Status of KIMS experiments

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On behalf of the KIMS Collaboration

KIMS (Korea Invisible Mass Search)

- Dark matter search at Yangyang underground laboratory
  - ❖ May have new laboratory in Samcheok
- Funded by National Research Foundation of Korea (2000)
  - ❖ Dark matter (DM) search with CsI(Tl) crystals (KIMS-CsI)
- Establishing the Center for Underground Physics (CUP) in the Institute of Basic Science (IBS) (2013)
  - ❖ Upgrade of KIMS-CsI
  - ❖ DM searches with NaI(Tl) crystals (KIMS-NaI)
  - ❖ DM searches with low temperature detector (KIMS-LT)

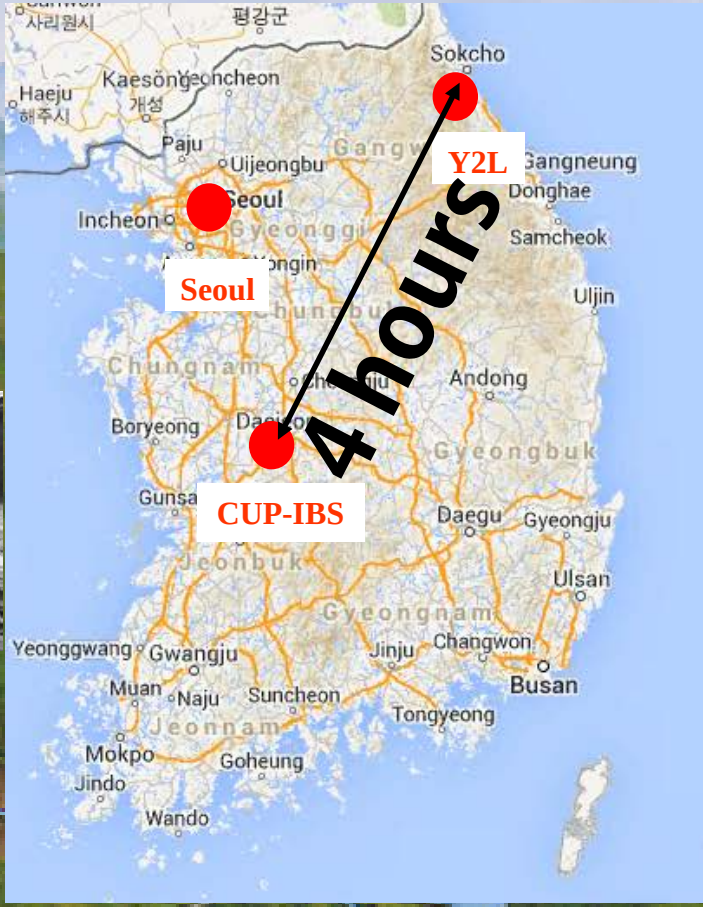
Yangyang Underground Laboratory

(Upper Dam)

Korea Middleland Power Co.
Yangyang Pumped Storage Power Plant

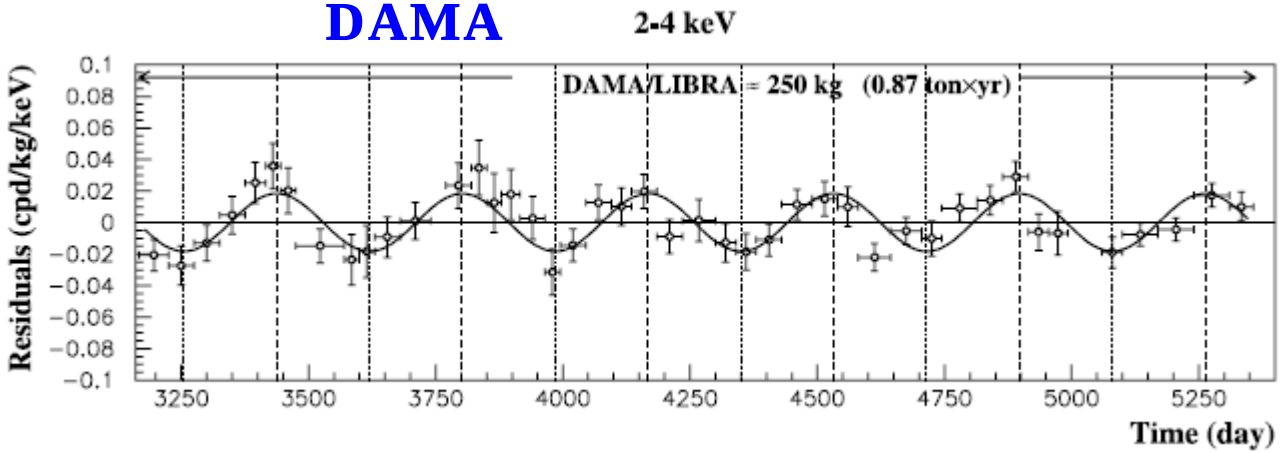
700 m

(Power Plant)



Minimum depth : 700 m
Access to the lab by car (~2km)

KIMS-NaI experiment



- To confirm DAMA annual modulation signature
  - ❖ CsI is not enough for WIMP-Na interaction
  - ❖ Same NaI crystal for the same annual modulation signature

- Need to develop ultra-pure NaI(Tl) crystals
  - ❖ Goal is less than DAMA background (~1 dru = 1 counts/keV/kg/day)
  - ❖ 200 kg× 3 years data will prove DAMA signature without any ambiguity

KIMS-NaI crystals

- Development of low background NaI(Tl) crystals

	NaI-001	NaI-002	NaI-003	NaI-004	NaI-005	NaI-006
Mass	8.26 kg	9.15 kg	3.35kg	3.35kg	9.16 kg	11.44 kg
Powder	AS	AS	SA-AG	SA-CG	AS	SA-CG
Crystal	AS	AS	AS	AS	AS	BH
Arrive	2013.9	2014.1	2014.8	2014.8	2014.11	2014.12

K.W.Kim et al., Astropart. Phys. 62, 249 (2015)

Glossary

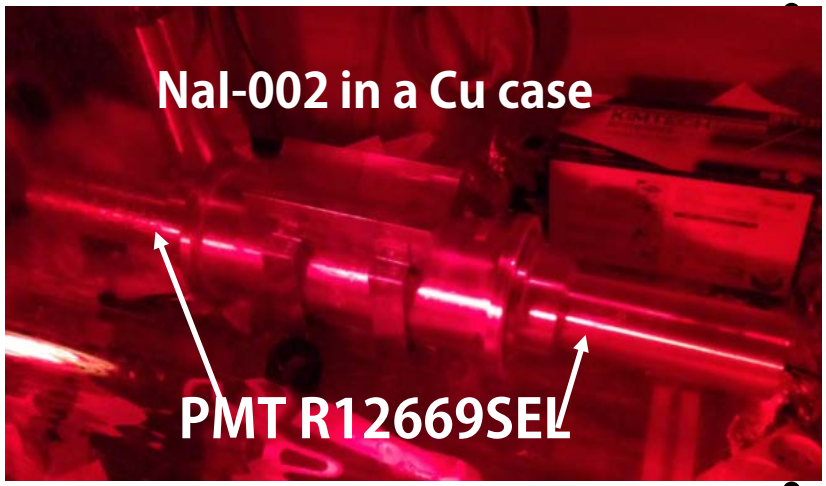
AS = Alpha Spectra Inc (US company)

SA-AG = Sigma Adrich, Astro-grade (less K40)

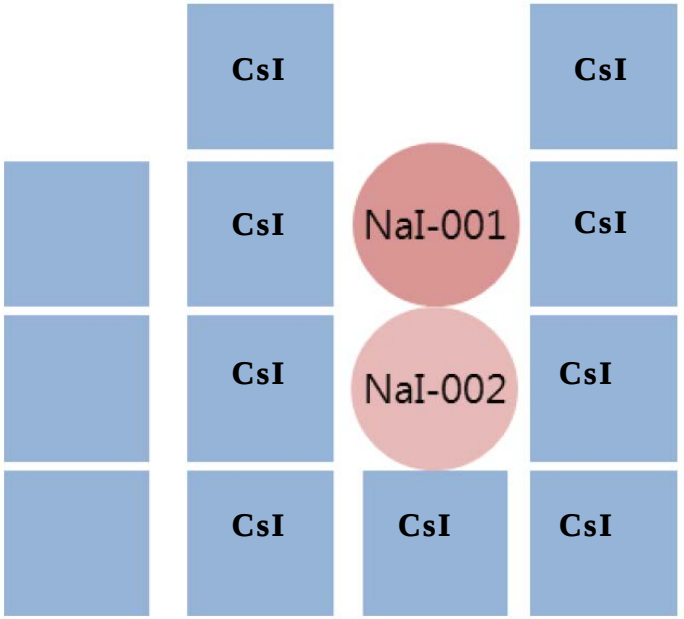
SA-CG = Sigma Adrich, Crystal-grade

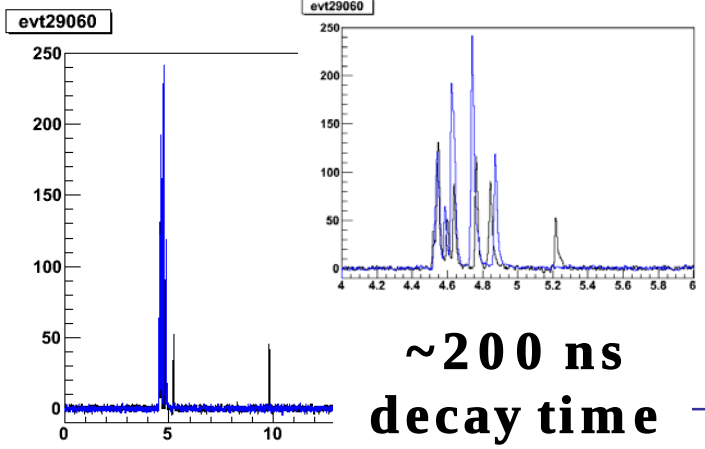
BH = Beijing Hamamatsu (China)

KIMS-NaI detector module



- Hamamastu R12669 PMTs are attached
  - ❖ Supposed same PMTs with recently upgraded DAMA PMTs
  - ❖ ~35% quantum efficiency at 420nm
- Light Yield: ~15 photoelectrons/keV
  - ❖ Consistent with ANAIS-25
- Data taking
  - ❖ 400MHz Flash ADC (Notice Korea)
    - ❑Flexible trigger logic with FPGA
    - ❑Trigger condition: 1 PE/PMT within 100ns





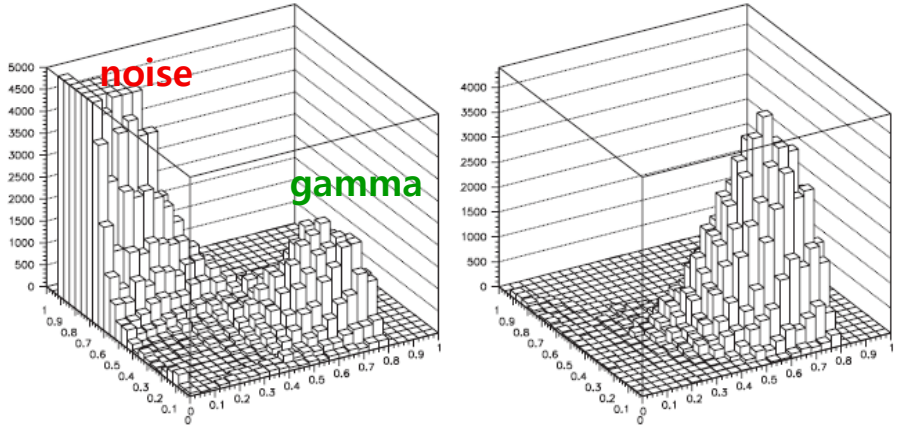
~200 ns decay time

PMT background

- **We can well identify PMT noise events using same parameter with DAMA**

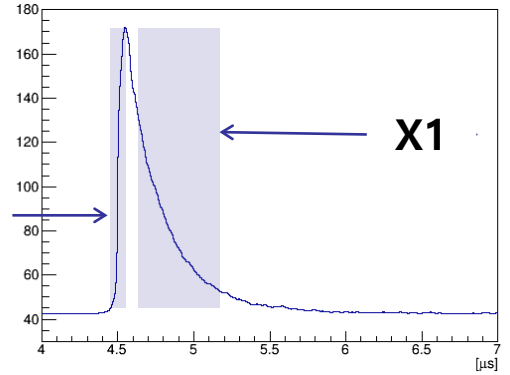
NIMA 592, 297 (2008)

DAMA



$$X_1 = \frac{\text{Area (from 100 to 600 ns)}}{\text{Area (from 0 to 600 ns)}}$$

