Low radioactivity CaF_2 scintillator crystals for CANDLES

OGAWA, Izumi(小川　泉)
for the CANDLES collaboration

Candles

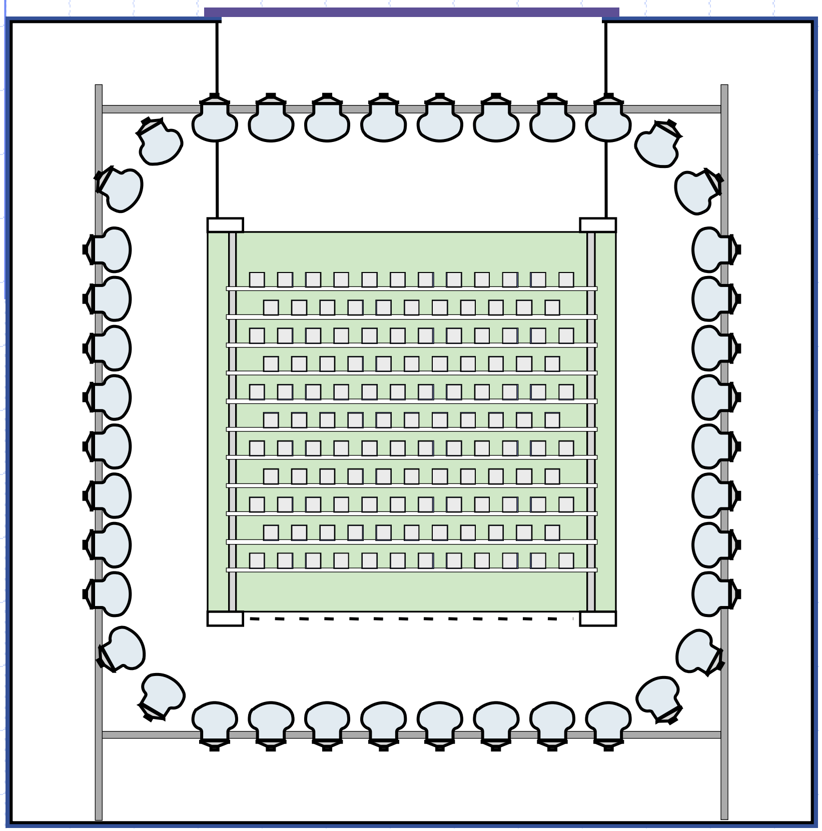
Double beta decay of ^{48}Ca

Candles

- Largest Q value (4.27 MeV)
  - next largest; ^{150}Nd (3.3 MeV)
  - large phase space factor
  - almost background free (γ: 2.6 MeV, β: 3.3 MeV)
- Low Natural abundance → 0.187%
  - large detector
  - enrichment
- Next generation detector : fight against BG!
  - $\langle m_\nu \rangle \propto T^{-1/2} \propto M_{det}^{-1/2}$ if background free
  - $\langle m_\nu \rangle \propto T^{-1/2} \propto M_{det}^{-1/4}$ if background limited

CANDLES

CAlcium fluoride for studies of Neutrino and Dark matters by Low Energy Spectrometer

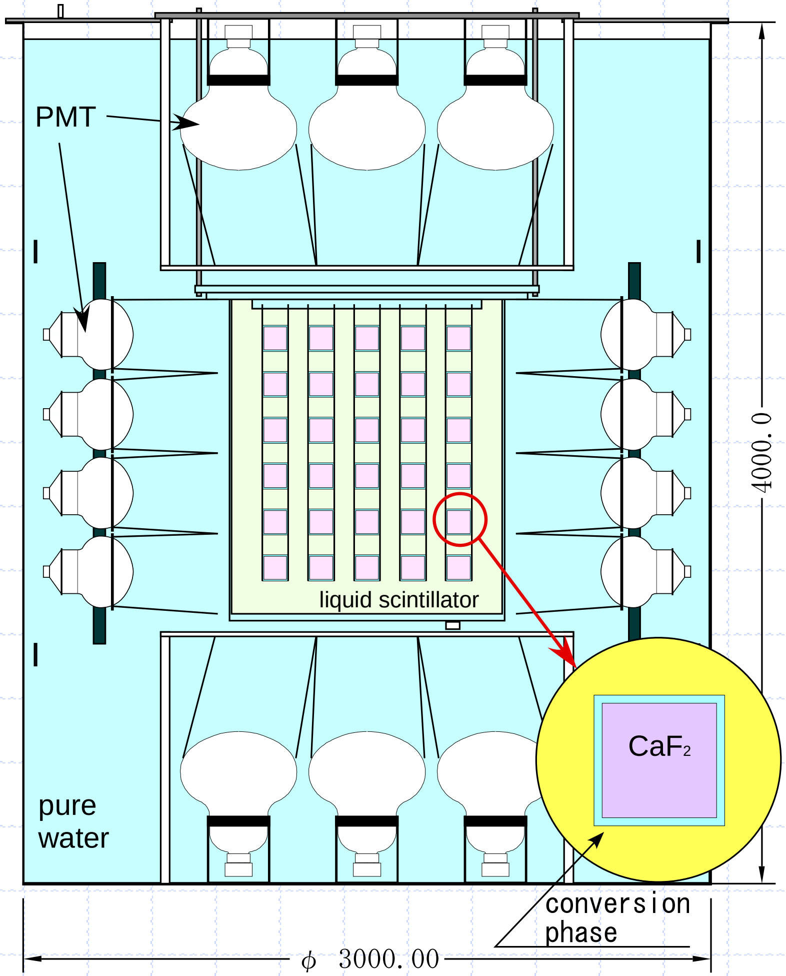


- undoped CaF_2 (CaF_2(pure))
  - ^{48}Ca ($Q_{\beta\beta}$=4.27 MeV)
  - Atten. length > 1 m
  - Low radioactive impurities
- Low background detector
  - 4π active shield (LS)
  - Passive shield (Water, LS)
  - Pulse shape information
- Good energy resolution
  - large photo-coverage
  - Two phase LS system

CANDLES III (U.G.) @Kamioka

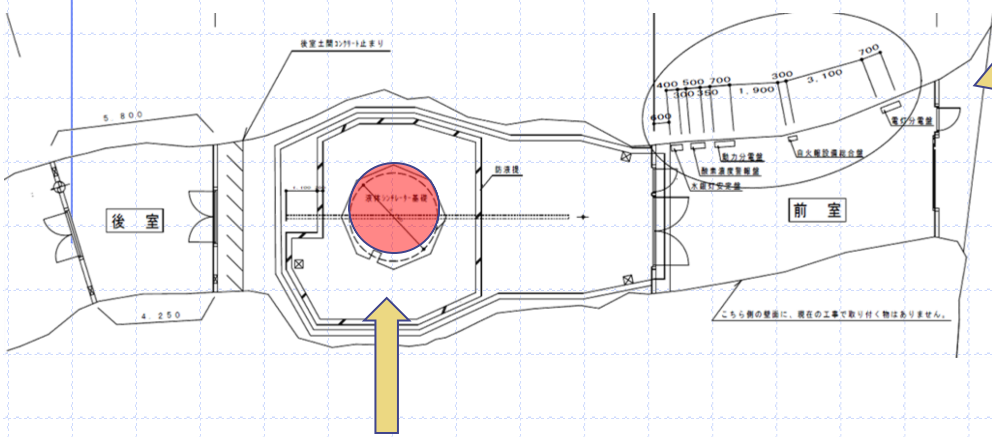
CANDLES III(U.G.)

- CaF_2(pure)
  - 10^3 cm^3 × 96 crystals; 305 kg
- Liquid scintillator
  - two phase system
  - Purification system
- H_2O Buffer
  - passive shield (larger tank)
- PMTs
  - 17” PMT (×14) : R7250
  - 13” PMT (×56) : R8055
- photon trans. simulation
  ⇨ energy res. ~4.0 % @ $Q_{\beta\beta}$
- Kamioka underground lab.

