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New fast-timing γ-ray detector system in Korea: KHALA

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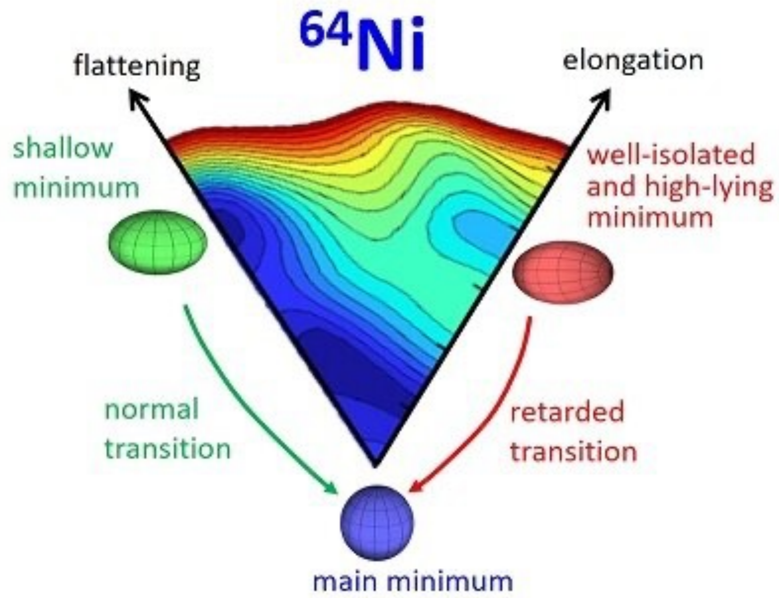
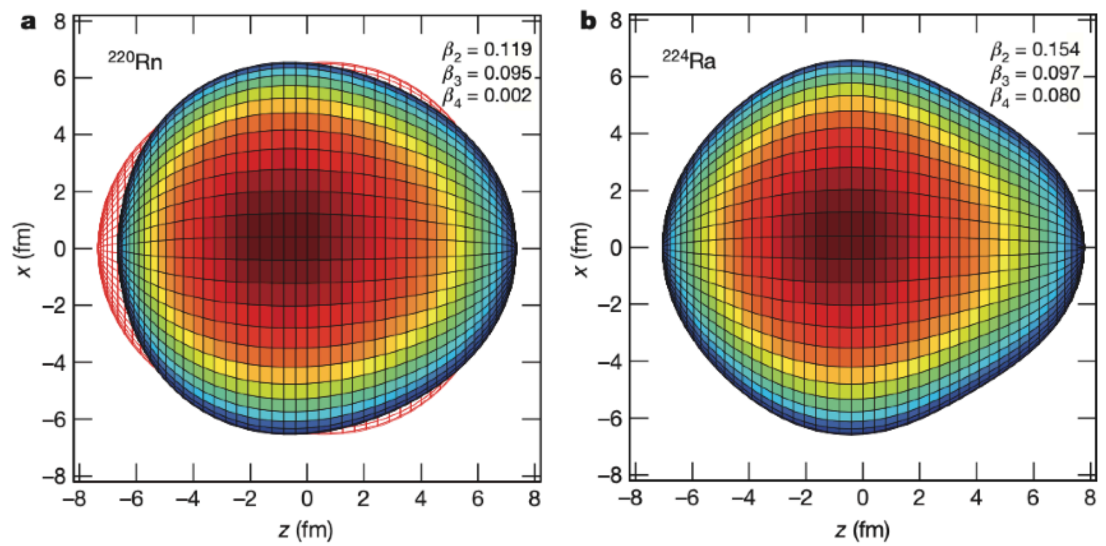
CENS CENTER FOR EXOTIC NUCLEAR STUDIES

Why fast-timing measurement?

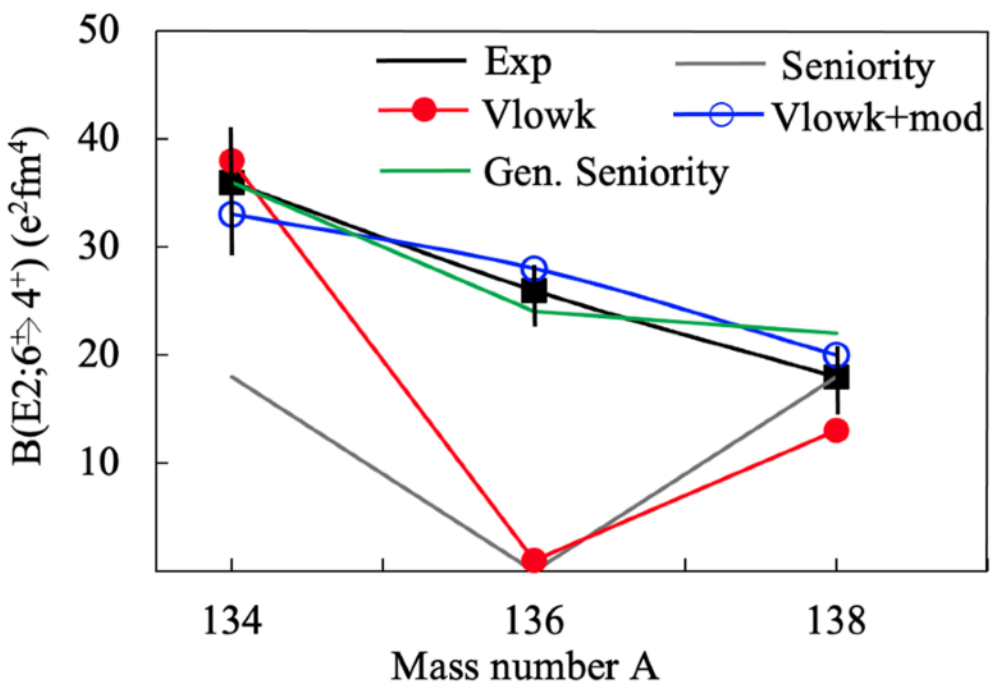
PRL **125**, 102502 (2020).



Nature **497**, 199 (2013).

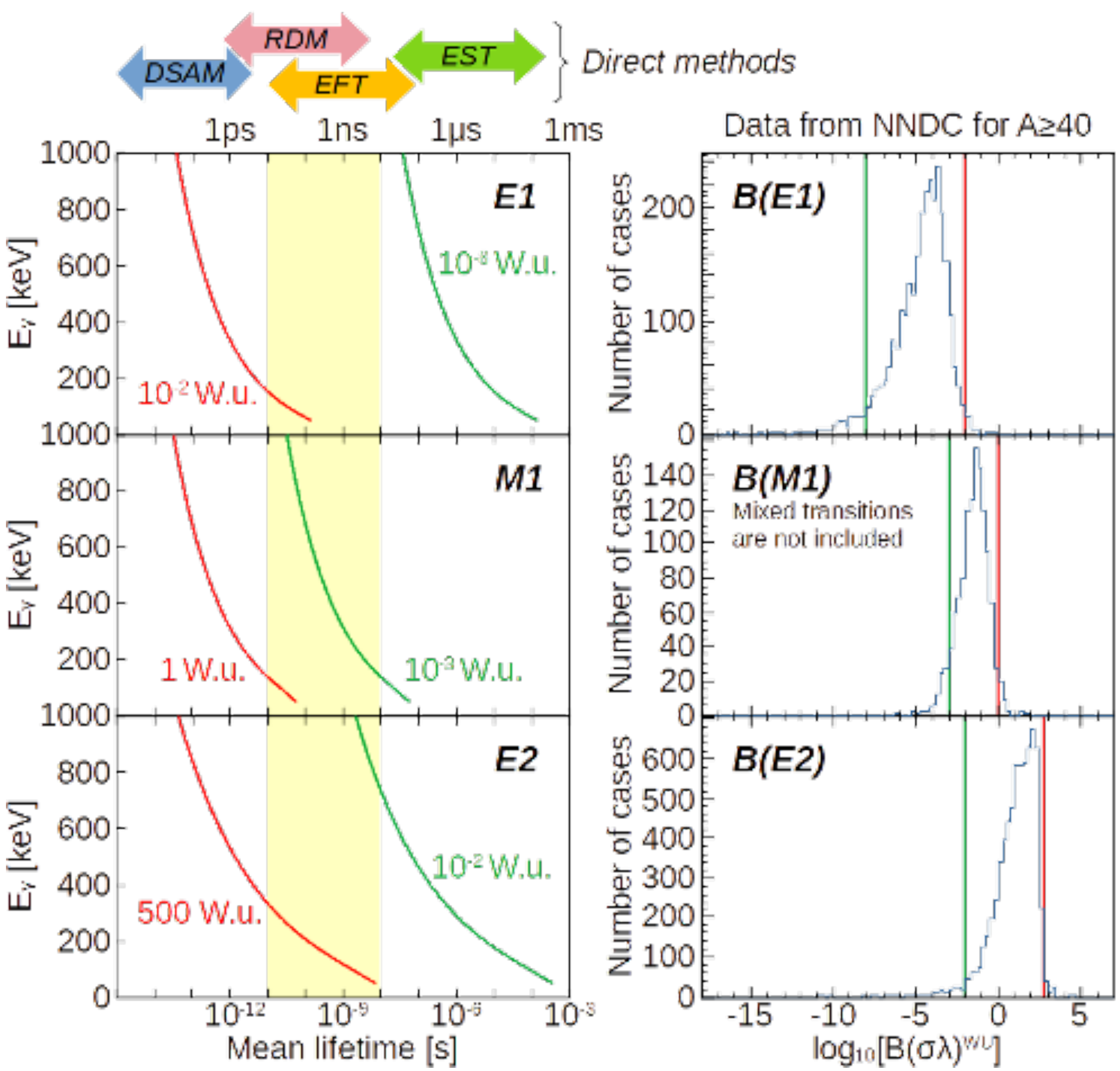


PRL **113**, 132502 (2014).