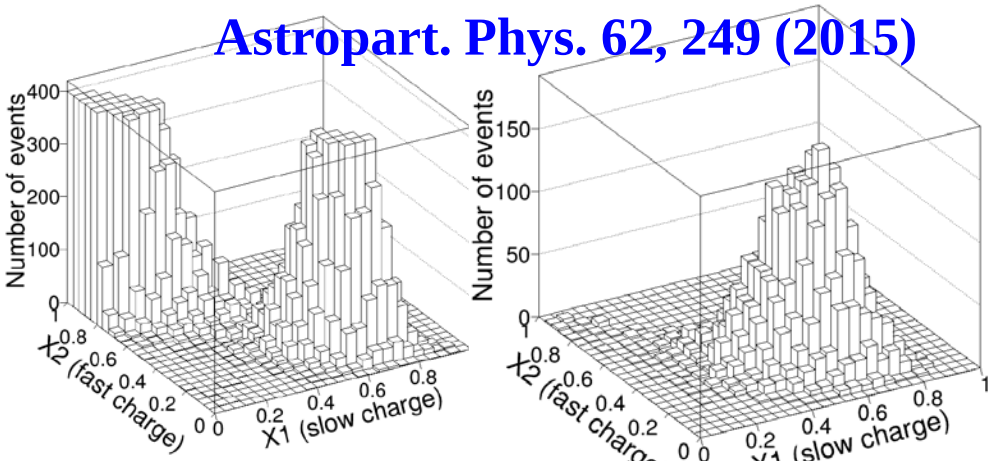
$$X_2 = \frac{\text{Area (from 0 to 50 ns)}}{\text{Area (from 0 to 600 ns)}}$$



2 keV≤ E ≤ 4 keV

Astropart. Phys. 62, 249 (2015)

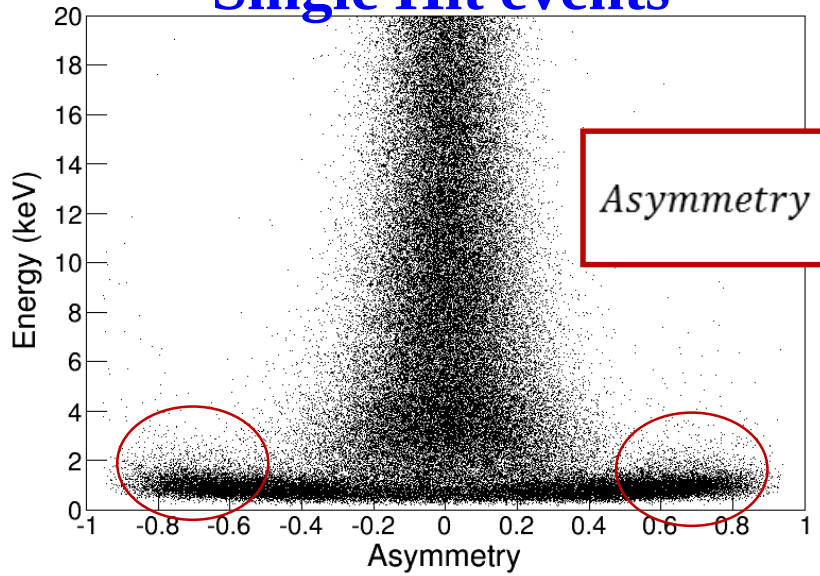
KIMS-NaI



Background data **X-ray source**

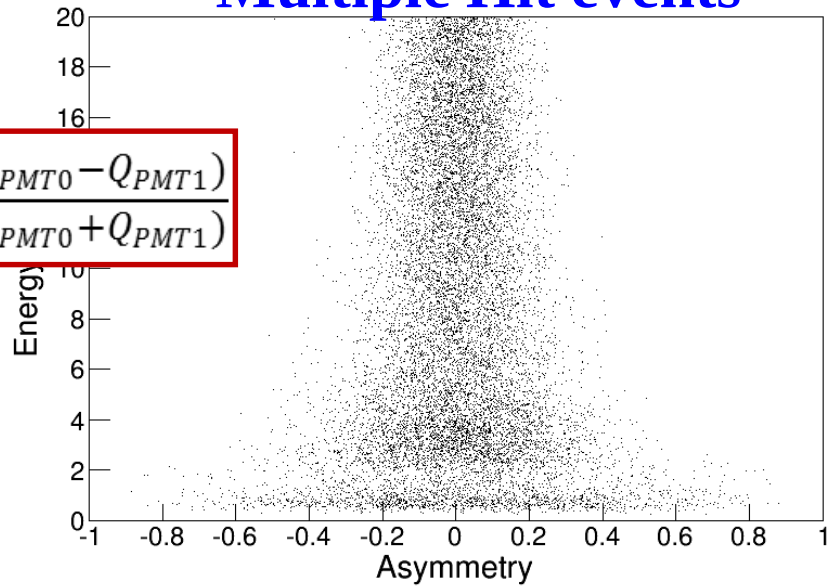
Remained noise?

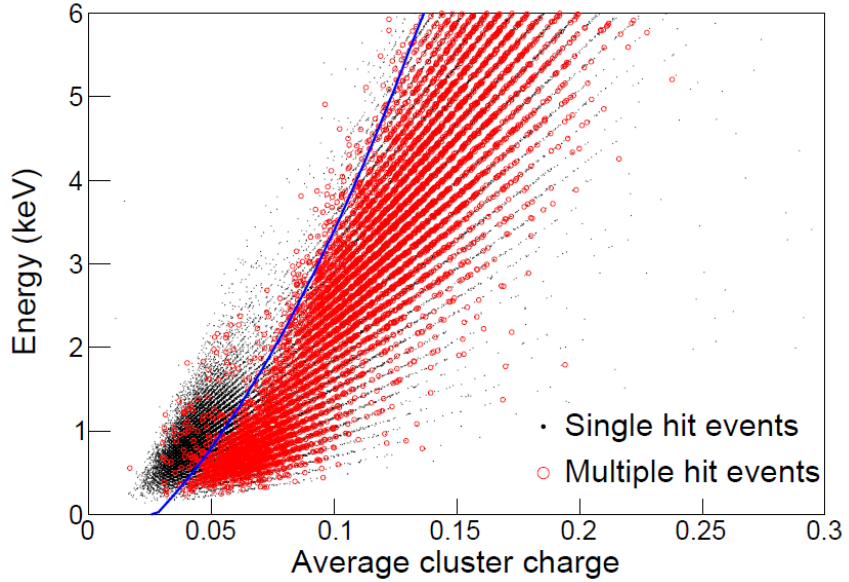
Single Hit events



$$Asymmetry = \frac{(Q_{PMT0} - Q_{PMT1})}{(Q_{PMT0} + Q_{PMT1})}$$

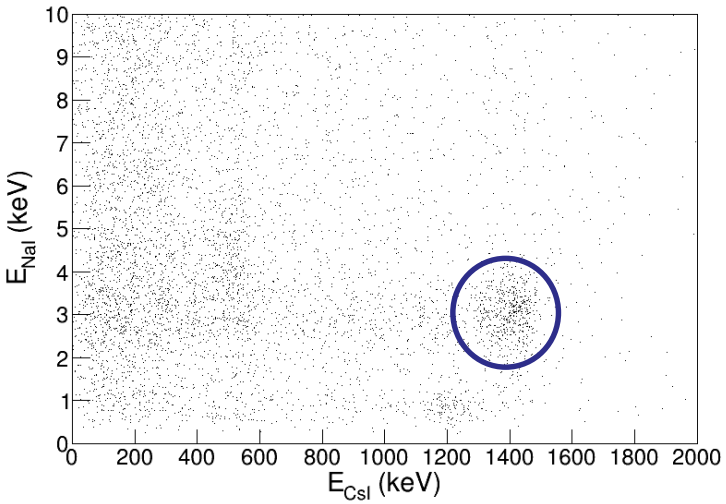
Multiple Hit events



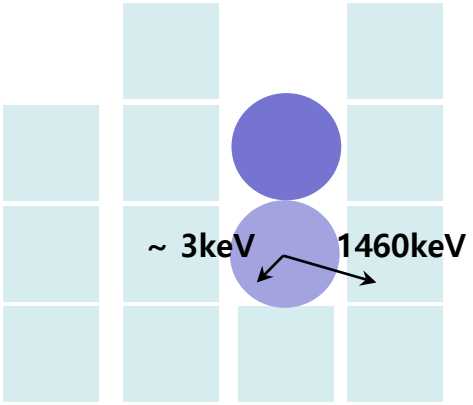


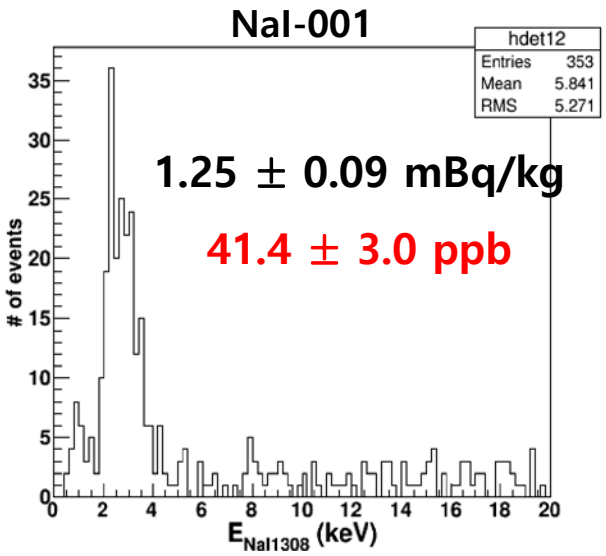
We should apply additional cuts to reject such noisy events

Intrinsic Background – K



Coincidence signals





DAMA crystals :
10~20 ppb

Geant4 simulation
on efficiency

	NaI-001	NaI-002	NaI-003	NaI-004	NaI-005	NaI-006
K (ppb)	41.4 ± 3.0	49.3 ± 2.4	25.3 ± 3.6	> 110	40.1 ± 4.2	> 130

Intrinsic Background – K

	NaI-001	NaI-002	NaI-003	NaI-004	NaI-005	NaI-006
K (ppb)	41.4 ± 3.0	49.3 ± 2.4	$\mathbf{25.3 \pm 2.4}$	> 110	40.1 ± 4.2	> 130
Powder	AS	AS	SA-AG	SA-CG	AS	SA-CG
K (powder)	?	?	25.07	~200	?	~200

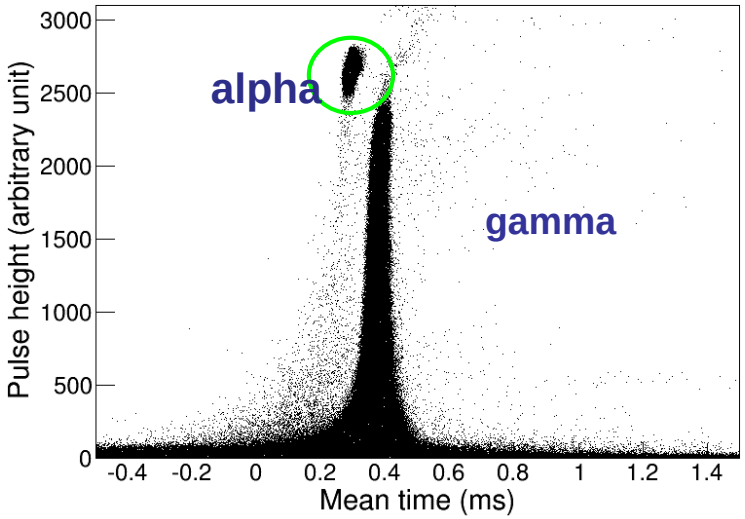
- NaI-003 used Sigma Adrich Astro-Grade (SA-AG) powder **25 ppb**
- NaI-004 & NaI-006 used **Crystal-Grade** (SA-CG) powder
- All Alpha Spectra prepared powders (NaI-001, NaI-002, NaI-005)

  ~ 40 ppb levels

NaI powder is a key of K contamination

- We asked crystallization using different batch of AG powder
  - ❖ AS (two crystals), BH (one), SCICCAS (one), ourself
  - ❖ ~10 ppb from ICP-MS by Sigma Aldrich
- **K measurement technique** from powder is under development