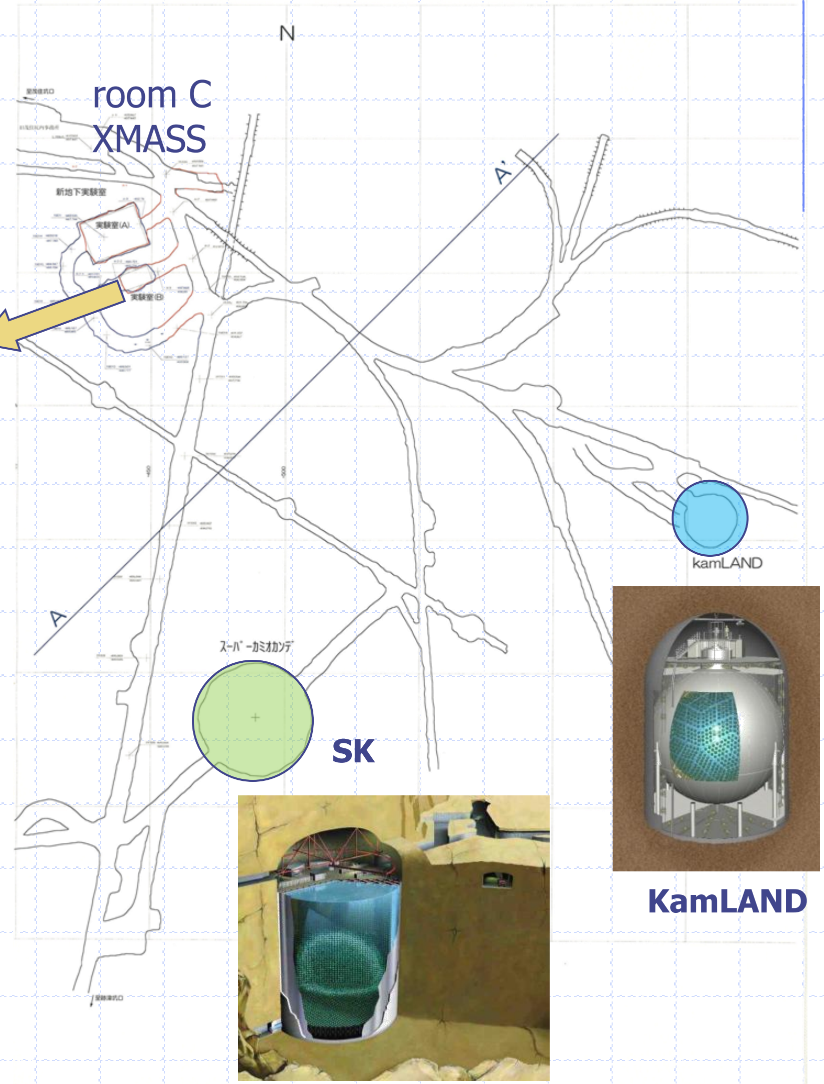


Kamioka new exp. room

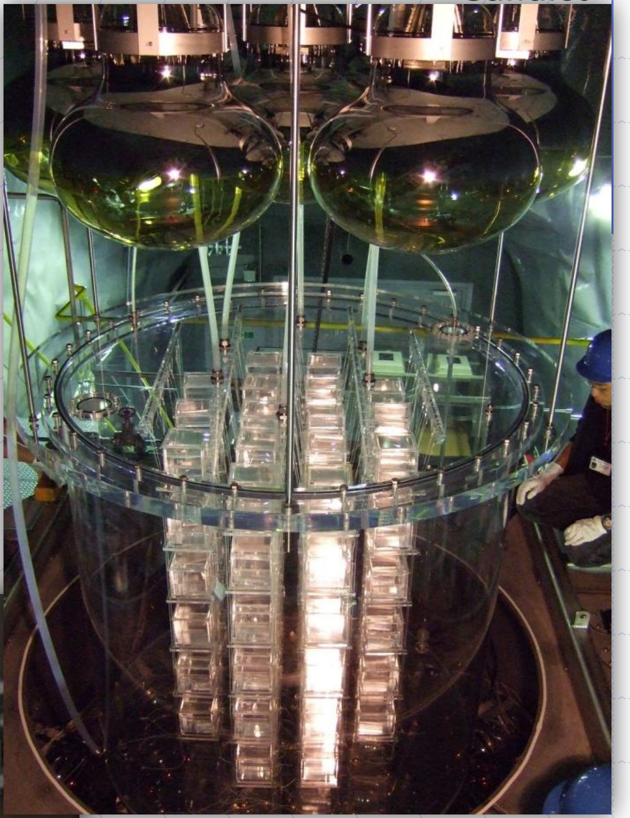
- experimental room D



San-chika



CANDLES III (U.G.)



Undoped CaF_2 scintillation crystal

Energy resolution

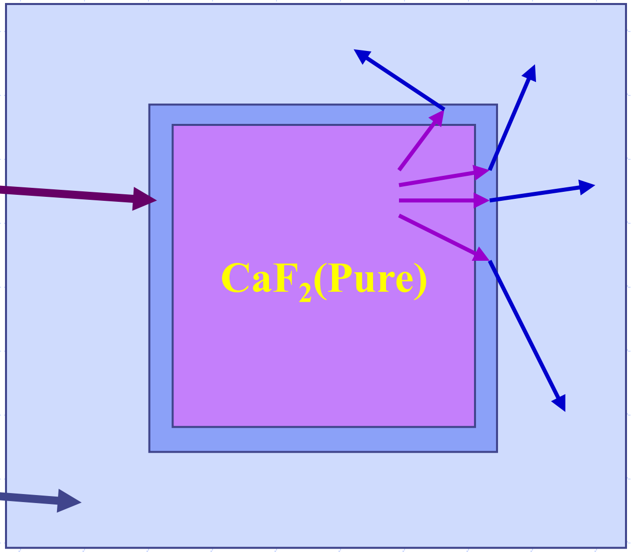
- Keep high transparency for both(CaF_2(UV), LS(vis.)) scintillation light

  CaF_2 crystal, LS, pure water, acrylic vessel,…

  - Undoped CaF_2 (attenuation length > 1m)
    - cf. CaF_2(Eu) ~10 cm
  - Shift wavelength of scintillation light from CaF_2 scintillators; UV ⇒ visible
- Large photo-coverage
  - Large (13,17 inch) PMT

Two Phase System

- Concept of Method
  - Conversion Phase
    - large conversion eff.
    - good transparency for UV
  - Veto Phase
    - large light output with aromatic solvent (absorb UV light)
    - good transparency for visible light



CaF_2 Emission (~285nm)

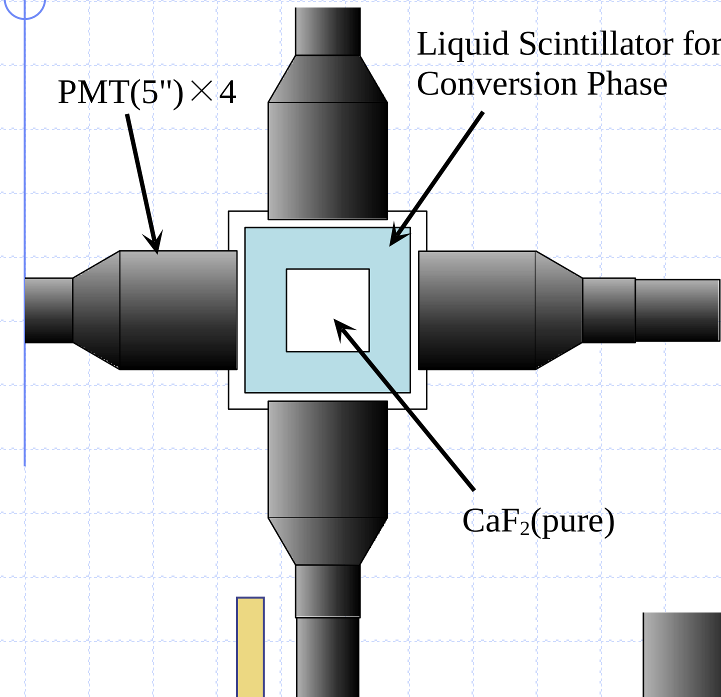
⇩

Conversion by WLS (350~400nm)

