for underground physics, IBS
Various research R&D

Critical players in rare phenomena searches:
COSINE, AMoRE, sterile neutrino search, LSC, so on








Acknowledgement:
KIMS collaboration
Thank you
for the attention