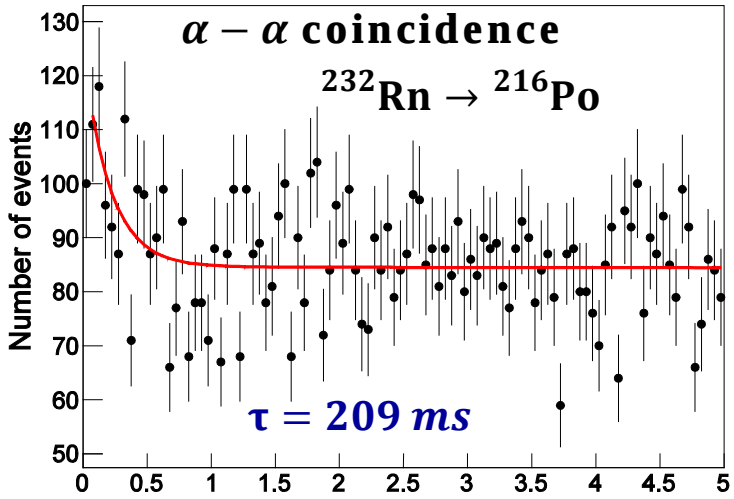
Intrinsic Background (alpha analysis)



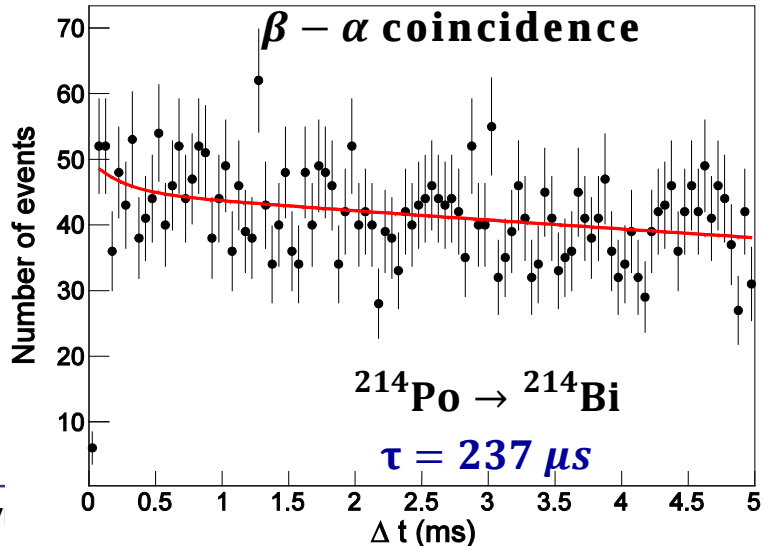
Radionuclei	NaI-001 [mBq/kg]	NaI-002 [mBq/kg]
^{238}U (^{214}Bi)	<0.007	<0.001
^{228}Th (^{216}Po)	<0.012	0.002±0.001
Total alphas	3.29±0.02	1.77±0.01

^{238}U and ^{228}Th contaminations were very small!!

^{232}Th chain



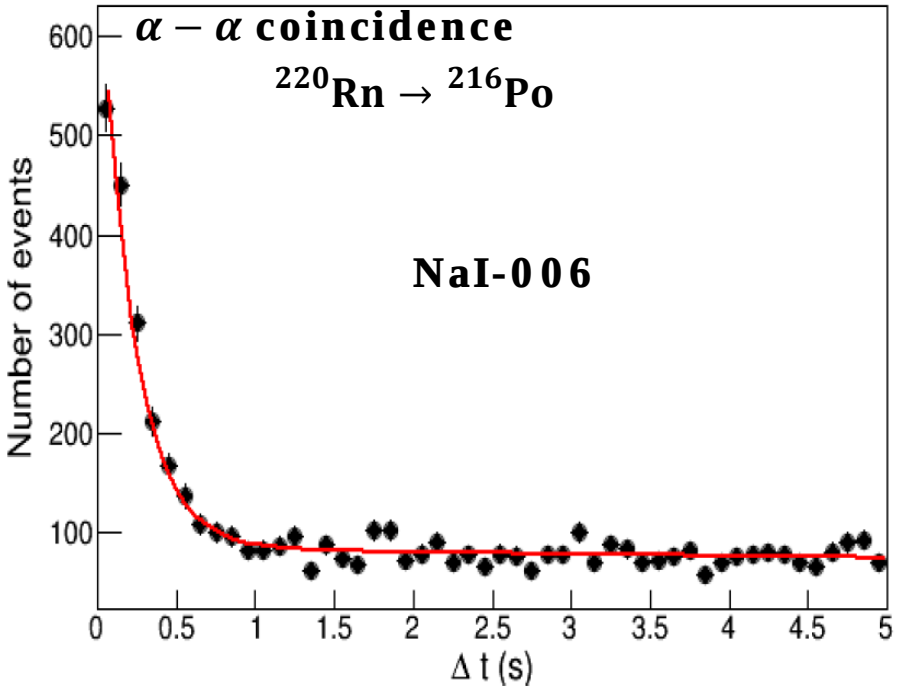
^{238}U chain



U, Th contamination

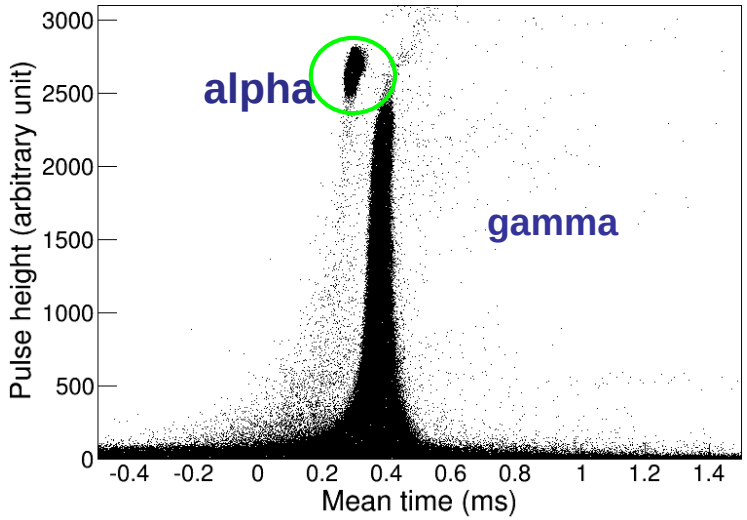
	NaI-001	NaI-002	NaI-003	NaI-004	NaI-005	NaI-006
U (ppt)	< 0.02	< 1.04	$< \mathbf{0.14}$	?	< 0.04	< 0.05
Th (ppt)	< 3.17	0.48 ± 0.20	0.46 ± 0.07	?	0.19 ± 0.01	8.9 ± 0.01
Company	AS	AS	AS		AS	BH

^{232}Th chain



- NaI-006 has a little large Th contamination
  - BH crystal with SA-CG
- ~0.04mBq/kg
  - ~0.2mBq/kg of alpha

Intrinsic Background – ^{210}Pb

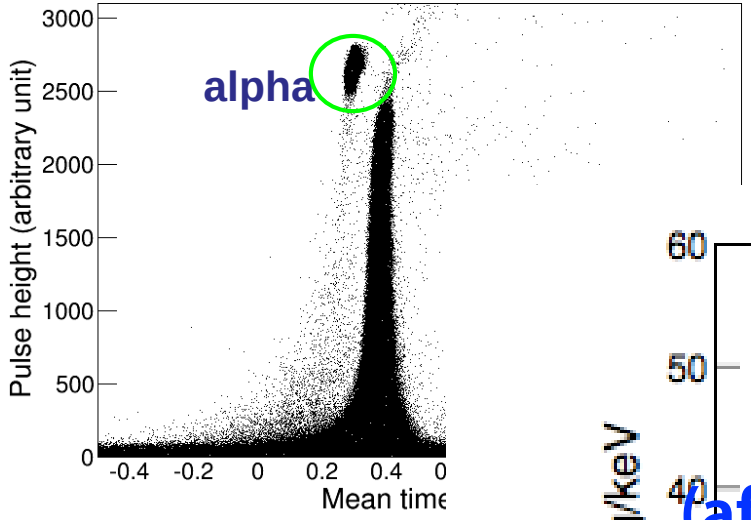


- Most of alphas are coming from ^{210}Po
- Broken equilibrium (^{222}Rn contamination) during powder or crystallization

	NaI-001	NaI-002	NaI-003	NaI-004	NaI-005	NaI-006
Total alpha (mBq/kg)	3.29 ± 0.01	1.77 ± 0.01	2.43 ± 0.01	-	0.48 ± 0.01	1.53 ± 0.01
Powder	AS	AS	SA-AG	SA-CG	AS	SA-CG

- **NaI-003, NaI-004, and NaI-005** had better treatment on air (Rn) contact during crystal growing
- **NaI-005** had better treatment of chemical process on powder

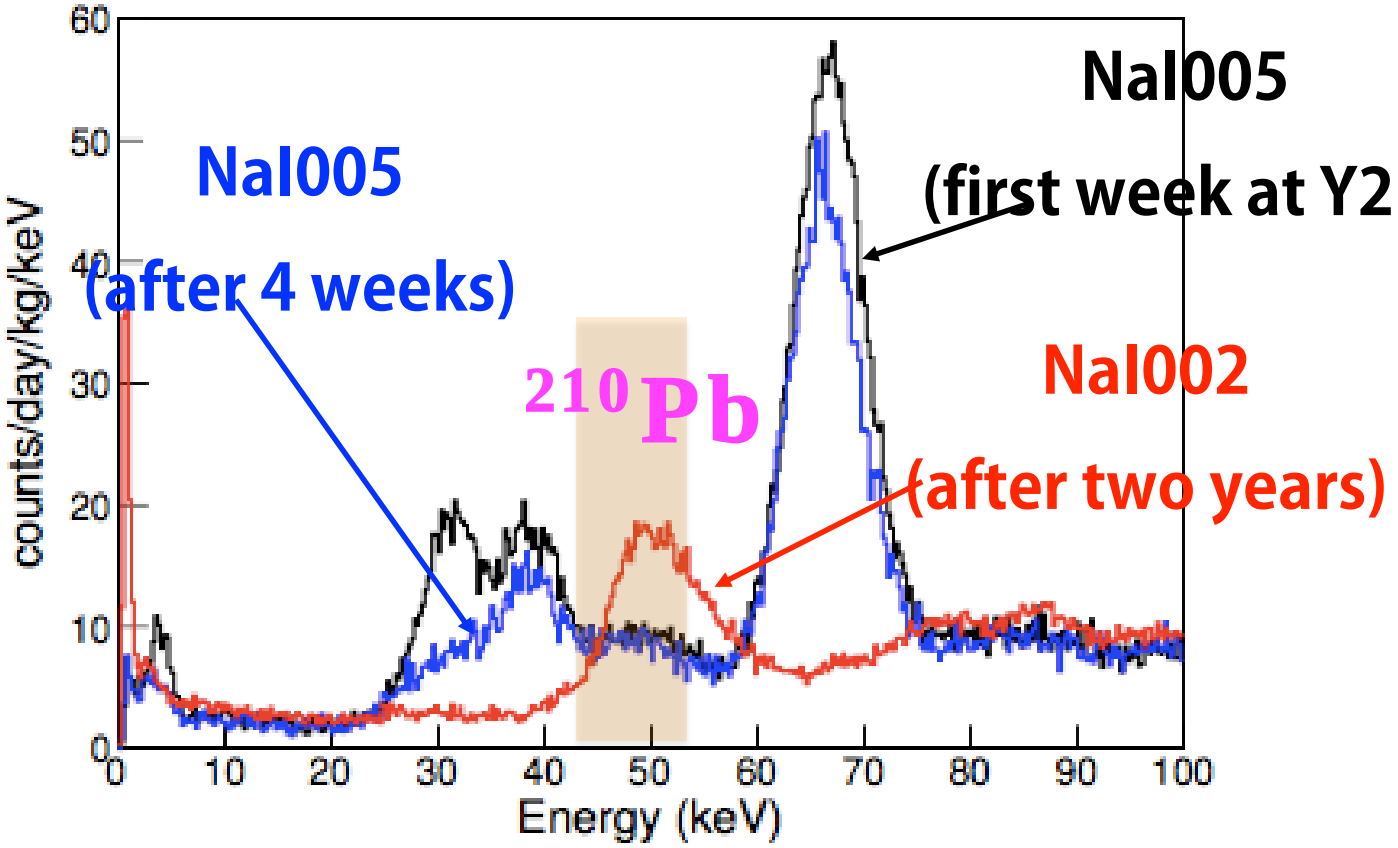
Intrinsic Background – ^{210}Pb



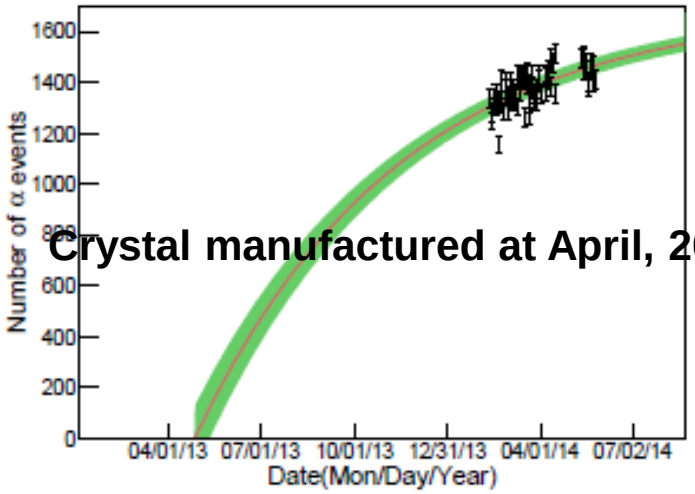
	NaI-001
Total alpha (mBq/kg)	3.29 ± 0.0
Powder	AS