- Energy information is insufficient to investigate nuclear structure.
- Transition rate information is necessary and it can be derived by lifetime measurements.
- Discriminate the nuclear shape: prolate, oblate, triaxial
- Seniority studies near magic numbers
- Nuclear shape coexistence
- Asymmetric reflection like octupole deformation

Then why $LaBr_3$(Ce) detector?



Credit by H. Watanabe

DSAM: Doppler-Shift Attenuation Method
RDM: Recoil Distance Method
EFT: Electronic Fast Timing
EST: Electronic Slow Timing

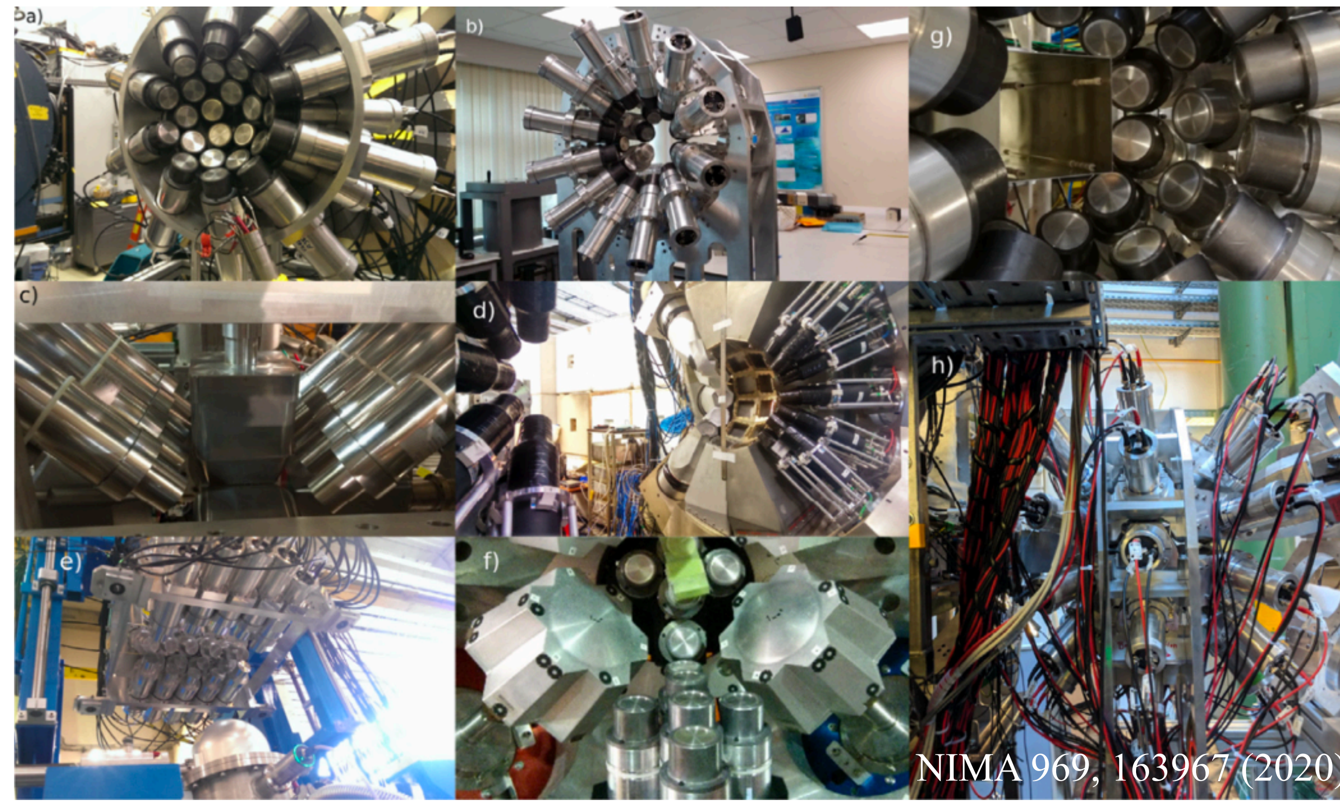
- Different lifetime sensitivity with different methodology.
- $LaBr_3$(Ce) based EFT (Electronic Fast Timing) is sensitive to the range of 10 ps - 10 ns.

Then why $LaBr_3$(Ce) detector?

Transition type	Transition rate (W.u.)	Transition energy	Physics case
Strongly enhanced E2	~100 W.u.	< 300 keV	2^+_1 to 0^+_1 in even-even well-deformed nuclei in medium mass region
Moderately enhanced E2	~30 W.u.	300 - 700 keV	2^+_1 to 0^+_1 in even-even vibrational nuclei in medium-heavy mass region
Hindered E2	0.1 - 1 W.u.	400 - 1000 keV	Same seniority multiplet in single closed shell nuclei
Highly hindered M1	10^{-3} - 10^{-2} W.u.	A few tens to hundreds of keV	Single-particle states of different l in closed-shell region
Hindered E1	10^{-6} - 10^{-5} W.u.	Several hundreds of keV	ΔK = 1 or 2 in well-deformed nuclei
Enhanced E1	10^{-4} - 10^{-2} W.u.	Several hundreds of keV	Yrast positive- and negative-parity states in reflection asymmetric nuclei

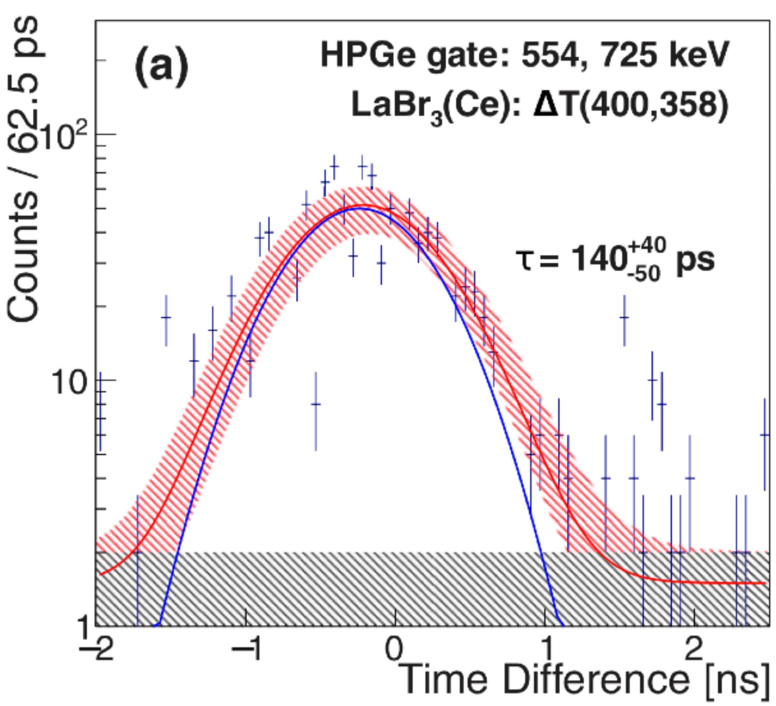
Successful case in the world

- FATIMA (**F**ast **TIM**ing **A**rray)
- 36 units of $LaBr_3(Ce)$ detectors
- Very active collaboration
  : GSI, GANIL, ANL, IPN Orsay, RIKEN
- Many works are being published now.