⇩ propagate

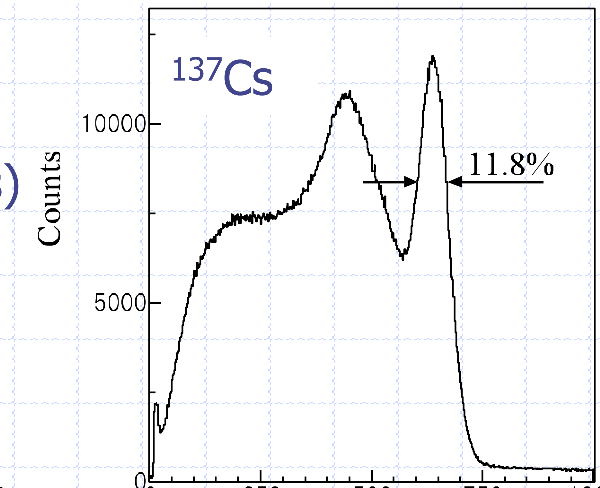
PMT

Performance of two phase system

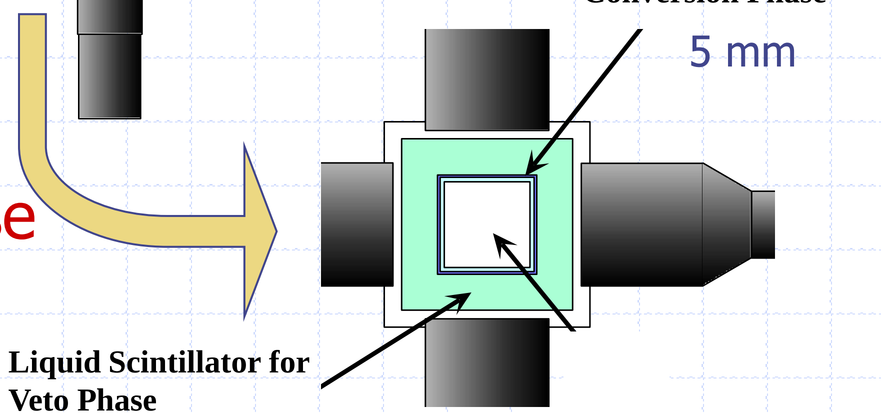


conversion phase only

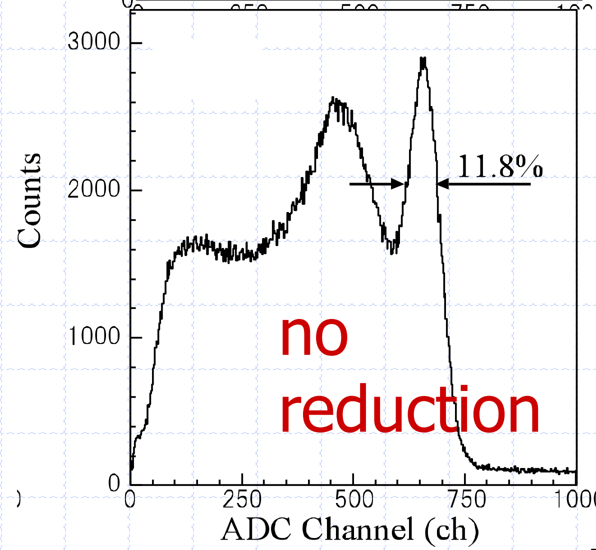
(5 cm thickness)



Two Phase system



5 mm

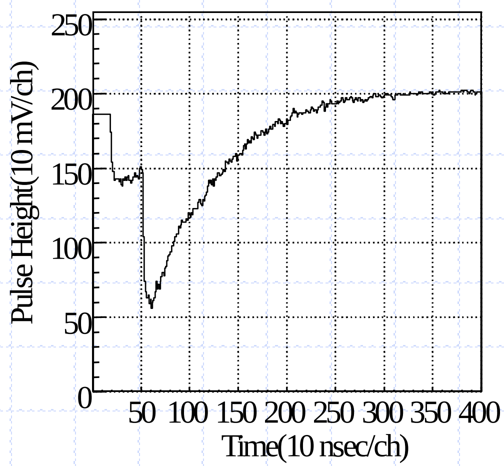


no reduction

Main BG in CaF_2 scintillator

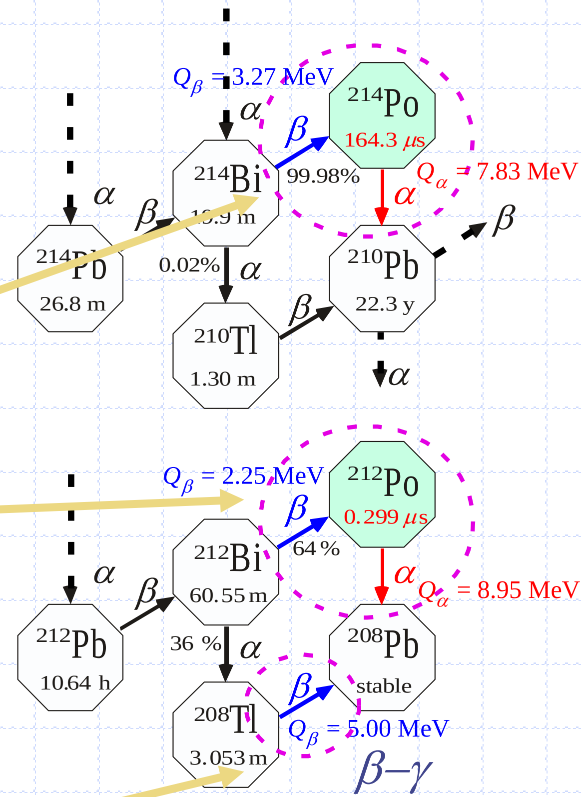
◆ BG

- Successive decays in U, Th



^{214}Bi (U)

^{212}Bi (Th)