- **NaI-003, NaI-**(contact during
- **NaI-005** had b

- Most of alphas are coming from ^{210}Po

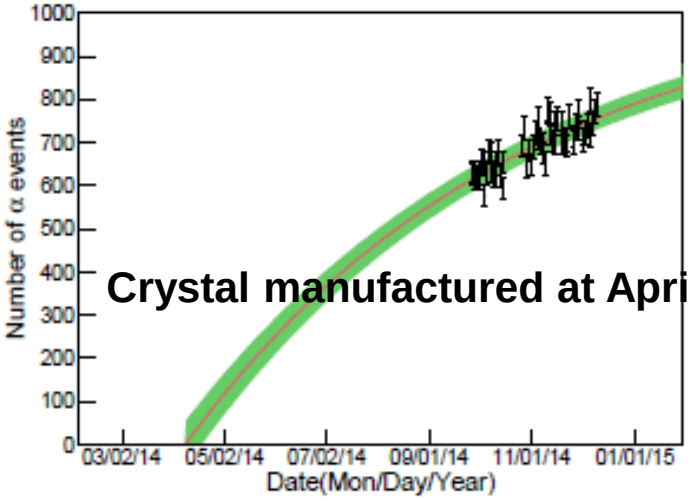


Intrinsic Background – ^{210}Pb



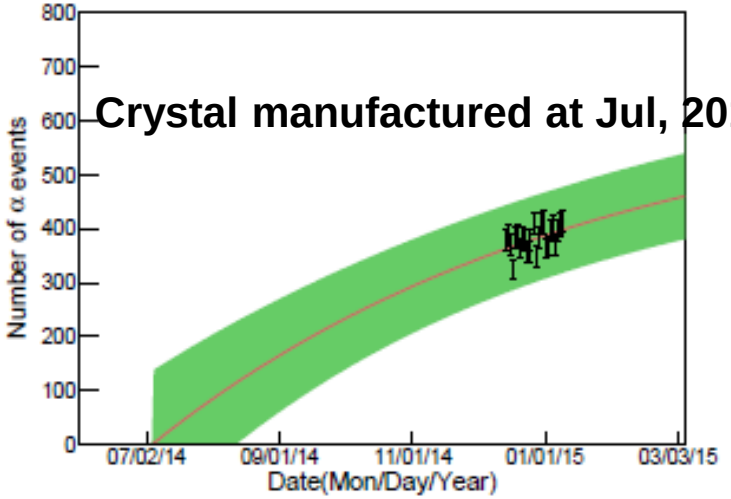
Crystal manufactured at April, 2013

(a) NaI-002



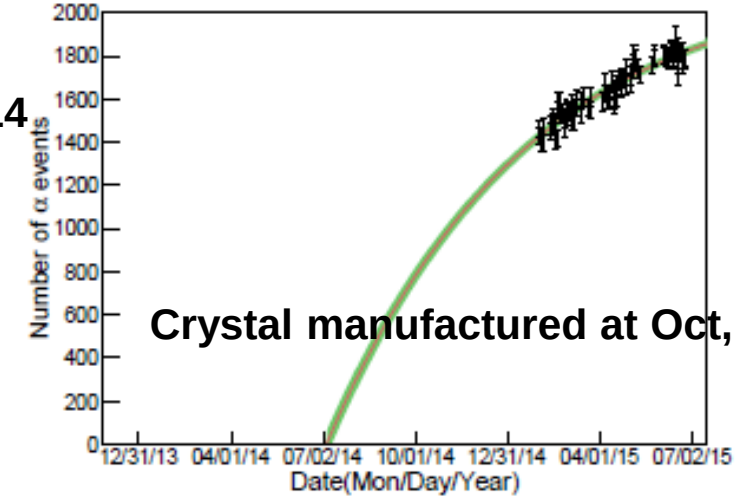
Crystal manufactured at April, 2014

(b) NaI-003



Crystal manufactured at Jul, 2014

(c) NaI-005

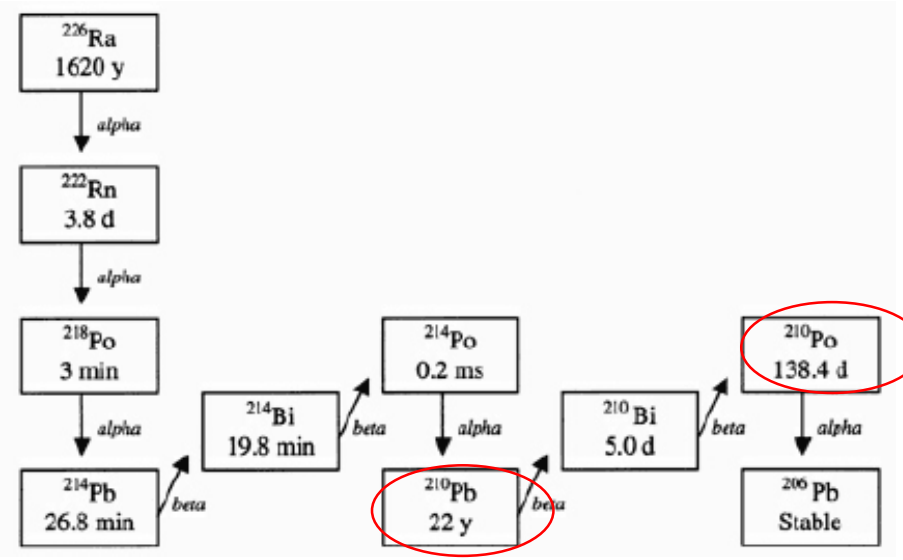


Crystal manufactured at Oct, 2014

(d) NaI-006

Intrinsic Background – ^{210}Pb

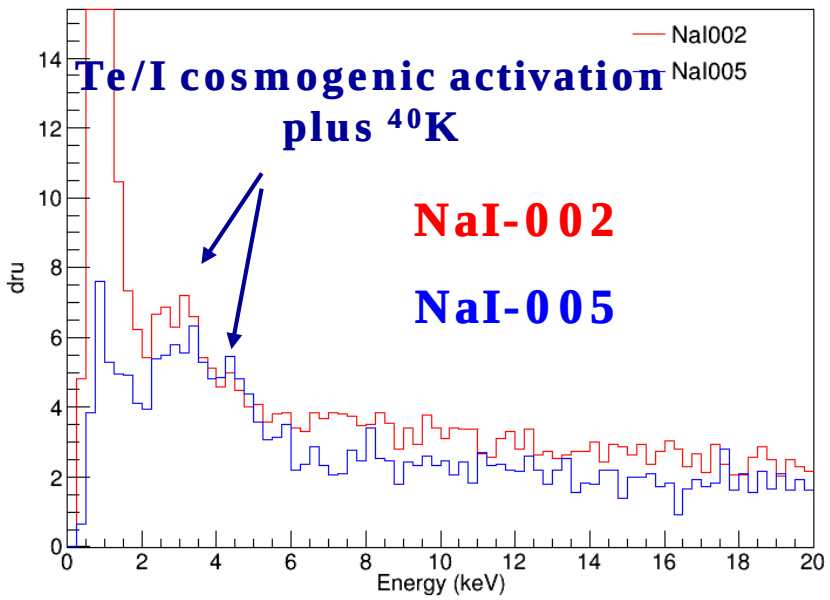
- Main Source.. Powder production or crystal growing?
  - ❖ Should know ^{210}Pb in powder
  - ❖ **Alpha rate measurements** at powder
    - ❑ Buy High sensitive alpha counters
    - ❑ Developing ZnS detector
  - ❖ **46 keV gamma** measurement
    - ❑ Considering Well-type Ge or Si detectors

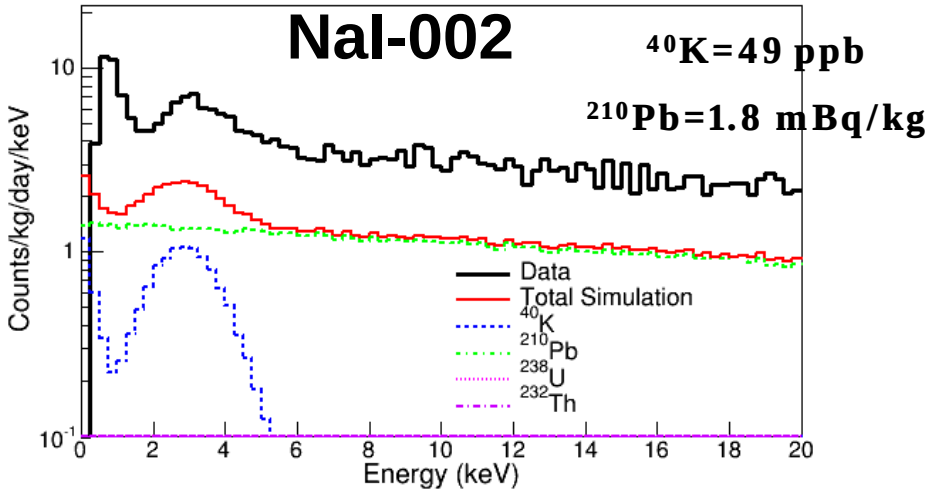


Kamland-pico demonstrates a reduction of ^{210}Pb in NaI powder with ion-exchange resin (arXiv:1407.3542): 50 μBq/kg in crystal

We just started ^{210}Pb reduction in powder with various resins
Co-worked with Russian chemists

Internal background

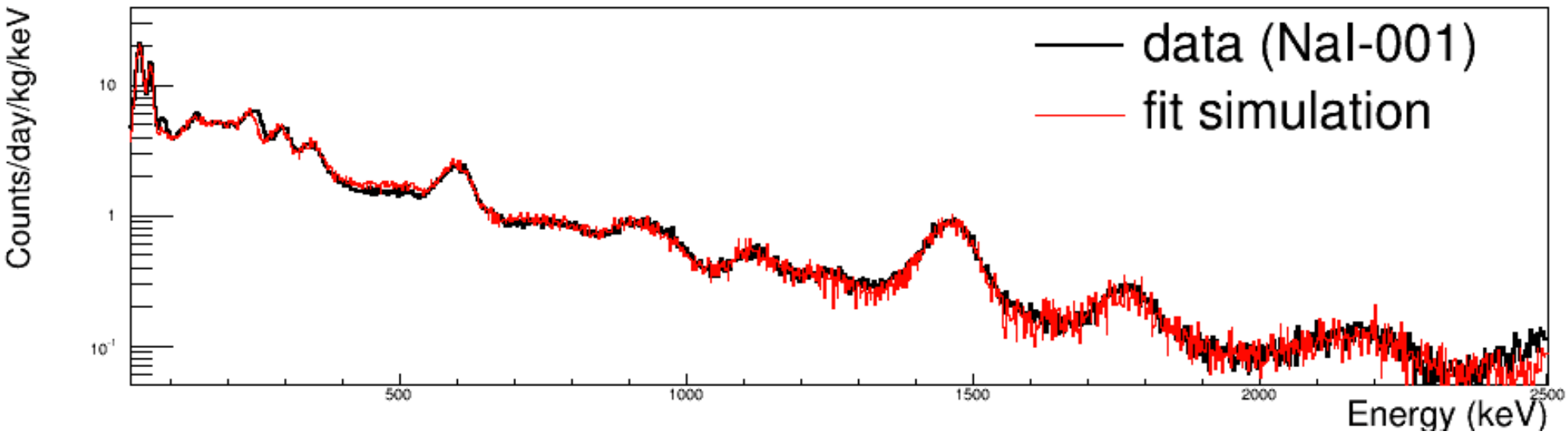




Simulation for external and cosmogenic activation is under development

- We achieved ~2 dru at 6keV
- ~ 0.5 dru caused by internal backgrounds (^{210}Pb)
  - ❖ Additional ~0.7 dru at 2-4 keV due to ^{40}K
- **~ 1.5 dru** caused by **external** (+cosmogenic)
- Goal : less than 1 dru (both less than 0.5 dru)