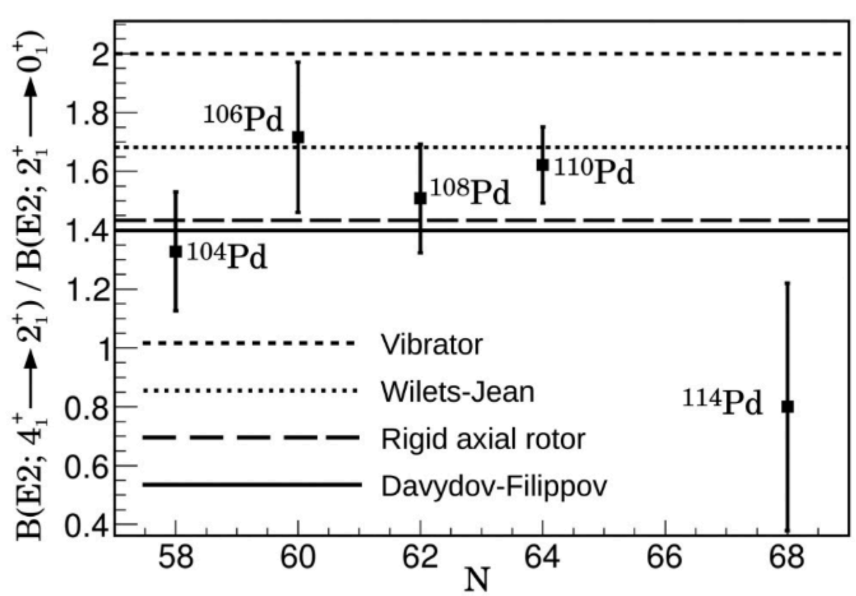


NIMA 969, 163967 (2020).

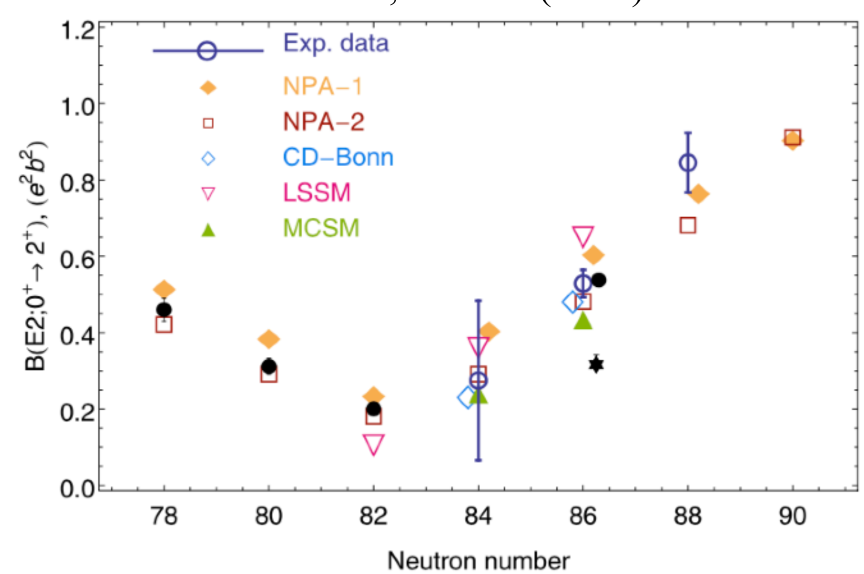
PRC 104, 014316 (2021).



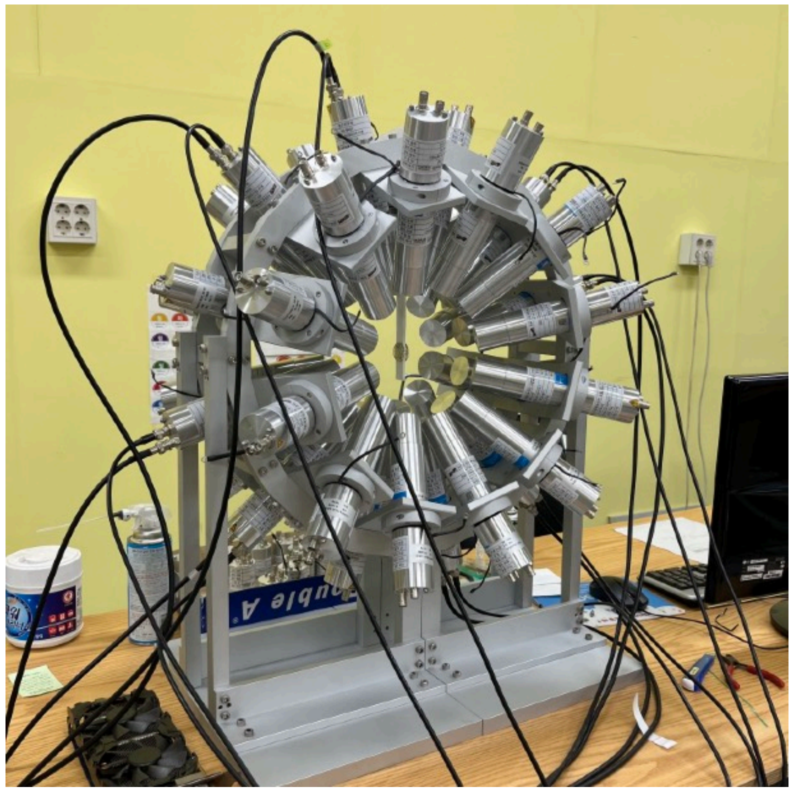
PRC 100, 044309 (2019).

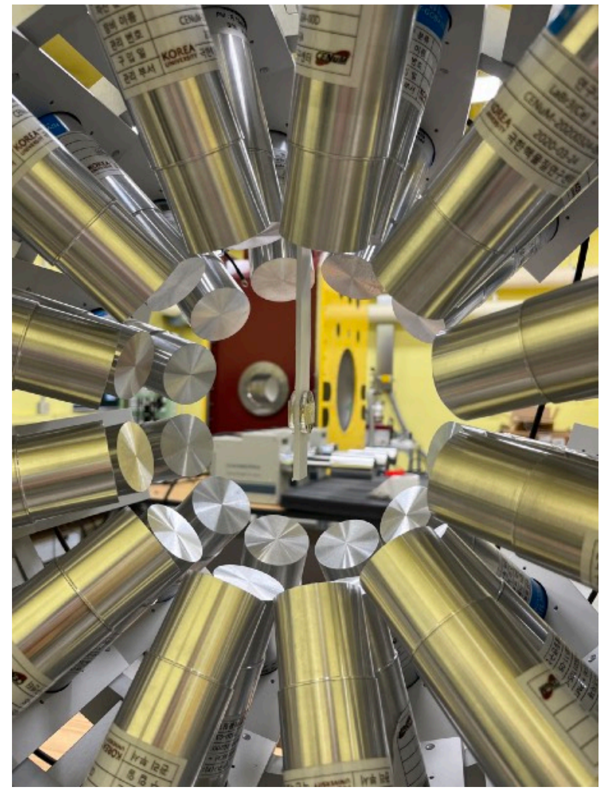


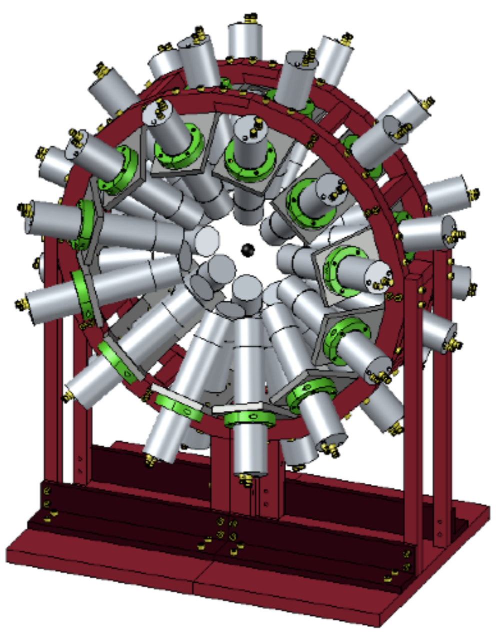
PRC 94, 034302 (2016).



Introduction to KHALA







- **<u>K</u>**orea **<u>H</u>**igh-resolution **<u>A</u>**rray of **<u>LA</u>**br$_3$(ce)
- B380 ϕ1.5inchX1.5inch-size LaBr$_3$(Ce) scintillator from Saint-Gobain
- Hamamatsu ϕ1.5inch-diameter R13408 PMT assembled
- 36 units available

Details of KHALA module

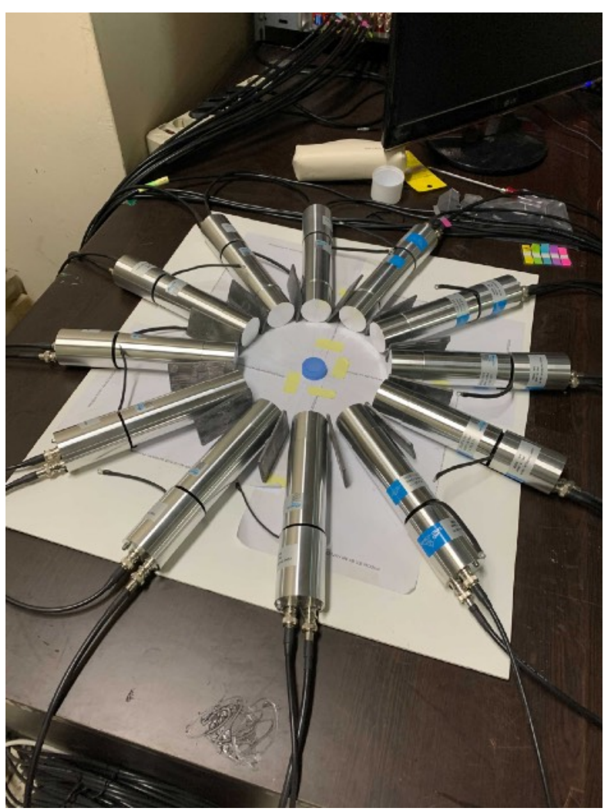

KHALA 36 EA

AS20 w/ dynode 16 EA
(Spare)