$$E_{vis} = Q_\beta + Q_\alpha \times f \approx Q_{\beta\beta}$$

f : Quenching factor for α

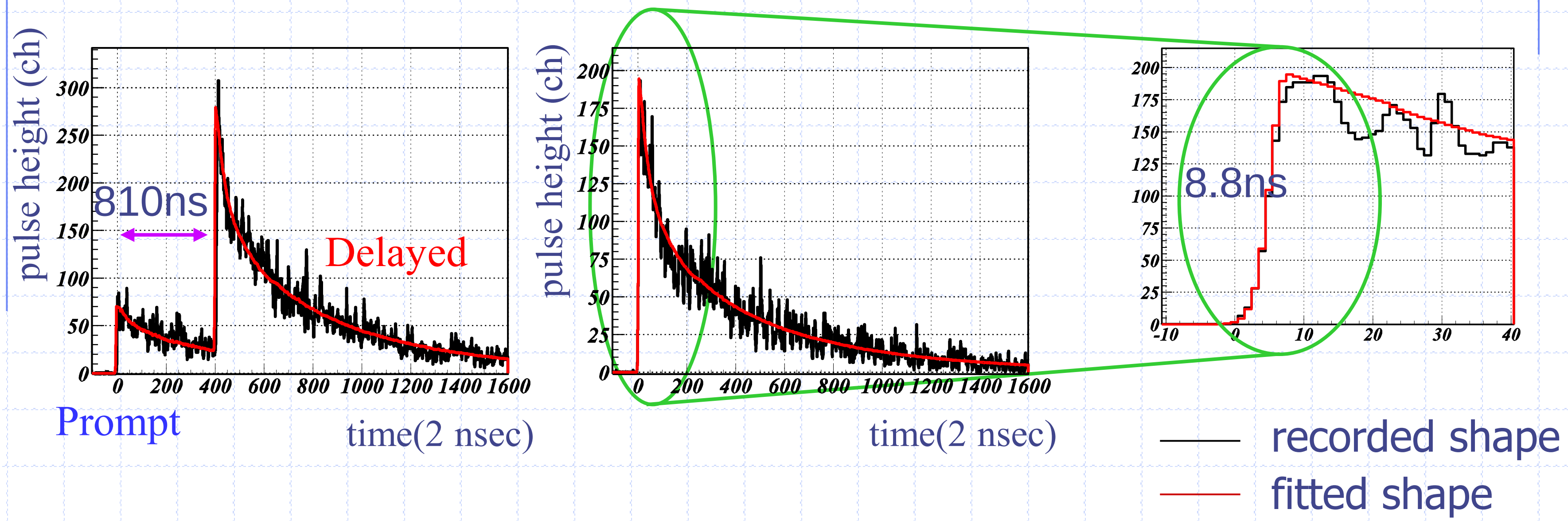
- ^{208}Tl : $\beta - \gamma$

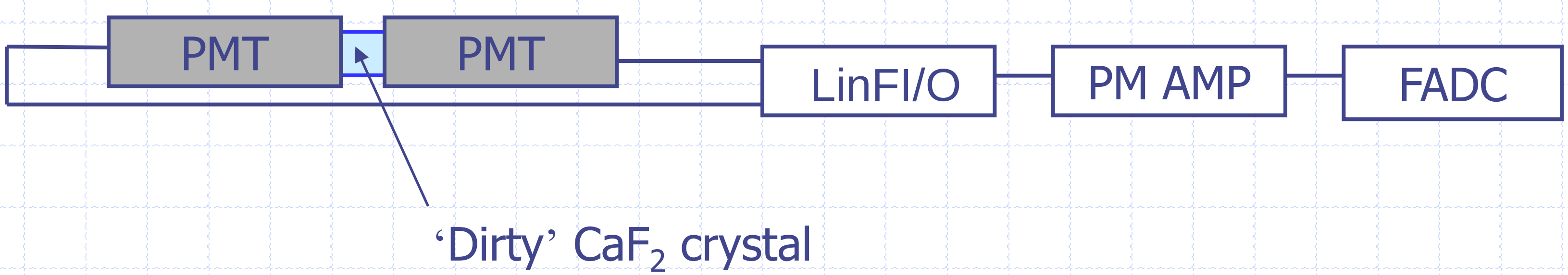
E_{max}=5.8 MeV (U)
5.3 MeV (Th)

Rejection of Double Pulse(DP)

Candles

Typical Pulse Shapes



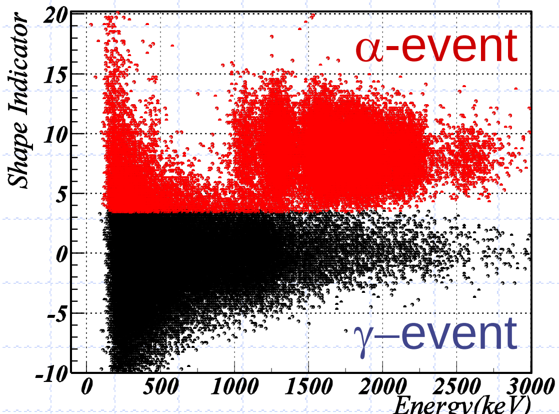


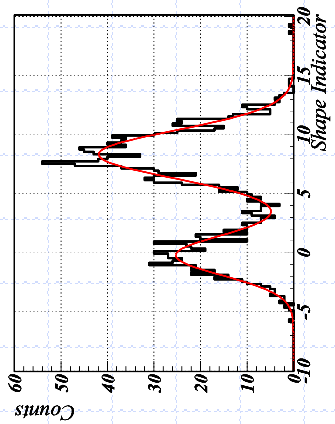
Pulse Shape Discrimination

Candles

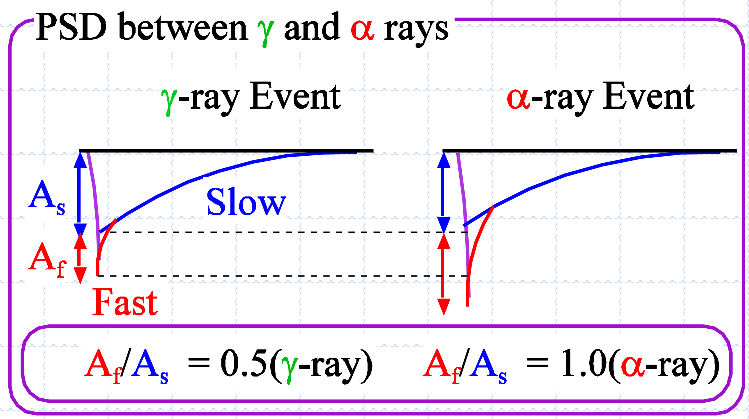
Pulse Shape discrimination

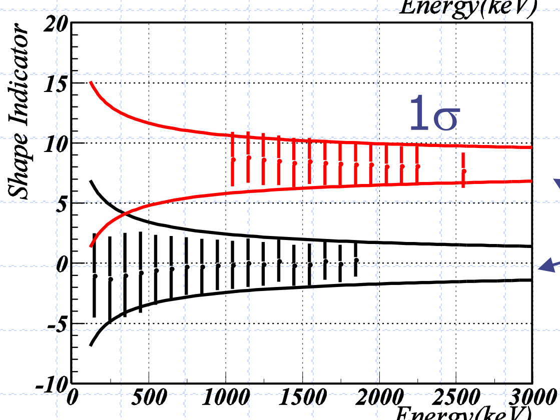
- Shape Indicator (PRC **67**(2003) 014310)





Difference in decay shape between α and γ rays





mean value:
no energy dependence (>1 MeV)

Development of High Purity CaF_2 Crystals

CaF_2(Eu) in ELEGANT VI
U-chain(^{214}Bi) :1100 μBq/kg
Th-chain(^{220}Rn) : 98 μBq/kg

U and Th
(ICP-MS)

Raw Materials $CaCO_3$, HF ⇒ **CaF_2 Powder** ⇒ **Fused CaF_2** ⇒ **CaF_2 Crystal**

Radioactivities in CaF_2 Powder (HPGe measurement) ⟷ Radioactivities in CaF_2(pure) Crystal (α-ray measurement)

(1) Powder selection
(2) Crystal growing

101 crystals

U-chain(^{214}Bi) ~36 μBq/kg …1/30 of Previous Crystals (14±5 μBq/kg ;Best)
Th-chain(^{220}Rn) ~28 μBq/kg …1/3 of Previous Crystals (6±1 μBq/kg ;Best)