Background understanding



- Including most of possible internal & external components
  - ❖ Some comsmogenic components are missed
- Amount of each components are in general float for the likelihood fit
- Final optimization is underway

Pb reduction

- Currently ~ 0.5 dru background
  - ~ factor 3 reduction is necessary
- Purification of powder is under developed (ion-exchange resin)

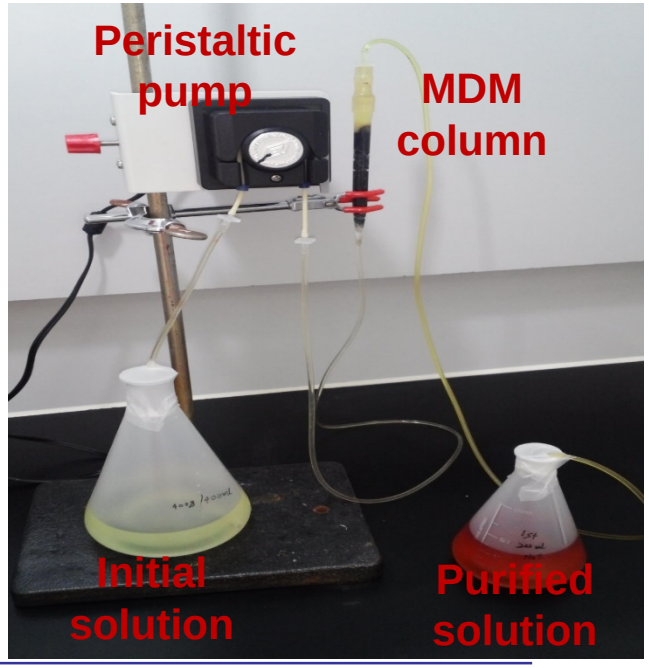
Pb contaminated powder

Sorbent	Before	After	D.F.
MDM-K	1931	0.35	5517
MDM-Na	1921	0.12	16008

Normal powder (SA-CG)

Elements	Before	After	D.F.
^{206}Pb	3.77	0.39	9.7
^{208}Pb	4.39	0.84	5.2
^{232}Th	0.24	0.12	2.0
^{238}U	0.84	0.99	0.85

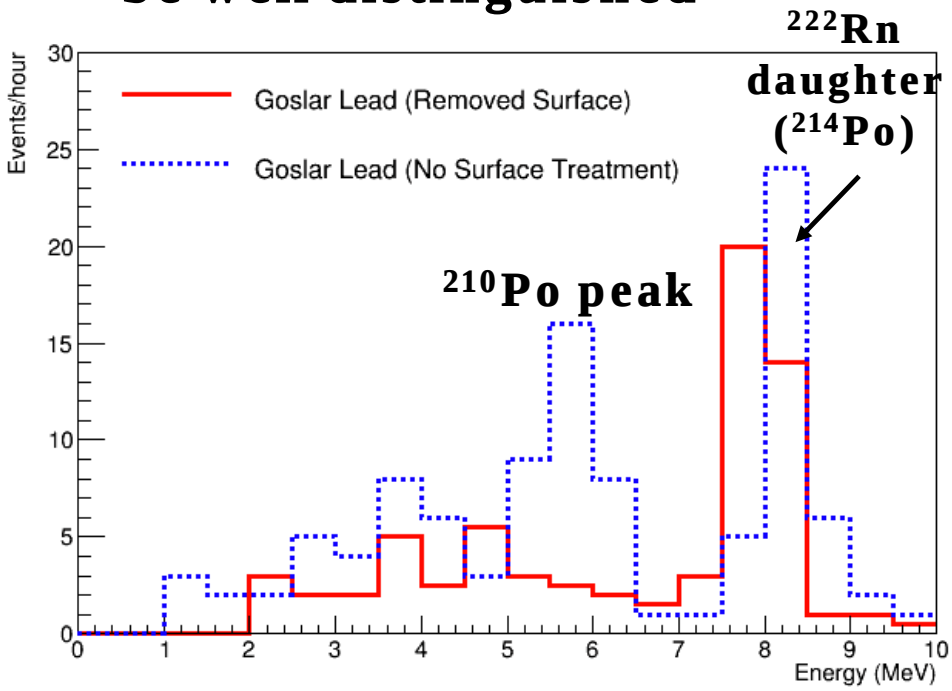
Preliminary



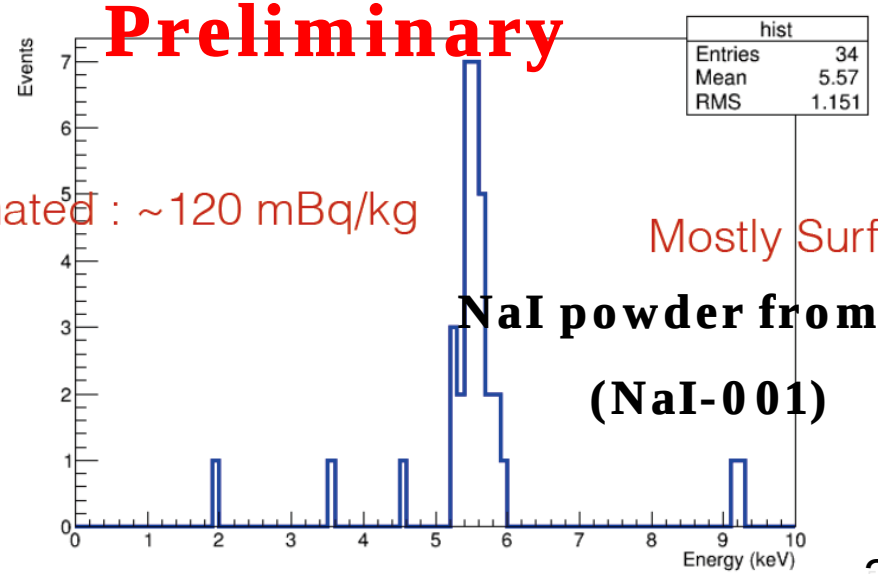
^{210}Pb in powder ?

Goslar lead measurements with/without surface polishing

Surface and bulk alpha can be well distinguished



Preliminary

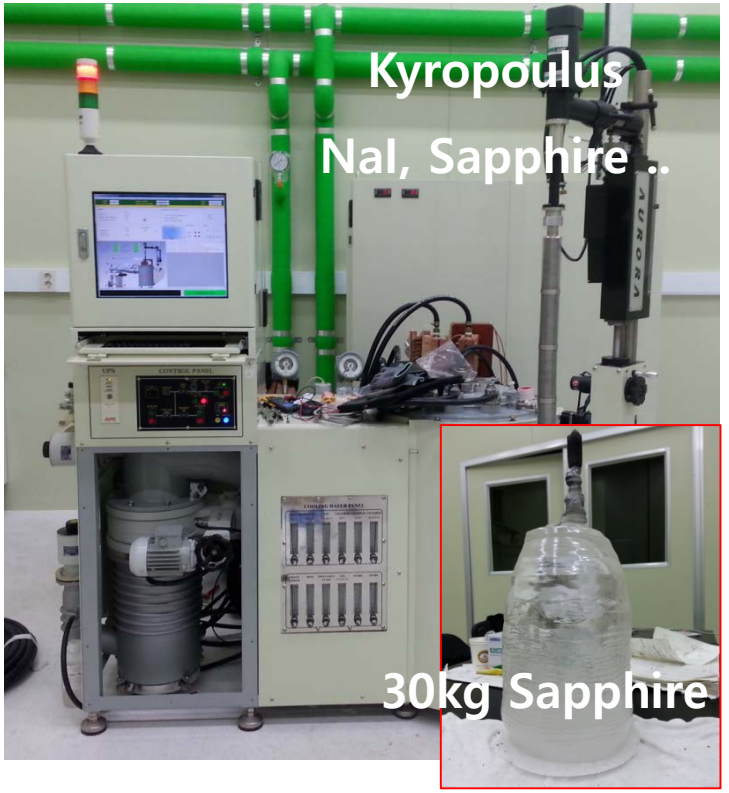


Estimated : ~120 mBq/kg

Mostly Surface

NaI powder from AS (NaI-001)

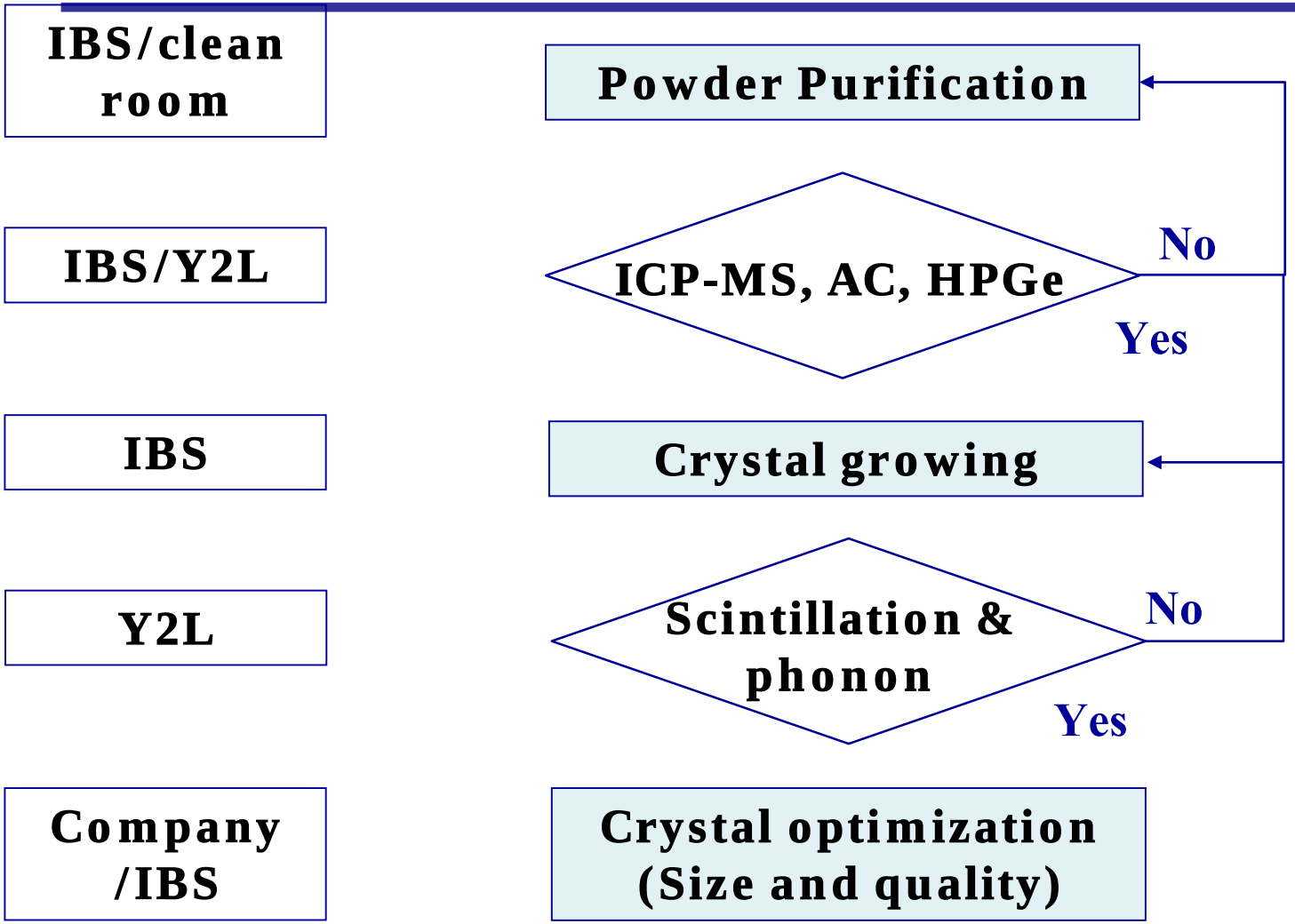
Crystallization (Fast background check)