AS20 w/o dynode 36 EA

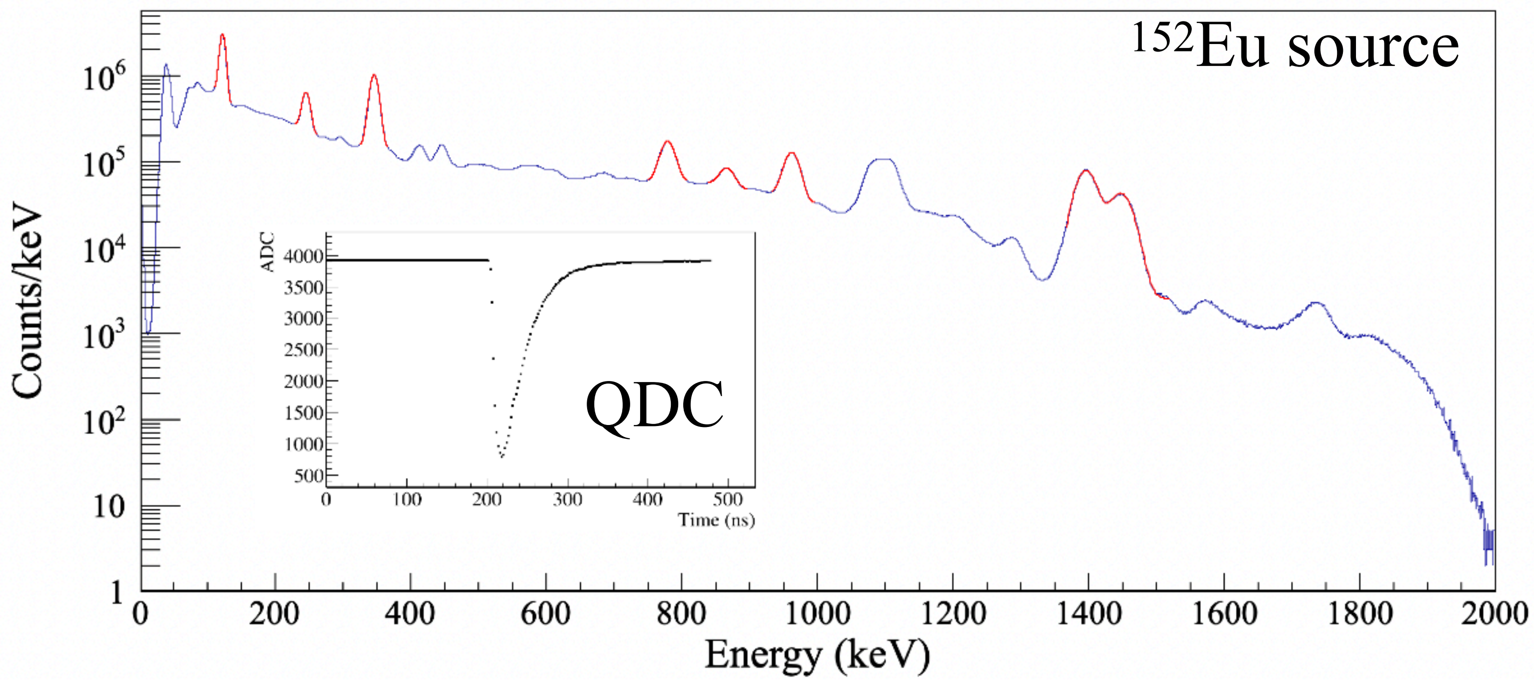
- KHALA detector module 36EA
- Voltage divider AS20 w/ dynode 16EA, w/o dynode 36EA
- Negative bias necessary
- 220-mm length w/o cable connectors, 43-mm width for the crystal, 45-mm width for the detector
- Ground cables coming from both detector and voltage divider
- Fully supported and owned by CENuM (Center for Extreme Nuclear Matters), Korea University.

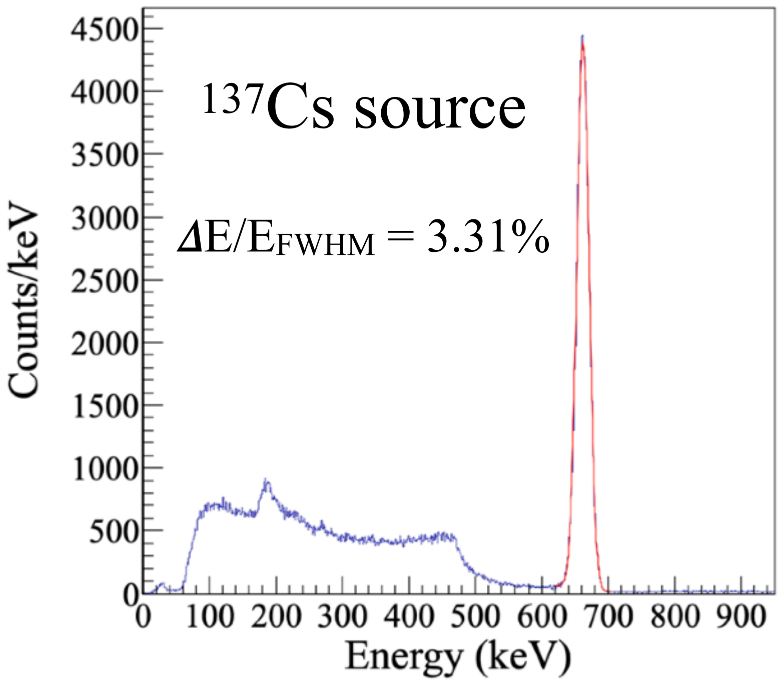
Electronics for bench test

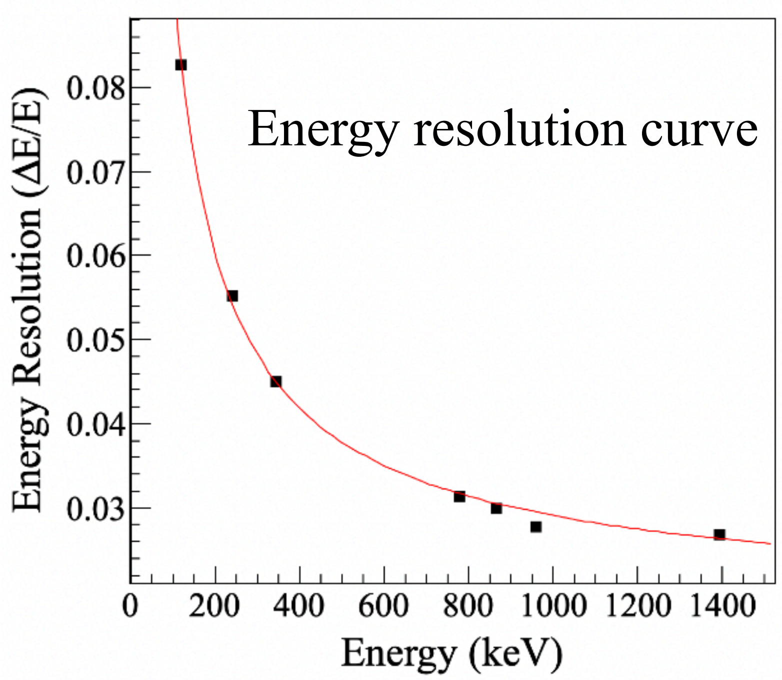


- A7236N, 24 channel negative 3.5kV high voltage module from CAEN
- V1742, 32-channel digitizer from CAEN
  - Using DRS4 chip, fixed sampling events of 1024
  - 5GHz, 2.5GHz, 1.0GHz, and 0.75GHz selectable sampling rate
  - 1 Vpp input dynamic range with 12-bit resolution ADC
  - Calibration issue on DRS4 chip, no further digital pulse processing firmware, but cheap and high channel density
- No analog conventional type used
- Offline pulse analysis
- See Jaehwan Lee’s poster presentation in terms of various DAQ electronics tests with KHALA