(1) Powder selection

- Measurements before (powder) and after crystallization

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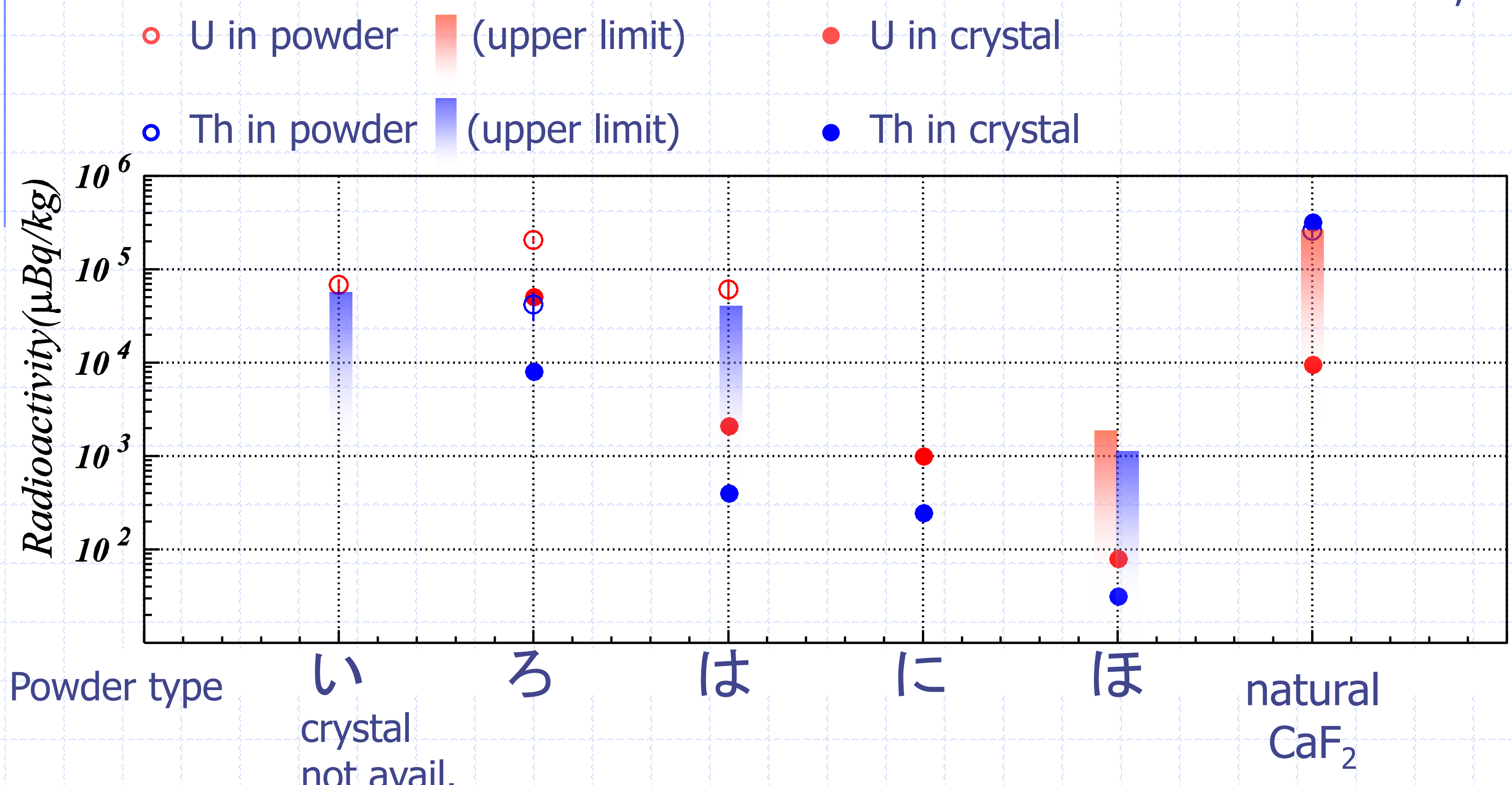
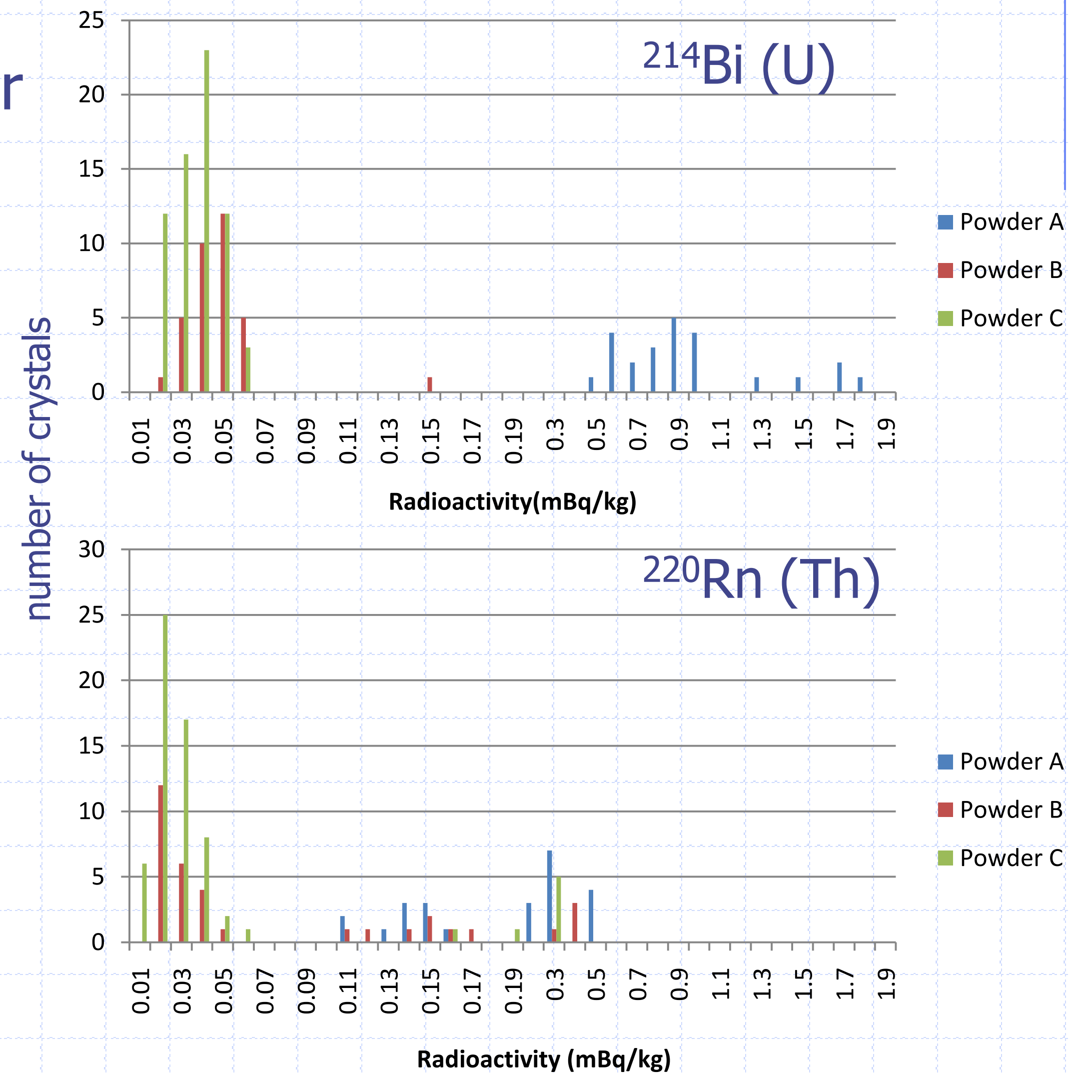


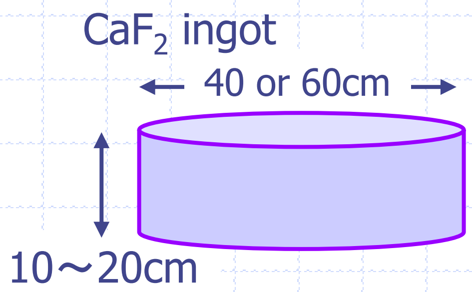
Powder type

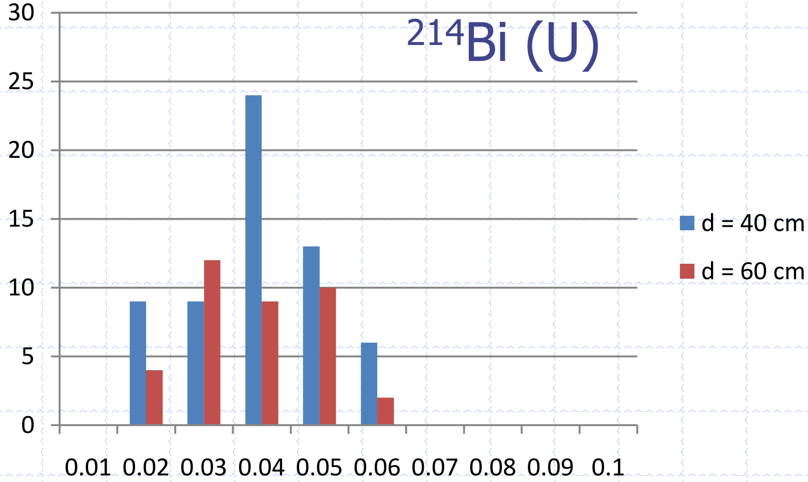
- 3 types of CaF_2 powder
  - Powder A
    24 crystals
  - Powder B
    34 crystals
  - Powder C
    66 crystals