$CaMoO_4$ Natural Crystal

NaI(Tl) crystal growth with Sigma Aldrich AstroGrade powder starts in July

Background reduction processes

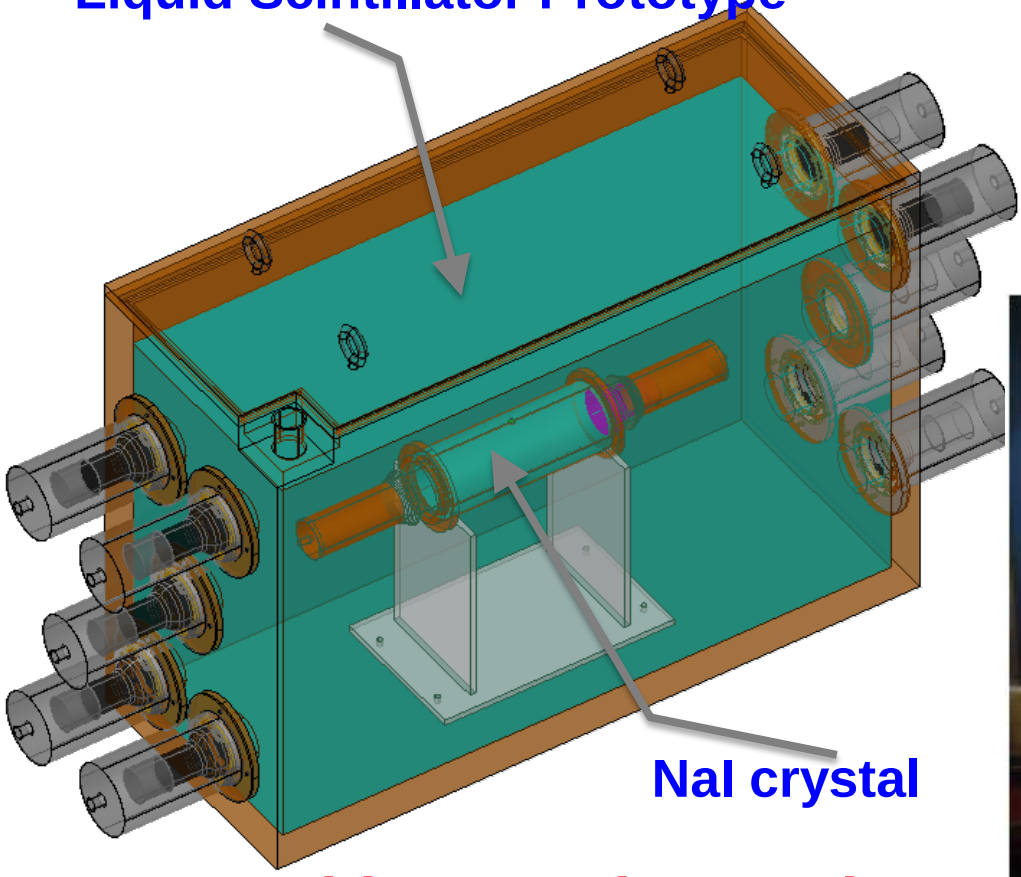


- Every process can be done by ourselves – fast feedback
- Good practice for KIMS-LT

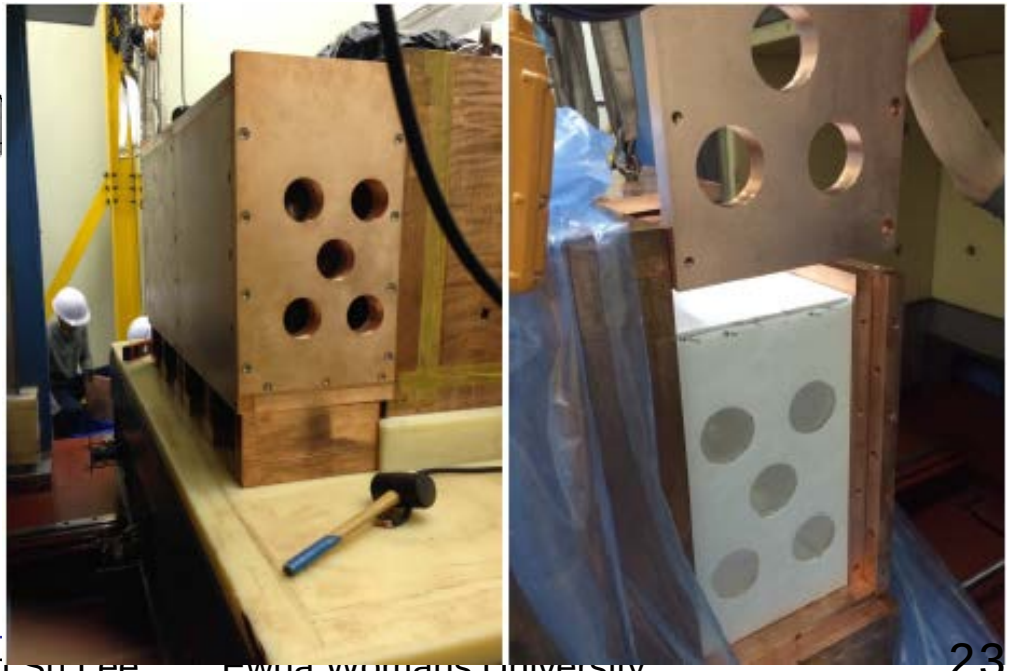
External background & internal K

- We prepared liquid scintillator active veto system
  - ❖ Veto efficiencies for sources from PMT radioisotopes (U, Th, K) were greater than 80% at low energy (0-10 keV)

Liquid Scintillator Prototype



Less than 0.5 dru from external might be possible

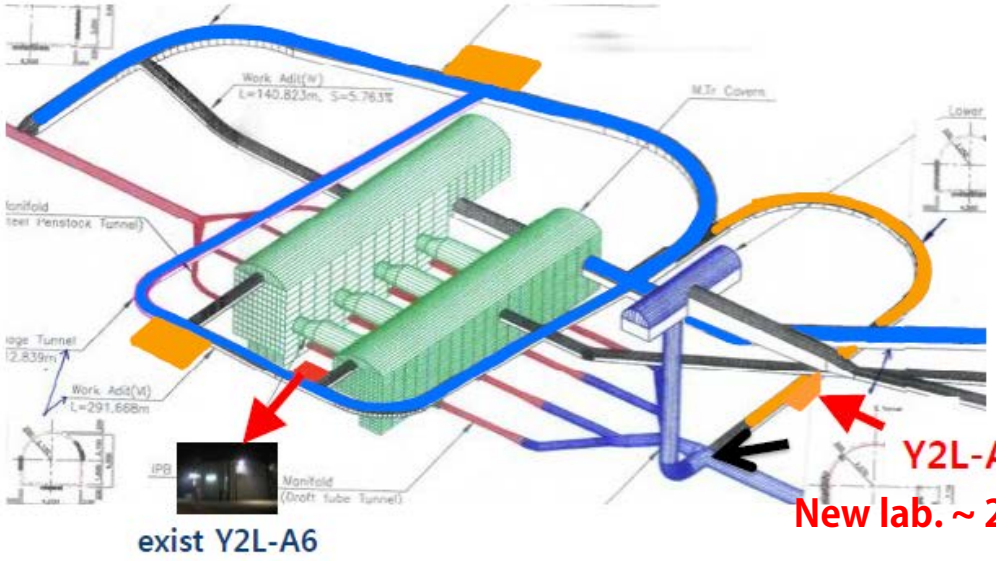


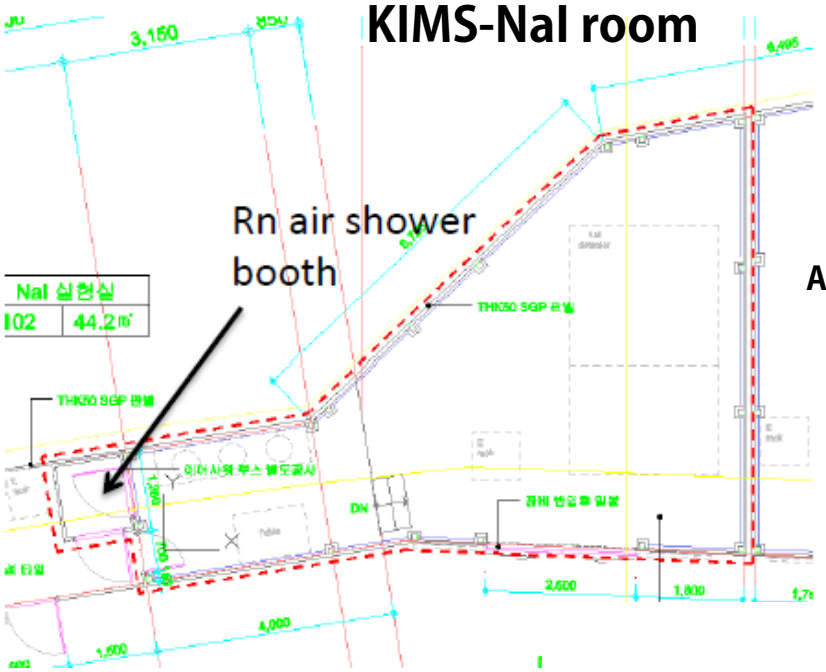
Dry run without LS is ongoing

Prospect of NaI(Tl) crystal development

- ^{40}K less than 10ppb
  - Astro-grade powders from Sigma-Adrich with ^{40}K less than 10ppb or additional purification with resin (**<0.2 dru**@2-4 keV)
  - ~factor two reduction with liquid scintillator veto system
- ^{210}Pb less than 0.2 mBq/kg
  - Already 0.5 mBq/kg
  - At least factor 2 reduction with powder purification (**<0.25 dru**@2keV)
- External
  - **less than 0.5 dru** with liquid scintillator veto system
- **Goal : 200kg NaI detectors (less than 1 dru background)** within 2 years

Underground laboratory

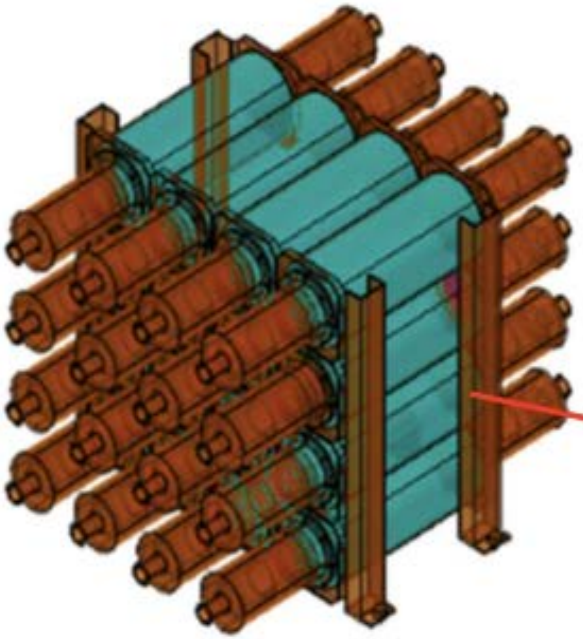




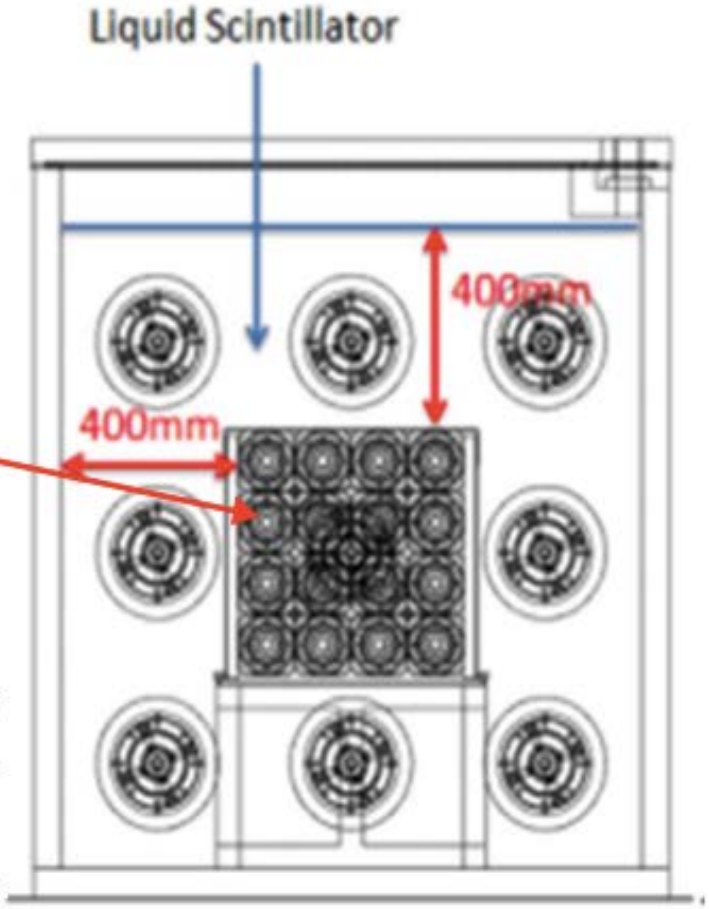
- Underground space for the KIMS-NaI was already prepared in Y2L
  - ❖ 10,000 class clean room
  - ❖ Rn free air will be supplied
  - ❖ Size of detector room ~ 49 m²