Energy resolution

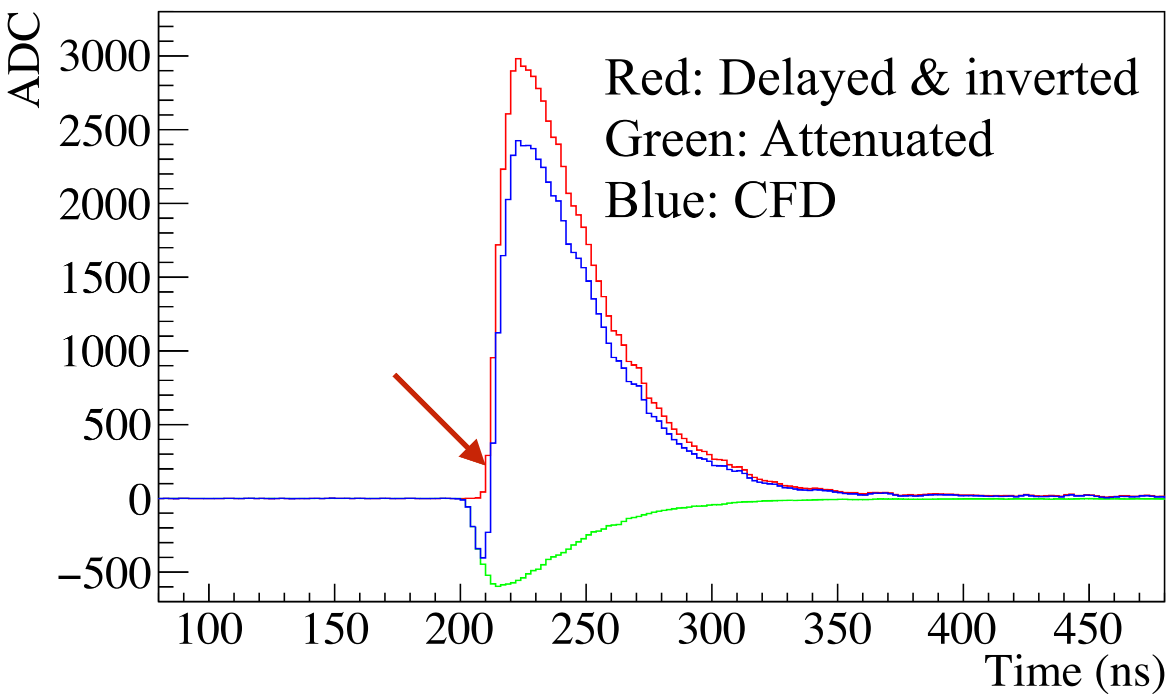


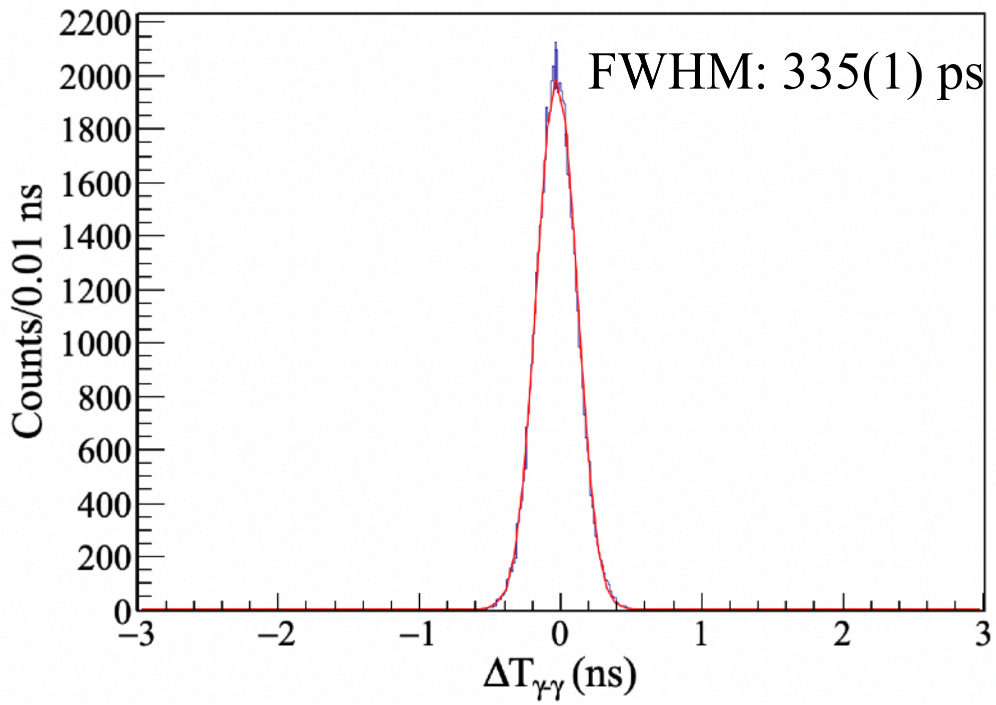




- Obtain energy information by integrating the pulse a.k.a QDC method.
- Data taken by using 12 KHALA detectors.
- Energy resolution at 662 keV: 3.31% in FWHM
- Energy resolution curve obtained from the ^{152}Eu source.