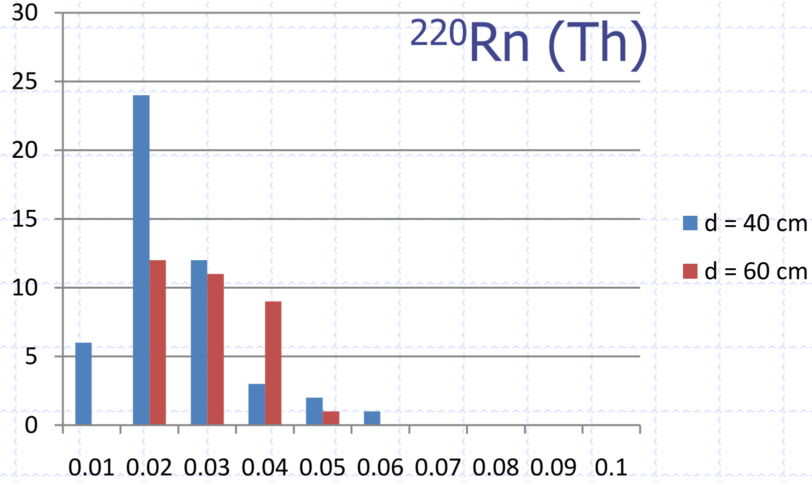


(2) Crystal growing

- Two types of melting pod
  - d = 40 or 60 cm



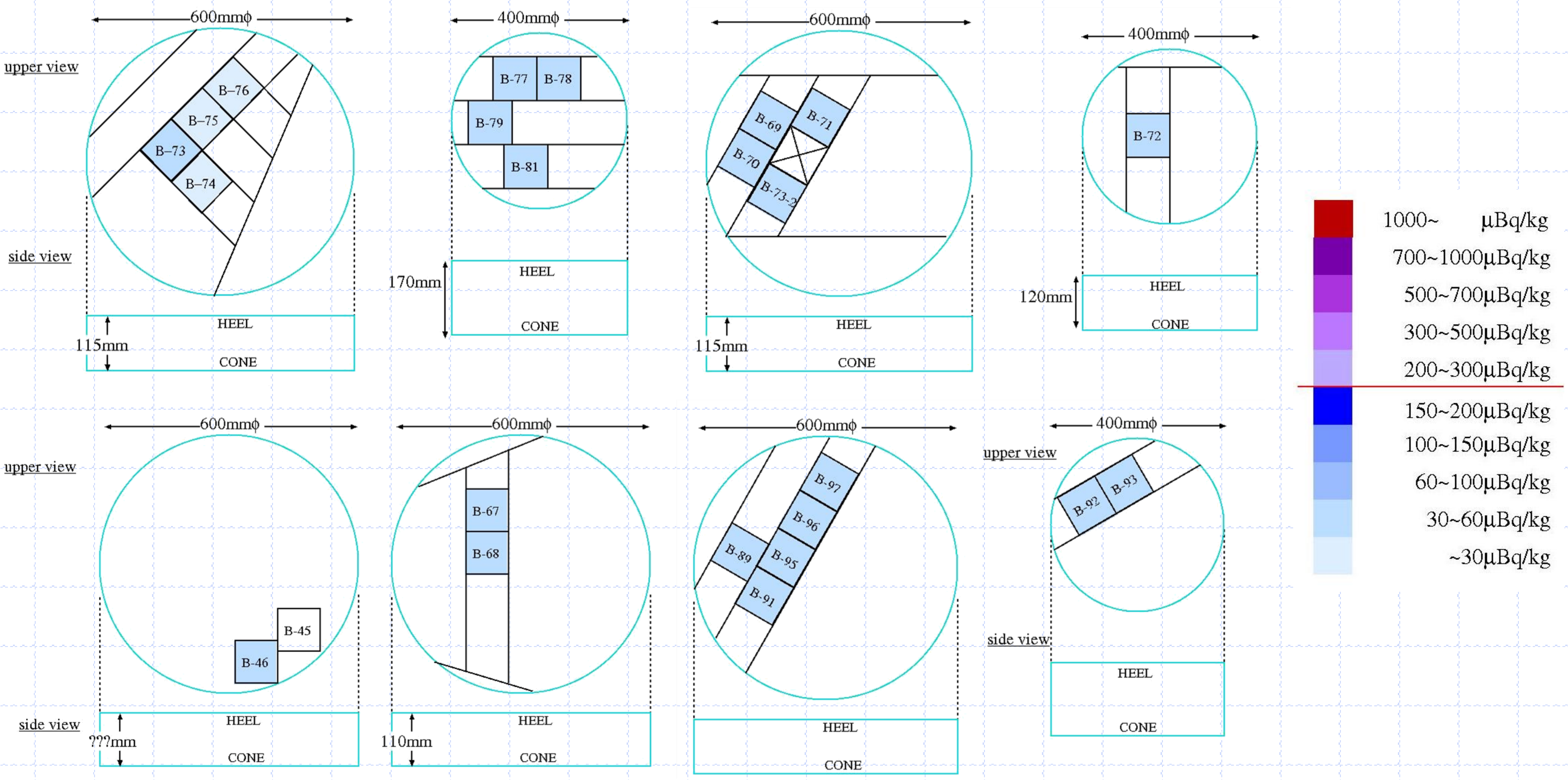




⇨ There is no big difference

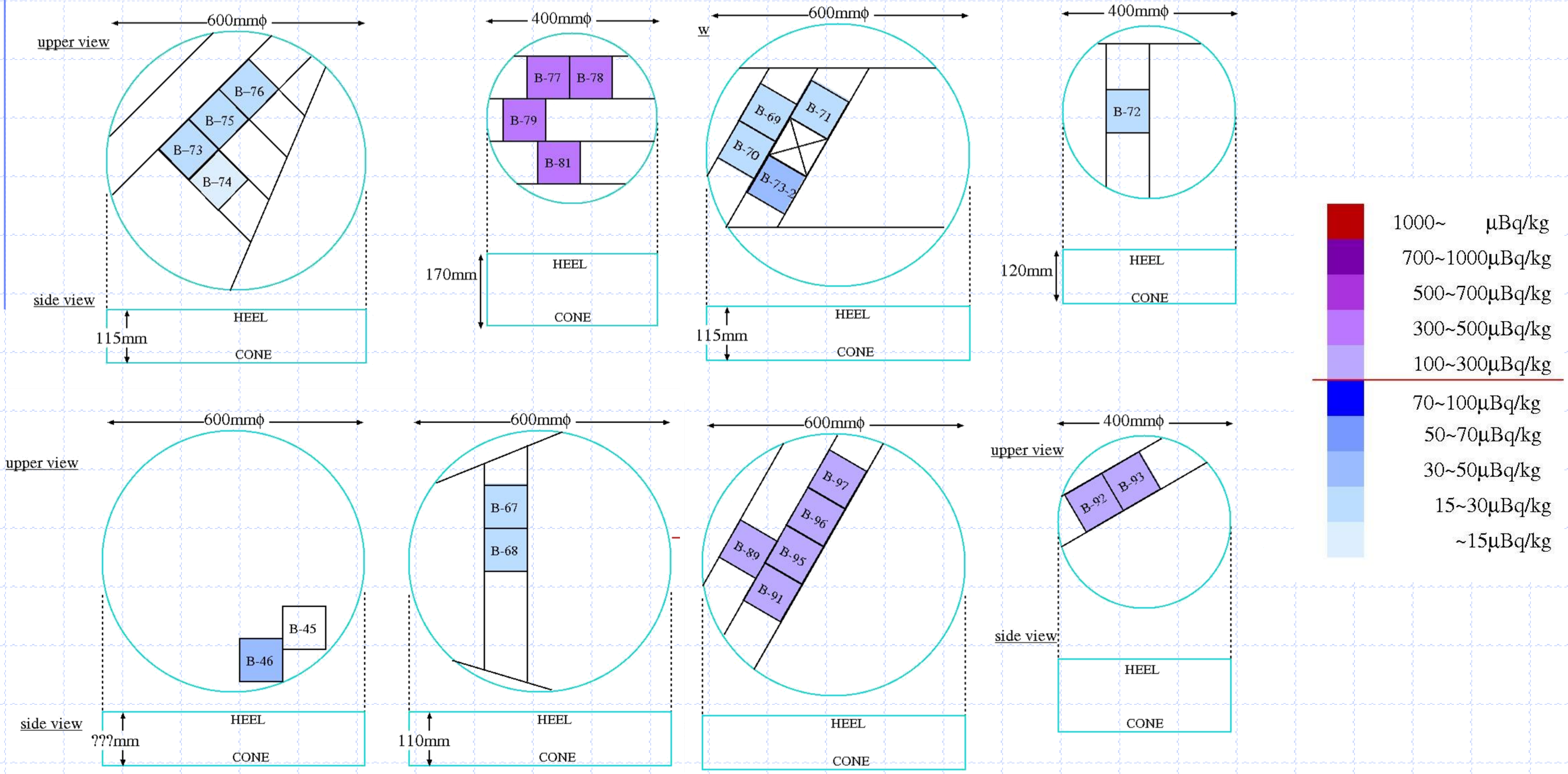
Position dependence

- ^{214}Bi(U-chain) → no position dependence



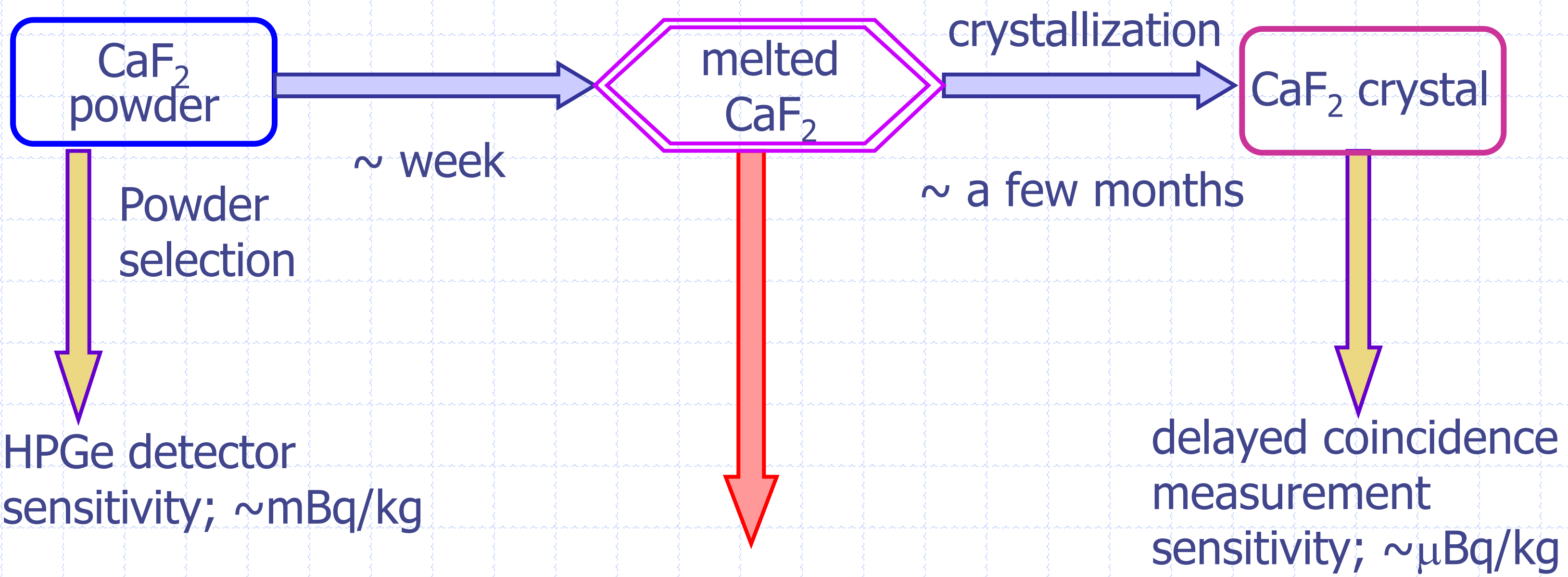
Position dependence