Design of KIMS-NaI experiment

NaI crystal Array
12.5kg X 16 crystals=200kg

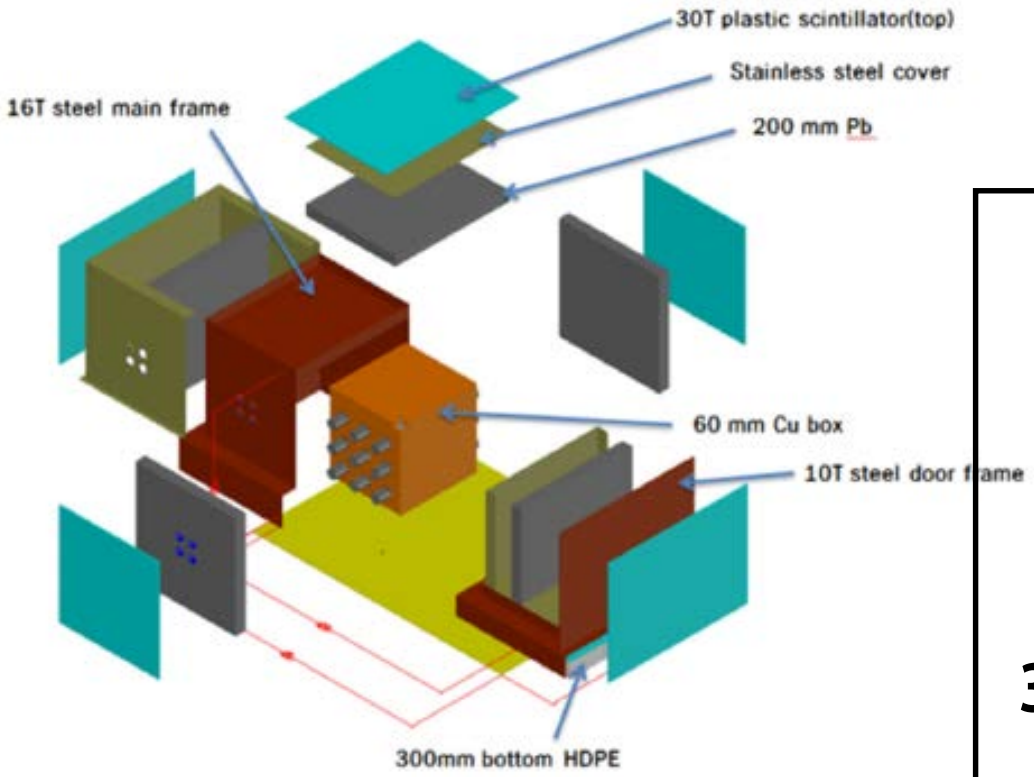


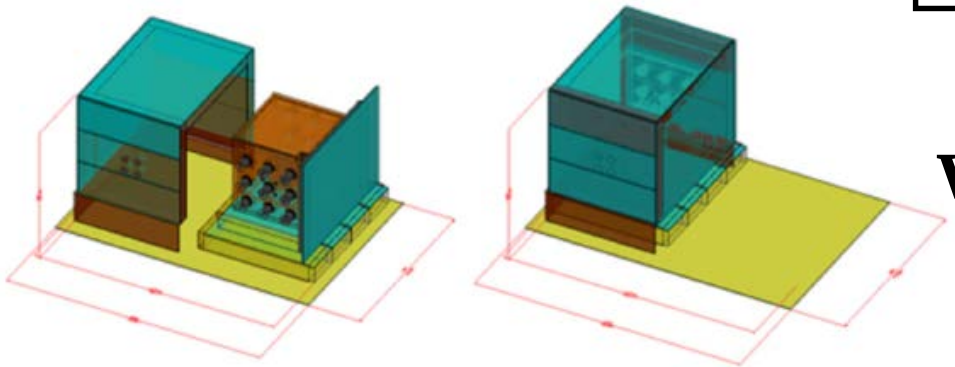
40cm Thick liquid scintillator active veto
To reduce the PMT related backgrounds



Veto Threshold	^{238}U	^{232}Th	^{40}K
0 keV	93.8%	94.5%	87.8%
100 keV	89.5%	90.4%	83.8%

Design of KIMS-NaI experiment





200 kg NaI (Tl) crystals

40 cm active LS veto

6 cm Cu

20 cm Pb (Gamma)

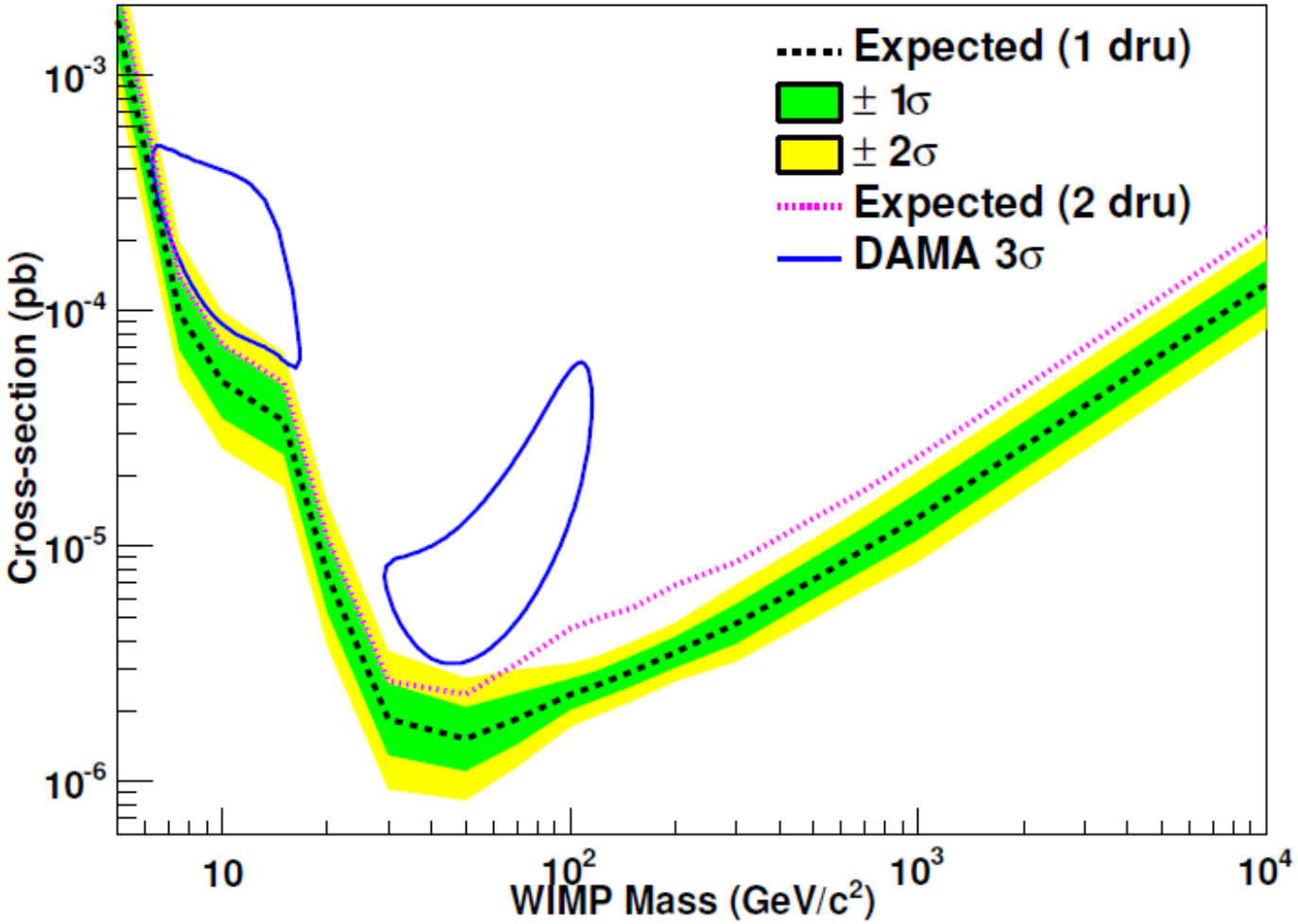
3 cm Plastic Scintillator (Muon)

30 cm Polyethylene(Neutron)

Will finish construction by Dec/2015

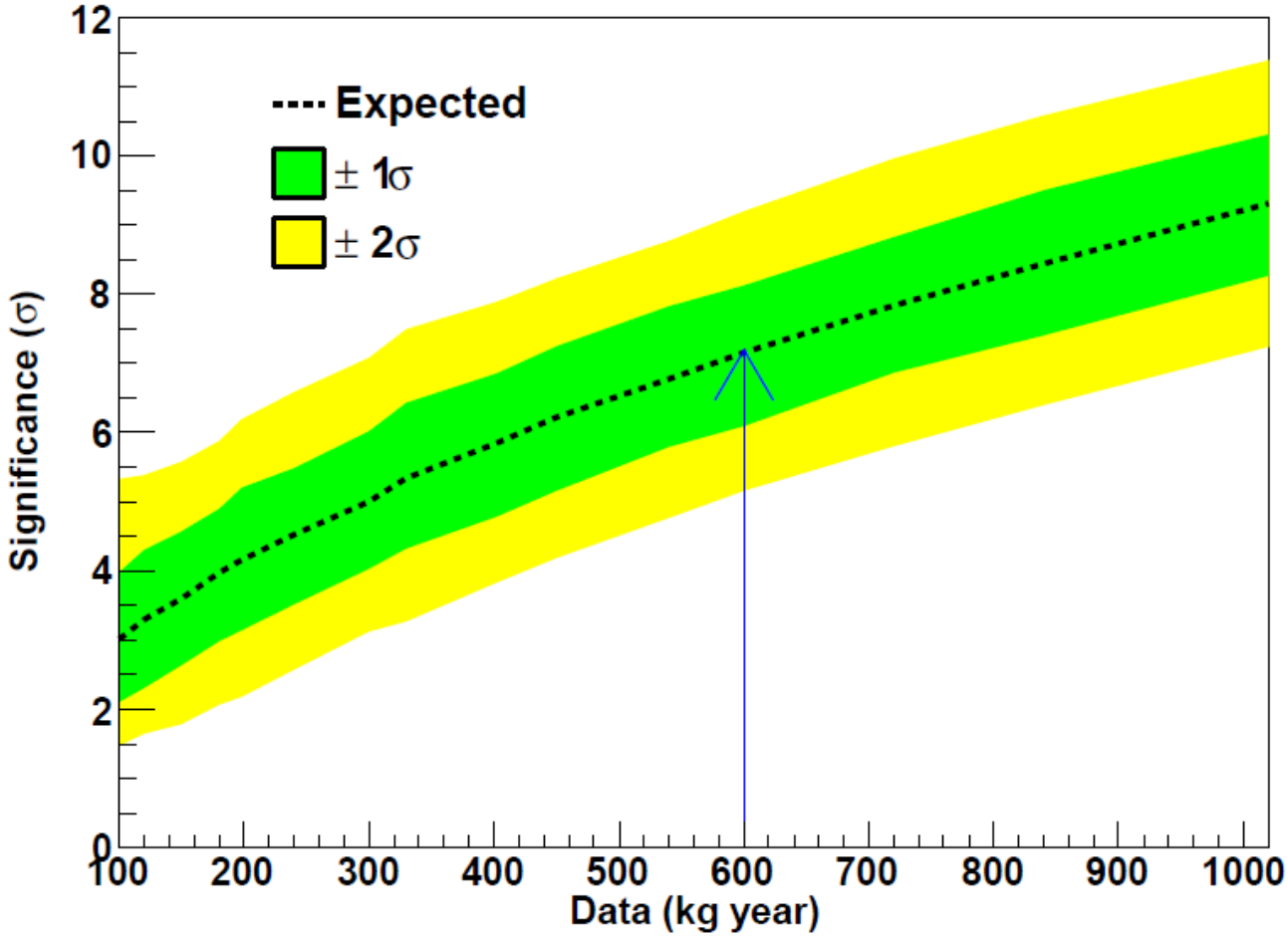
Sensitivity of KIMS-NaI experiment

- Assuming 200 kg 3 year operation (2keV threshold)