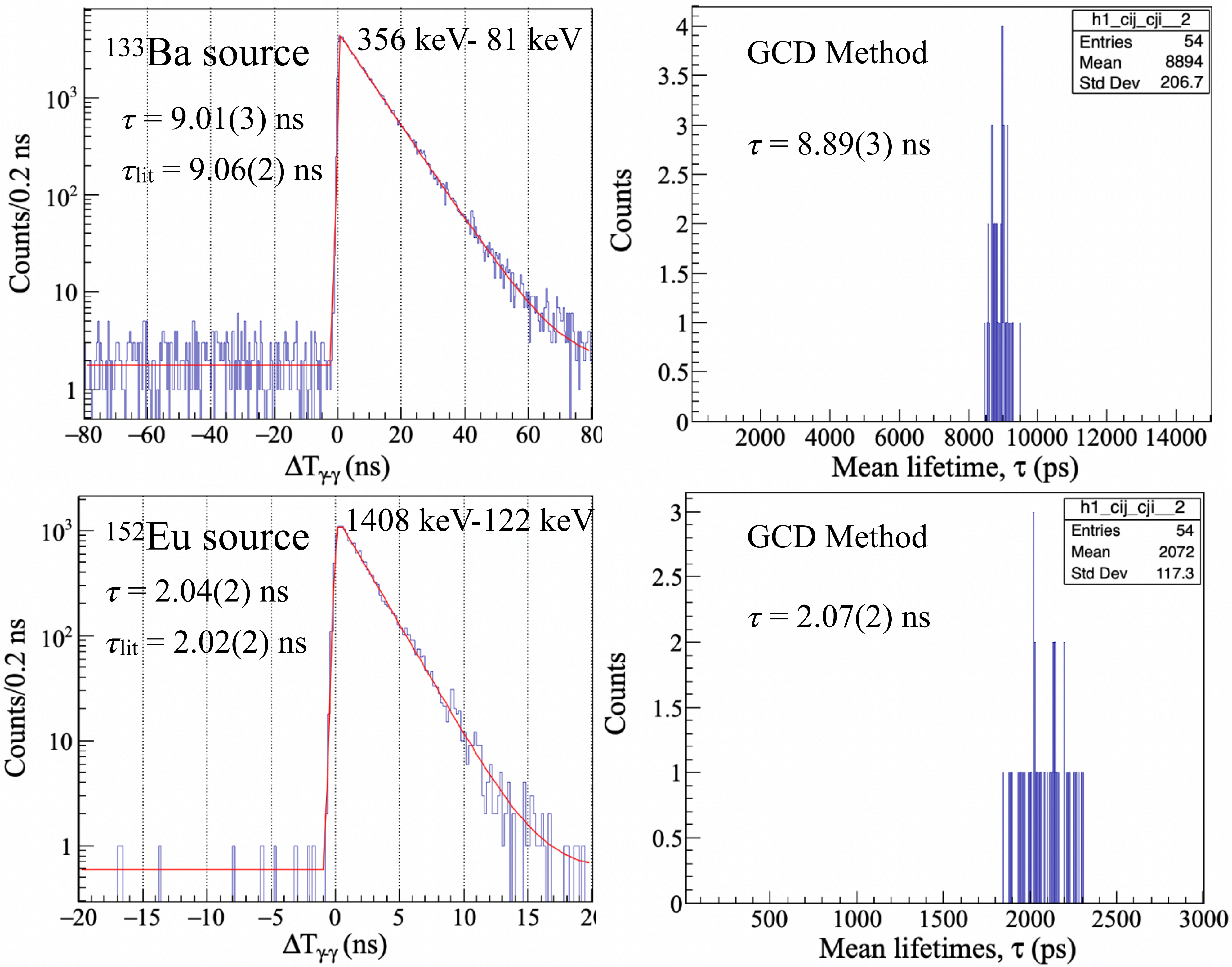
Timing resolution





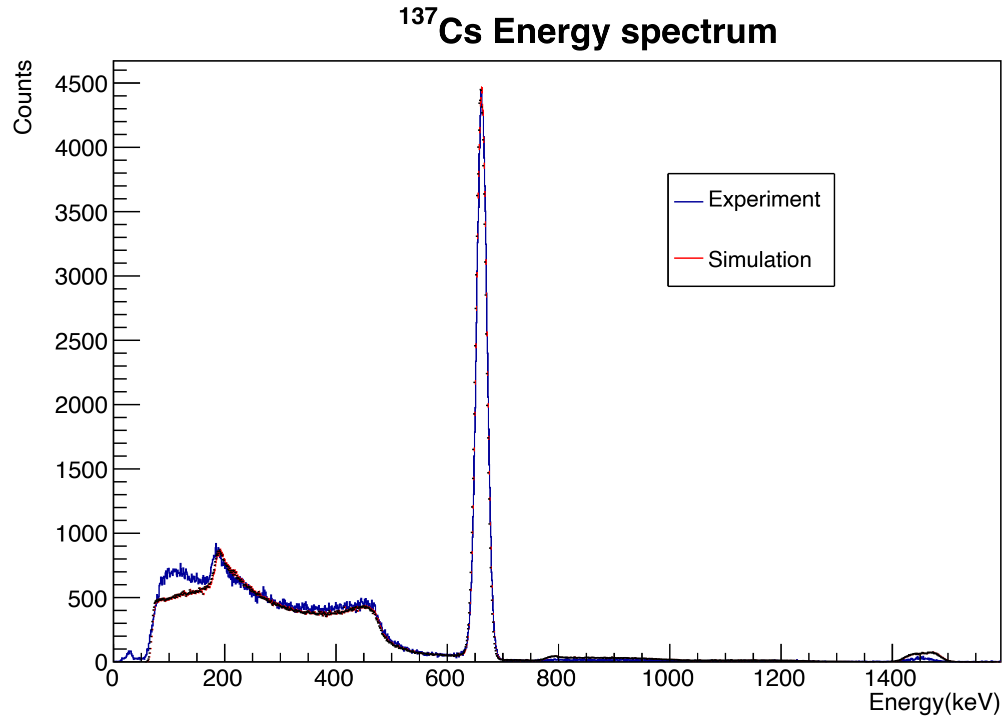
- Digital constant fraction discrimination method to obtain TDC information
- Use the offline pulse analysis.
- Data taken by using 12 KHALA detectors.
- ^{22}Na γ-ray source: 511-keV two photons
- Timing resolution of 335(1) ps in FWHM

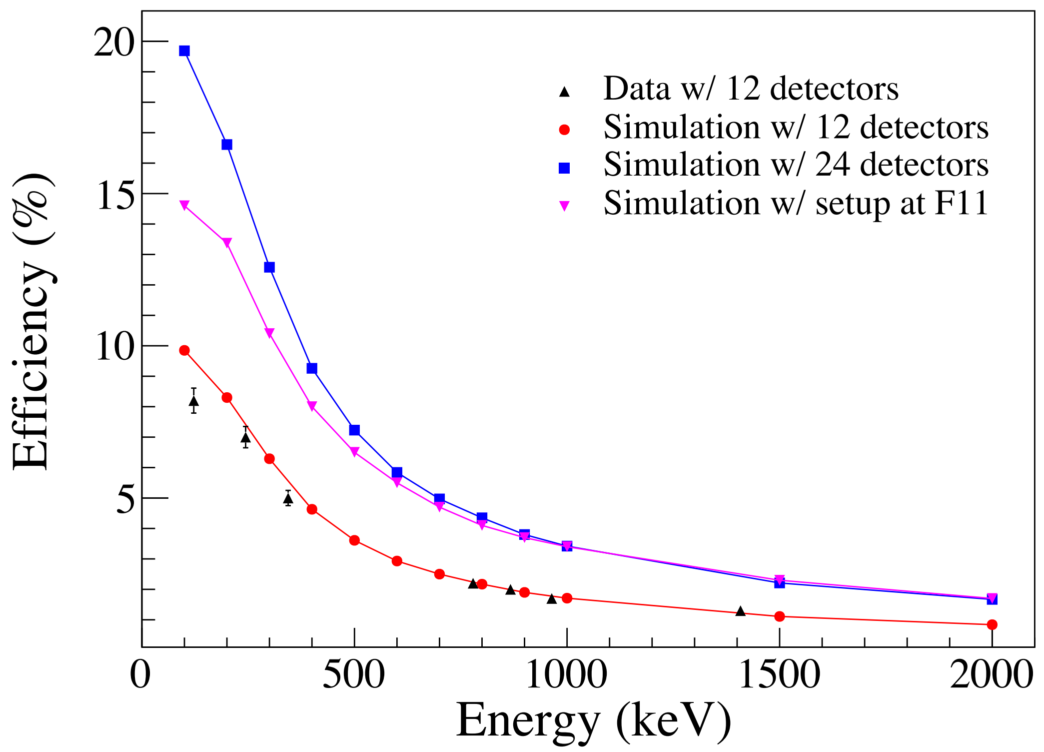
Lifetime measurement



- Sufficient to deduce few nanosecond lifetime by using the convolution fit method
- Consistent results obtained by the generalized centroid difference (GCD) method

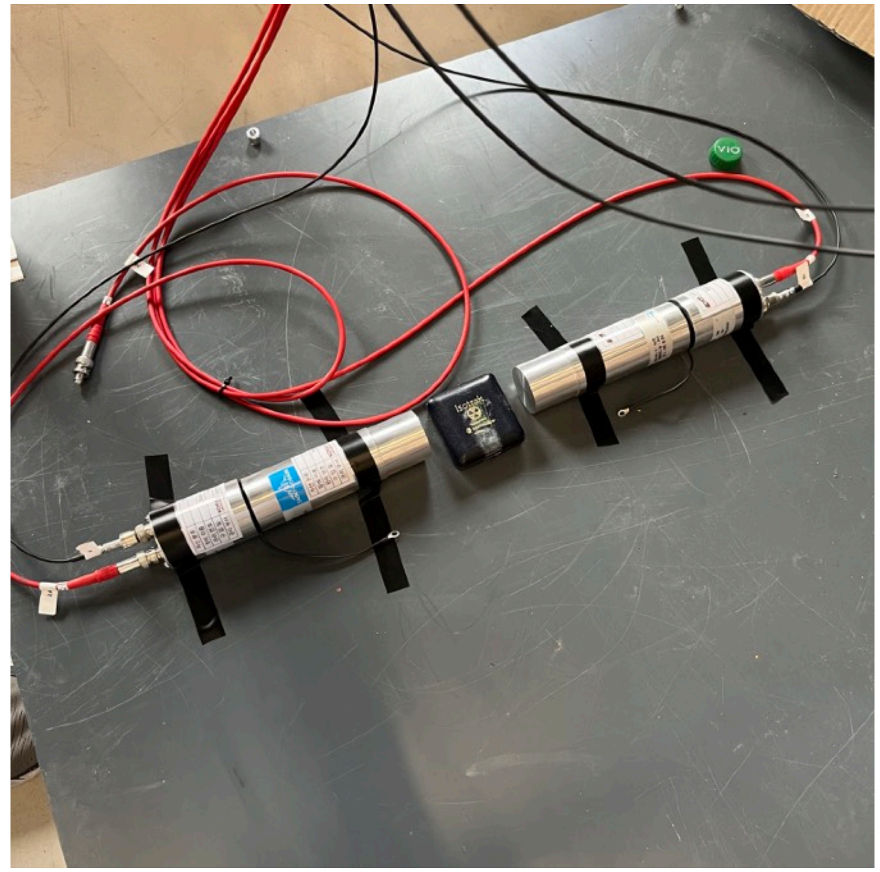
Geant4 simulation

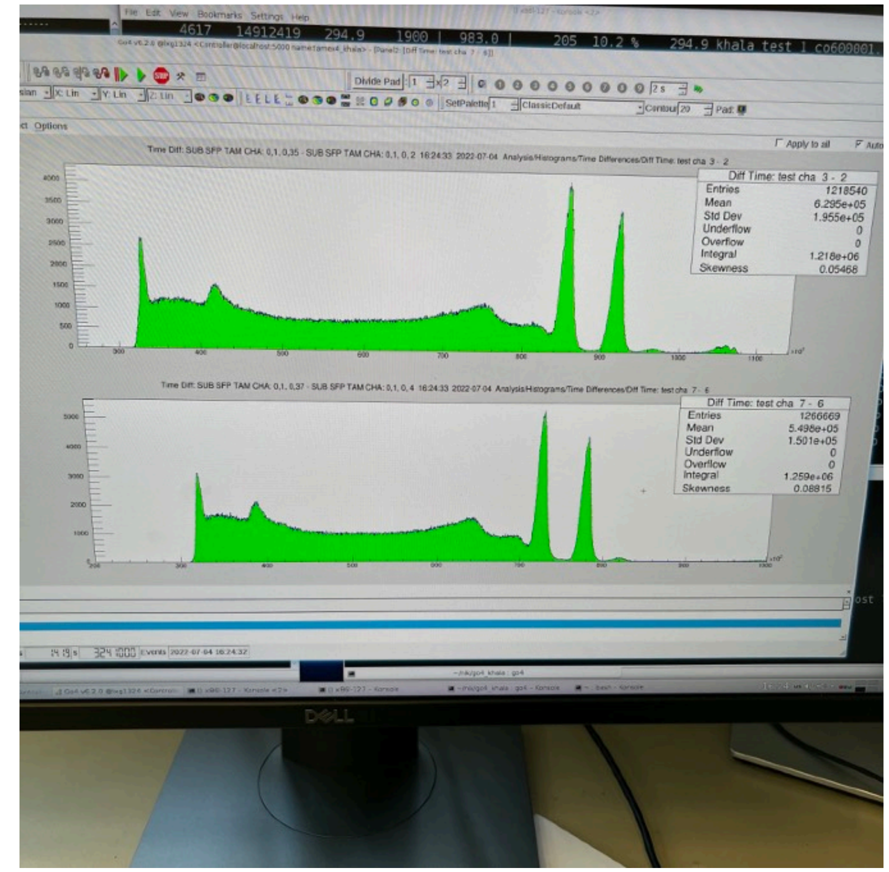




- Geant4 simulation has been performed with the bench test setting.
- Distance from the center: 10 cm
- Verified the reliability by reproducing the ^{137}Cs source spectrum.
- Checked the expected results and verified with the experimental result with the 12-unit setup.
- Plan to examine the detection efficiency for the full system (36 units) with new electronics system.