- ^{220}Rn(Th-chain) → no position dependence



R&D (1)

- Purity measurement using melted CaF_2



- Can we measure the radioactivity of melted CaF_2?
  - If scintillated, we can use delayed coincidence technique.

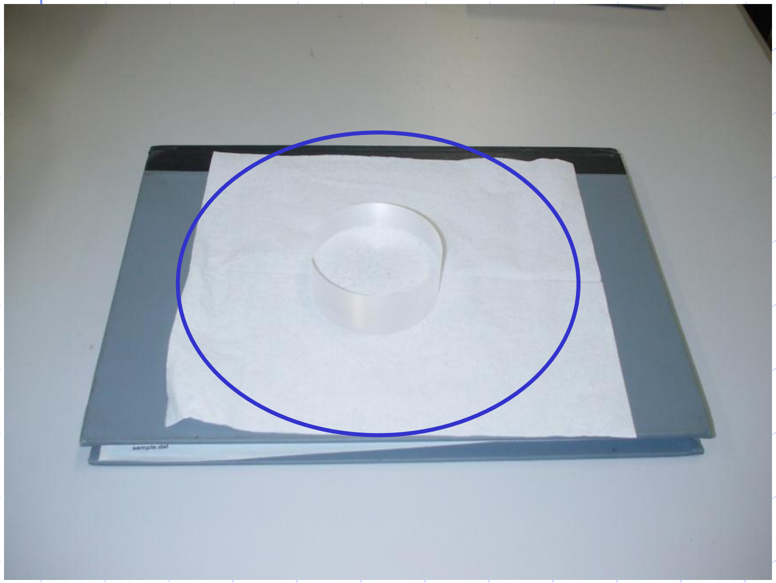
⇩

  - high sensitivity in short time

Melted CaF_2 samples

Stella Chemifa Corp.