Observation probability

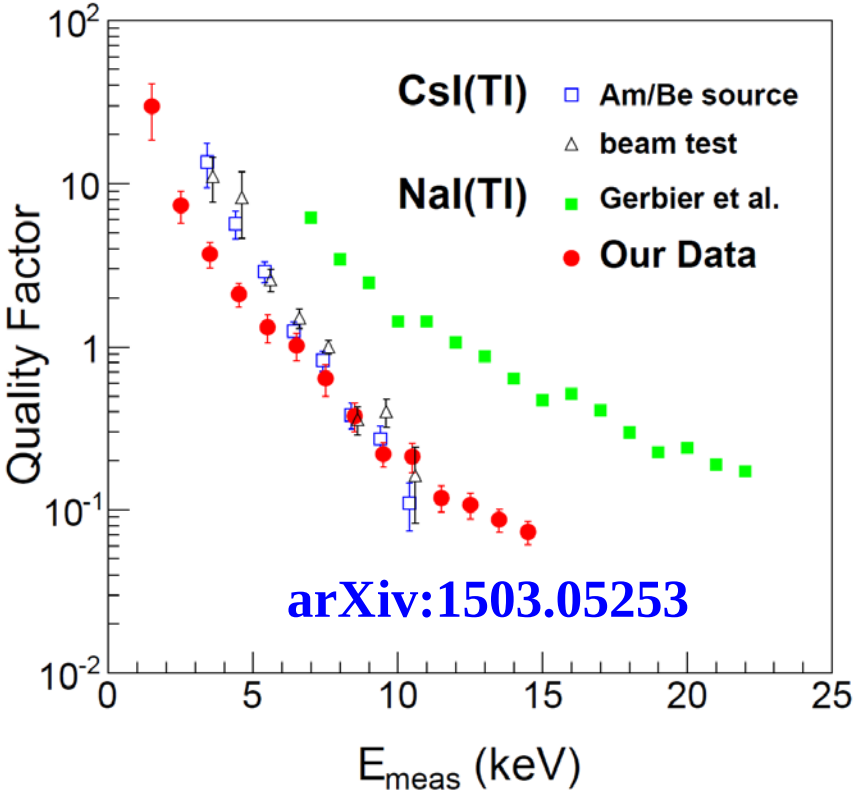
- Assuming DAMA/LIBRA are correct
- Expected significance of observation as a function of data size



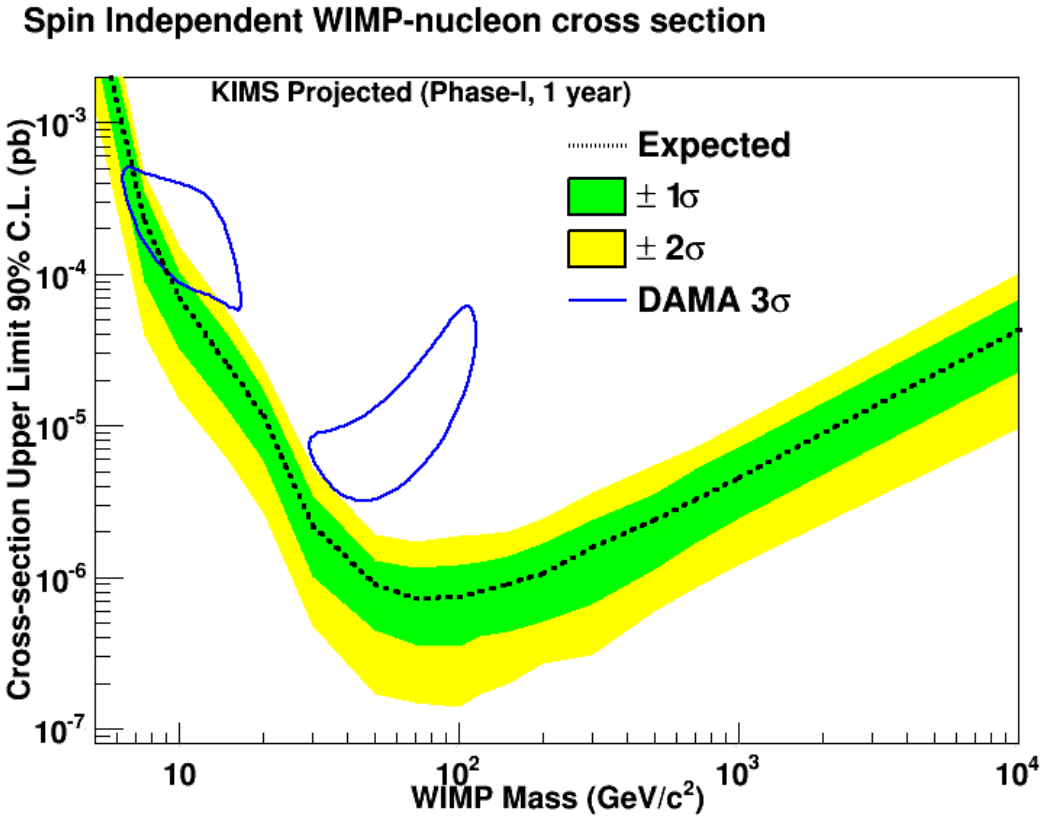
KIMS-NaI phase I

- Final crystal of 1 dru background needs at least one year
  - ½ year on background reduction
  - ½ year on crystallization
- Current best crystal has ~2 dru background @ 6keV
  - 3keV contribution from K can be effectively reduced by immersing into liquid scintillator (~ factor 2)
  - We ordered 2 (25kg) additional modules
- Running five modules before we get 200 kg NaI crystals
  - ~ one year data taking might be possible
  - Pulse shape discrimination analysis
  - Annual modulation searches

Pulse shape discrimination analysis



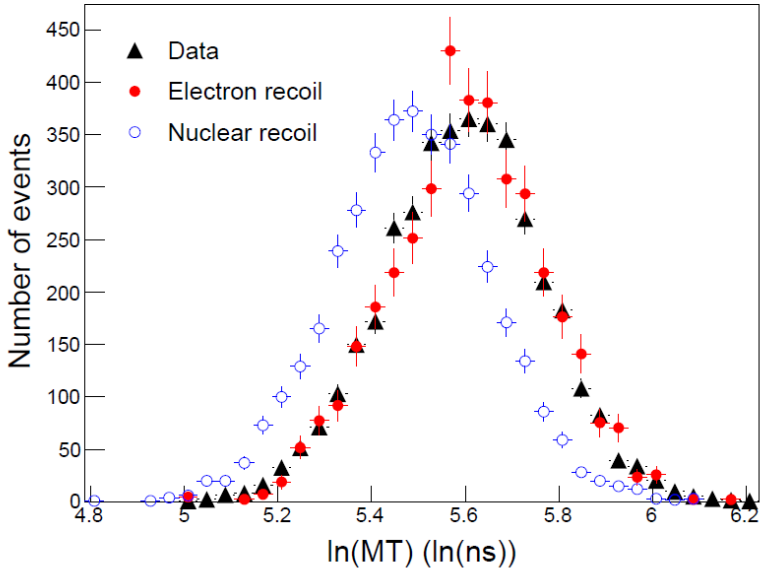
- Expected sensitivity with PSD analysis
  - 60 kg 1 year data
  - 4dru (2-6keV), 2dru(>6keV)



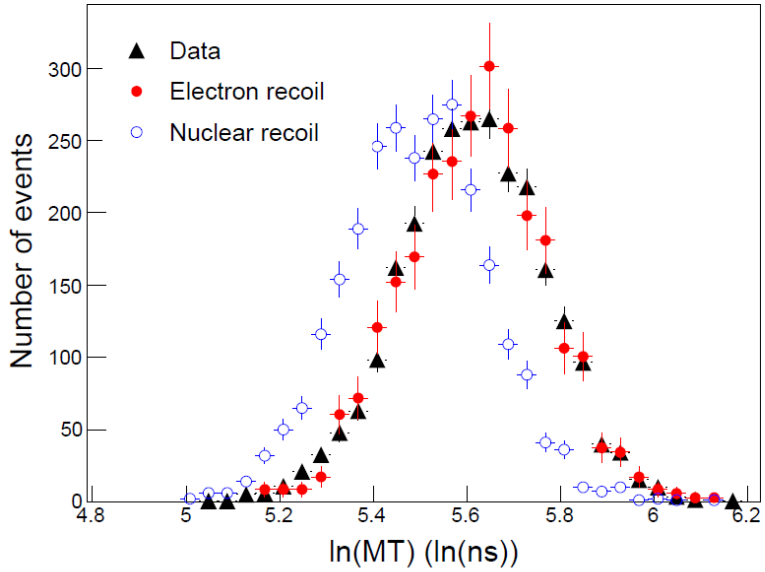
We can start phase-I from end of this years

PSD of current data

- NaI-002 (9.15 kg)
- Feb/2014-Aug/2014 (133.7 days)



(a) 3-4 keV



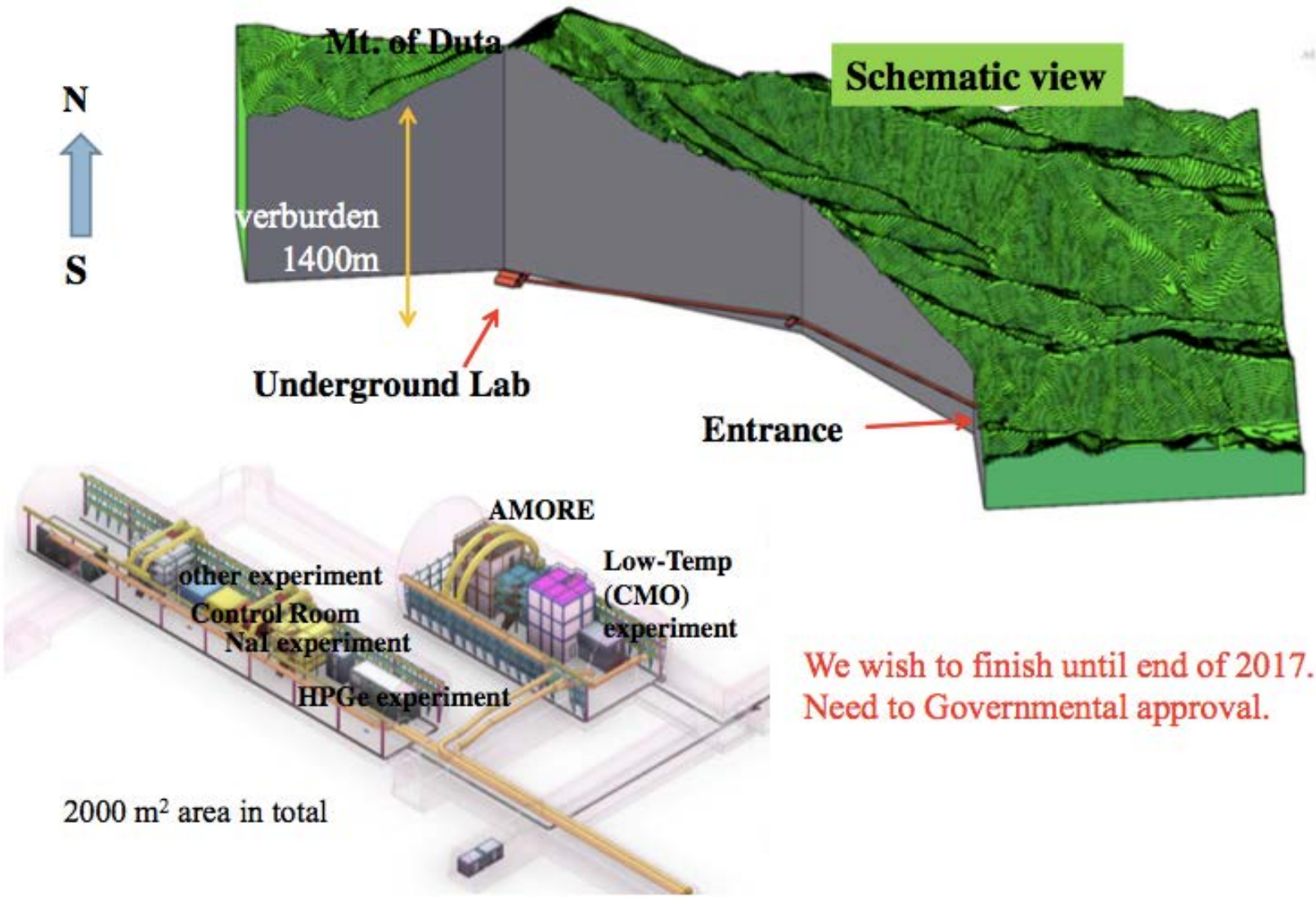
(b) 4-5 keV

- Working on
  - ❖ Understanding of systematic uncertainty
  - ❖ Evaluation of limit

Conclusion

- **KIMS-NaI** experiment start to grow the ultra-low background NaI(Tl) crystals for the WIMP search
  - Current ~2dru @ 6keV
  - Goal ~1dru @ 2keV (might be possible within one year)
  - We will start phase-I experiment using existing crystals at end of this year
  - We will definitely **confirm (or refute) the DAMA/LIBRA** observation within a couple of years

Proposed New Lab at Samcheok



We wish to finish until end of 2017.
Need to Governmental approval.