New DAQ electronics system





- Twinpeaks FEE + TAMEX TDC modules developed by GSI
- Capability of applying a long gate width (able to measure long-lived isomers)
- Advantage of the compact system, cheap price, and small dead time
- 16 input channels per a card with two amp types
- The system will be soon shipped to Korea.

See Jaehwan Lee's poster presentation!

IDATEN project at RIBF

NP2112-RIBF212

Title: **Fast-timing γ-ray spectroscopy of exotic nuclei at RIBF**

Spokesperson(s): **Hiroshi Watanabe**

Approved — Grade A
1.5 days

1.5 days(including 0.5days for BigRIPS tuning)

A construction proposal of the fast-timing measurement at RIBF was approved.

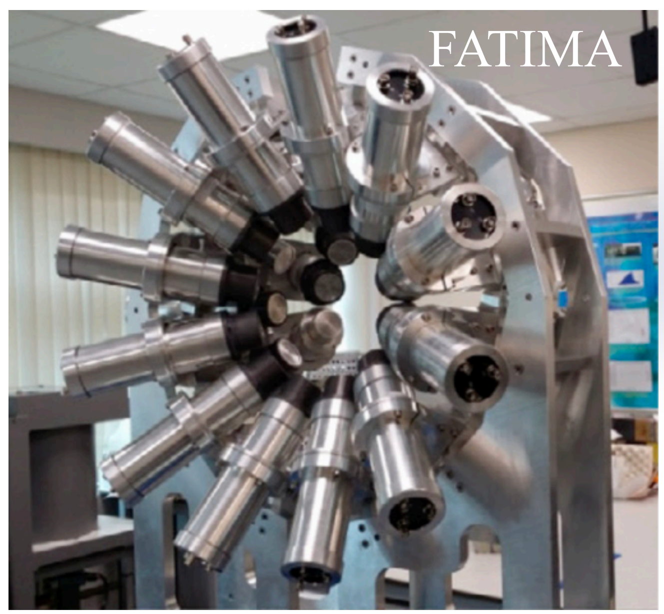
Spokespersons: H. Watanabe (Beihang U.), P. H. Regan (U. Surrey), and B. Moon (IBS CENS)
In-house contact person: S. Nishimura (RNC)

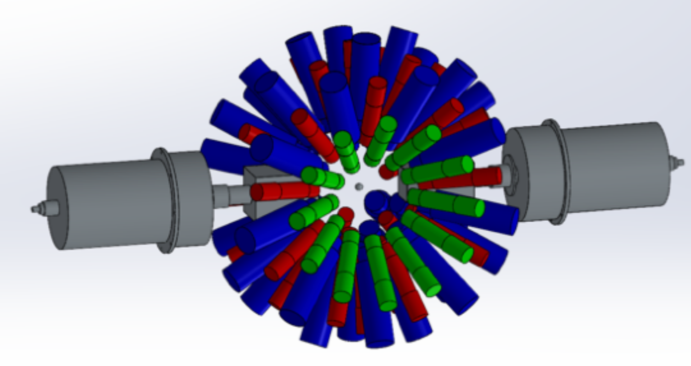
The world largest fast-timing array is coming…

What is IDATEN?

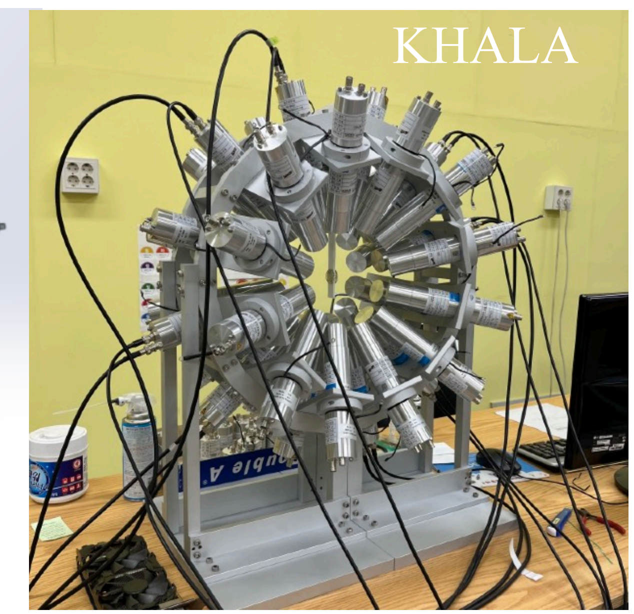
International Detector Assembly for fast-Timing measurements of Exotic Nuclei

IDATEN is a Japanese word for the god of speed from Buddhism and Hinduism.
韋馱天 / 위타천 / स्कन्द / Iskandar / Alexander the Great
In Japanese baseball pro games, a speedy player is called as Idaten.





IDATEN-84 array



A large array of 84 $LaBr_3(Ce)$ detectors
36 FATIMA
36+12 KHALA
… and two clover detectors