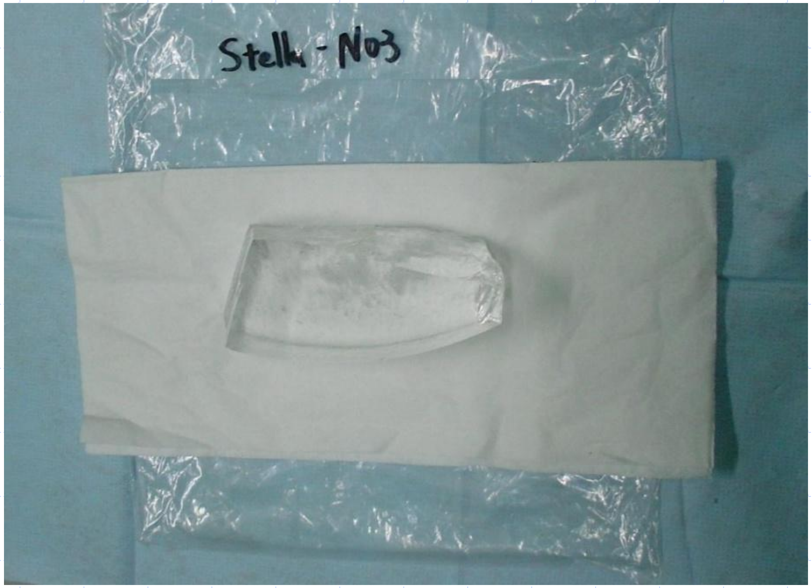
Sample #1



367.5g, $\phi 7 \times {}^{t}3$ cm^3

from pure CaF_2 powder

Sample #2



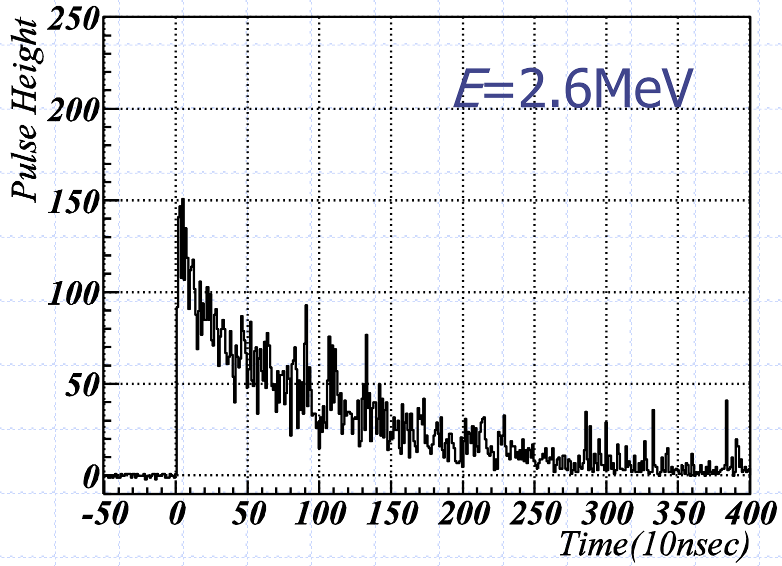
341.7g

High radioimpurity CaF_2 powder

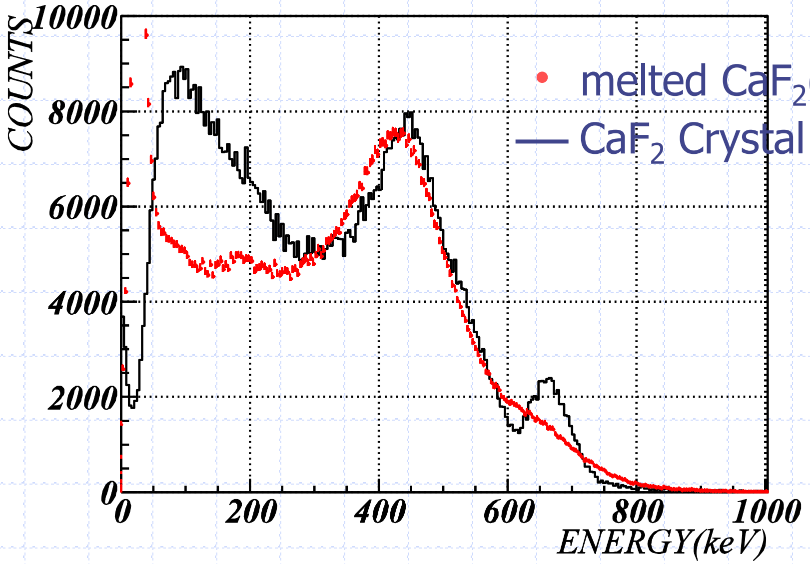
Scintillation measurement

Stella Chemifa Corp.

Pulse shape



Energy spectra (^{137}Cs)



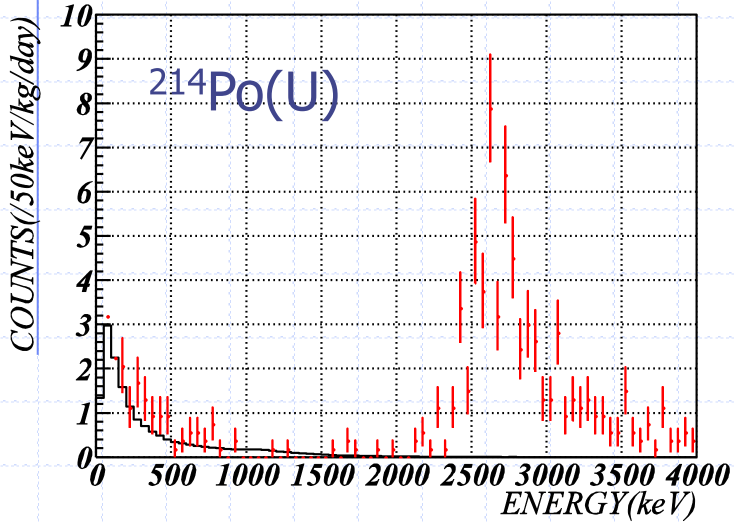
- Weak scintillation light observed
- poorer energy resolution, but enough for radioactivity measurement

Radioactivity measurement

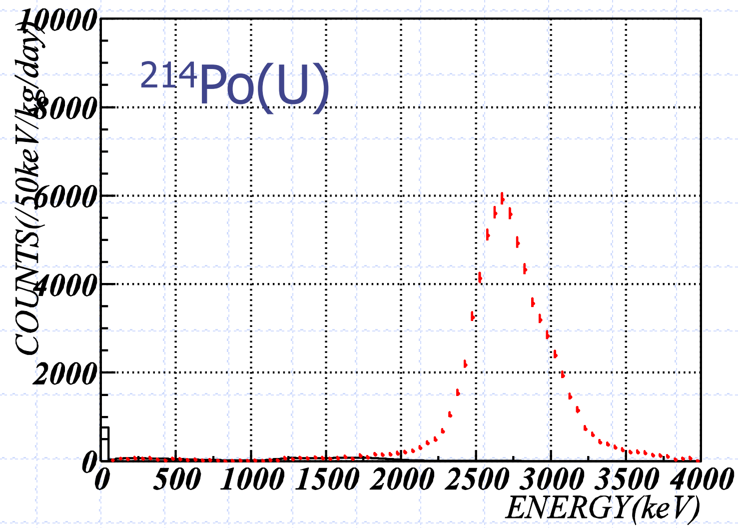
Candles

Stella Chemifa Corp.

- Sample #1



Sample #2



^{214}Po(U): 0.87±0.05mBq/kg

^{216}Po(Th): 0.083±0.020mBq/kg

^{214}Po: 927±6mBq/kg

^{216}Po: <9.1mBq/kg

meas. time: 14.5 days

1.0 day

comparison with ICP-MS

Candles

Stella Chemifa Corp.

Delayed coinc.

Sample #2

^{214}Po(U):	75.0±0.5 ppb
^{212}Po(Th):	<2.2 ppb

Sample #3

^{214}Po(U):	100.1±0.7 ppb
^{212}Po(Th):	<3.3 ppb

sensitivity

^{214}Po(U)	~0.001ppb
^{212}Po(Th)	~0.002ppb

ICP-MS

U:	80 ppb
Th:	<20 ppb

U:	100 ppb
Th:	<20 ppb

sensitivity

U	0.2ppb
Th	0.3ppb

R&D (2)

Candles

- Rinse the powder with HNO_3 (3 wt%)

Oken co., ltd.

  - same powder (type, lot)
  - contamination measurement was done after crystallization

without rinsing

^{214}Po(U-chain) : $1.12 \pm 0.03(\mathit{stat.})^{+0.10}_{-0.12}$ (*syst.*) mBq/kg

^{212}Po(Th-chain) : 1.67 ± 0.04 mBq/kg

^{215}Po(Ac-chain) : $1.69 \pm 0.03(\mathit{stat.})^{+0.30}_{-0.35}$ (*syst.*) mBq/kg

⇩

with rinsing

^{214}Po(U-chain) : $0.07 \pm 0.02(\mathit{stat.})^{+0.01}_{-0.02}$ (*syst.*) mBq/kg

^{212}Po(Th-chain) : 0.95 ± 0.03 mBq/kg

^{215}Po(Ac-chain) : $0.70 \pm 0.03(\mathit{stat.})^{+0.13}_{-0.14}$ (*syst.*) mBq/kg

Summary

- CANDLES project
  - Study of ^{48}Ca double beta decay
- CaF_2(pure) scintillation crystal
  - Material (CaF_2 powder) selection is quite important
  - No significant difference in radioactivity measurement with two types of ingot size
  - No position dependence in radioactivity measurement for each ingot
  - Melted CaF_2 can be used to measure the radioactivity in the CaF_2 powder
- CANDLES III(U.G.) @Kamioka
  - Under construction
  - Expected BG: 0.18 ev/year

CANDLES Collaboration

Candles

- Osaka U.（大阪大学）
  - T. Kishimoto, I. Ogawa, S. Umehara, K. Matsuoka, Y. Hirano, Y. Tsubota, G. Ito, K. Yasuda, H. Kakubata, M. Miyashita, M. Nomachi, Y. Kohno, M. Saka, S. Ajimura
- Fukui U.（福井大学）
  - Y. Tamagawa, T. Hayashi, Y. Maekawa, S. Isogai, T. Sato, T. Jinno
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- Tohoku U.（東北大学）
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- Tokyo Institute of Technology（東京工業大学）
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- U. Tokushima（徳島大学）
  - K. Fushimi