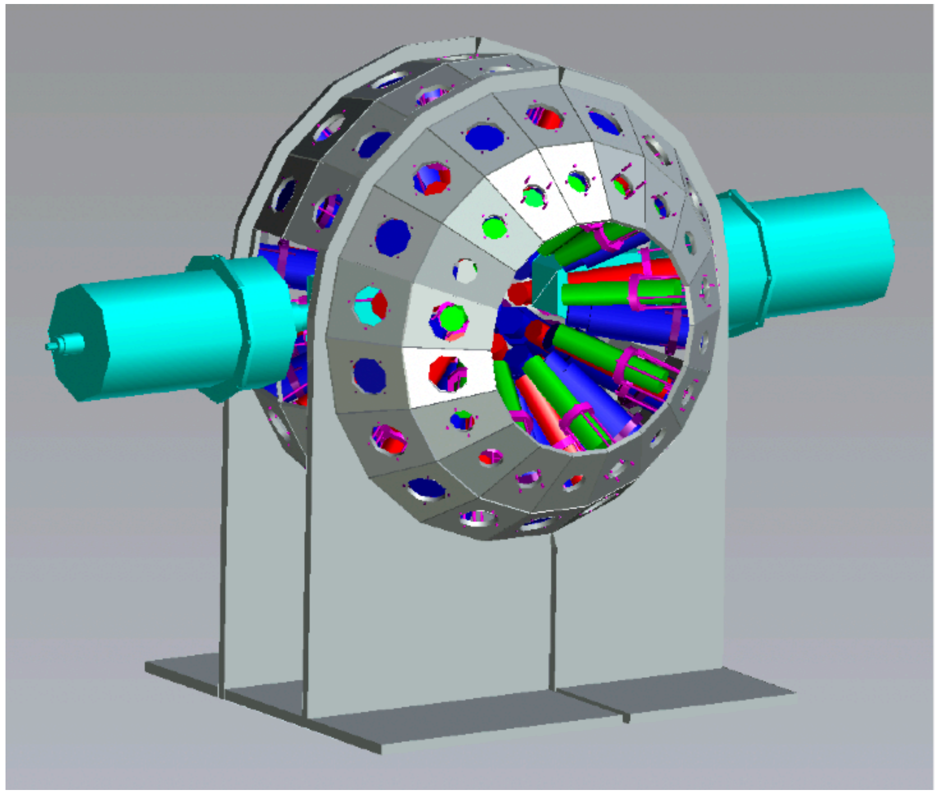
IDATEN proposals to be submitted

Title of proposal	Expected beamtime	Contact person	E-mail address
Shape coexistence at the center of the N=40 island of inversion	5 days	Bruno Olaizola	bruno.olaizola@cern.ch
Shape coexistence and collectivity in the doubly magic 78Ni region	7 days	Eda Sahin	eda.sahin@fys.uio.no
Shape Evolution and New Isomer in N~60 Neutron-Rich Selenium Isotopes	4 days	Quanbo Zen	zengquanbo@impcas.ac.cn
Exploring quantum shape phase transition around Z = 40 and N = 60 with gamma-gamma fast timing	5 days	Tumpa Bhattacharjee	btumpa@vecc.gov.in
Lifetime measurement of excited states in 108Zr	1.5 days	Byul Moon	mb0316@ibs.re.kr
Nuclear structure study of Pd, Ag, and Cd isotopes towards N=82 with fast-timing lifetime measurement	7 days	Hiroshi Watanabe	hiroshi@ribf.riken.jp
Seniority and collectivity in nuclei beyond doubly-magic 132Sn	4 days	Byul Moon	mb0316@ibs.re.kr
Probing octupole collectivity and dipole polarizability in neutron-rich Ba, La, and Ce isotopes by lifetime measurement of excited states	4 days	Hiroshi Watanabe	hiroshi@ribf.riken.jp
Study of the deformation pattern in the rare-earth region	5 days	Sorin Pascu	s.pascu@surrey.ac.uk
First 2+ state lifetime measurement for the neutron-rich Yb and Er isotopes: a quest for strong deformation around N=110	4 days	Jeongsu Ha	jeongsu.ha@kuleuven.be
Exploring the structure of the neutron-rich heavy nuclei beyond 208Pb	5-6 days	Andrea Gottardo	Andrea.Gottardo@lnl.infn.it
Fast-timing spectroscopy of excited states in N ~ Z nuclei below 100Sn	5 days	Joochun Park	jcpark@ibs.re.kr
Study of shell structure, core-breaking and seniority-breaking effects close to 100Sn with IDATEN	5-7 days	Andrey Blazhev	a.blazhev@ikp.uni-koeln.de

Many proposals with various physics cases will be submitted in this year.
Stay tuned!

Summary

- KHALA is a new fast-timing γ-ray detector system in Korea.
- 36 units are all procured and the new DAQ system will be soon arrived.
- KHALA will be used for IDATEN project at RIBF in 2023 and 2024.



Collaborators

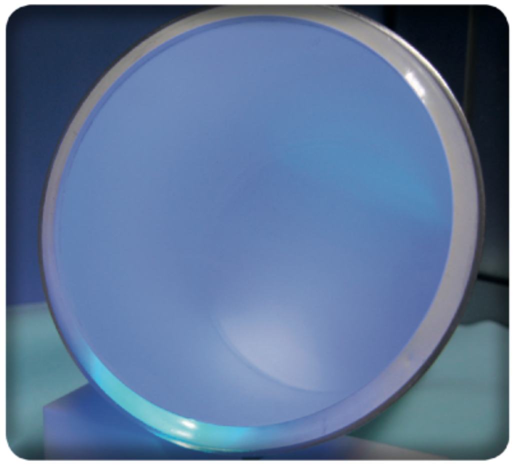
- Contact person: Byul Moon (CENS/IBS)

- Core members
  Byungsik Hong, Youngseub Jang, Jaehwan Lee (KU, CENuM)
  Sunghoon Ahn, Sunghan Bae, Yung Hee Kim, Joochun Park (CENS/IBS)

Backup slides

Specification of $LaBr_3(Ce)$ crystal

Scintillator	Light Yield (photons/keV)	1/e Decay time t(ns)	F.O.M. √(t/LY)	Wavelength of maximum emission λm (nm)	Refractive index at λm	Density (g/cm³)	Thickness (cm) for 50% attenuation (662keV)
NaI(Tl)	38	250	2.6	415	1.85	3.67	2.5
BrilLanCe™ 350	49	28	0.8	350	~1.9	3.85	2.3
BrilLanCe™ 380	63	16	0.5	380	~1.9	5.08	1.8
BaF2	1.8	0.7	0.6	~210	1.54	4.88	1.9
PreLude™ 420	32	41	1.1	420	1.81	7.1	1.1
BGO	9	300	5.8	480	2.15	7.13	1.0



- The $LaBr_3(Ce)$ scintillator crystal is BrilLanCe380 from Saint-Gobain.
- Excellent light yield, decay time, and density.
- Diameter: 1.5 inch / Height: 1.5 inch for KHALA
- Problem of self radioactivity

Specification of R13408 PMT

Type No.	Spectral response: Range (nm)	Spectral response: Peak wavelength (nm)	Ⓐ Photo-cathode material	Ⓑ Window material	Ⓒ Dynode structure / Stages	Maximum ratings: Supply voltage between anode and cathode (V)	Maximum ratings: Average anode current (mA)	Anode to cathode supply voltage (V)	Cathode characteristics: Luminous Min. (µA/lm)	Luminous Typ. (µA/lm)	Blue sensitivity index (CS 5-58) Typ.	Ⓓ Radiant Typ. (mA/W)
R13478	300 to 650	420	BA	K	L/8	1750	0.1	1500	70	95	10.0	80
R13449	300 to 650	420	BA	K	L/8	1750	0.1	1500	70	95	10.0	80
R13408	300 to 650	420	BA	K	L/8	1750	0.1	1500	70	95	10.0	80
R13089	300 to 650	420	BA	K	L/8	1750	0.1	1500	70	95	10.0	80

NOTE: Ⓐ BA: Bialkali Ⓑ K: Borosilicate glass Ⓒ L: Linear-focused
Ⓓ Measured at the peak sensitivity wavelength.

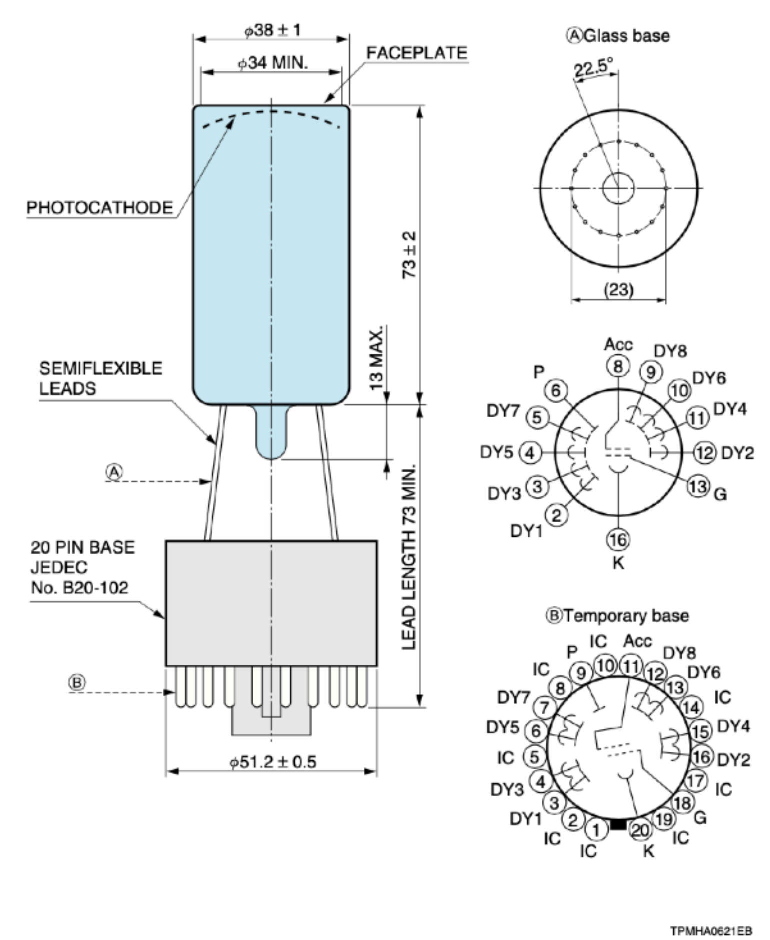
Anode characteristics: Luminous Typ. (A/lm)	Radiant Typ. (A/W)	Gain Typ.	Dark current (After 30 min) Typ. (nA)	Dark current Max. (nA)	Time response: Rise time Typ. (ns)	Transit time Typ. (ns)	T.T.S. (Transit Time Spread) (FWHM) (ps)	Pulse linearity: ±2 % deviation (mA)	±5 % deviation (mA)	Storage temperature (°C)	Operating ambient temperature (°C)	Type No.
50	4.2×10^4	5.3×10^5	3	30	0.9	9.1	130	10	25	-80 to +50	-30 to +50	**R13478**
50	4.2×10^4	5.3×10^5	3	30	0.9	10	170	10	30	-80 to +50	-30 to +50	**R13449**
50	4.2×10^4	5.3×10^5	3	30	1.2	13	190	20	50	-80 to +50	-30 to +50	**R13408**
30	2.5×10^4	3.2×10^5	10	50	2.0	20	230	30	60	-80 to +50	-30 to +50	**R13089**

VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE

Electrodes	K		G		Dy1		Dy2		Dy3		Dy4		Dy5		Dy6		Dy7		Dy8(Acc)		P
Ratio		1.3		4.8		1.5		1.5		1		1		1		1		1		1	

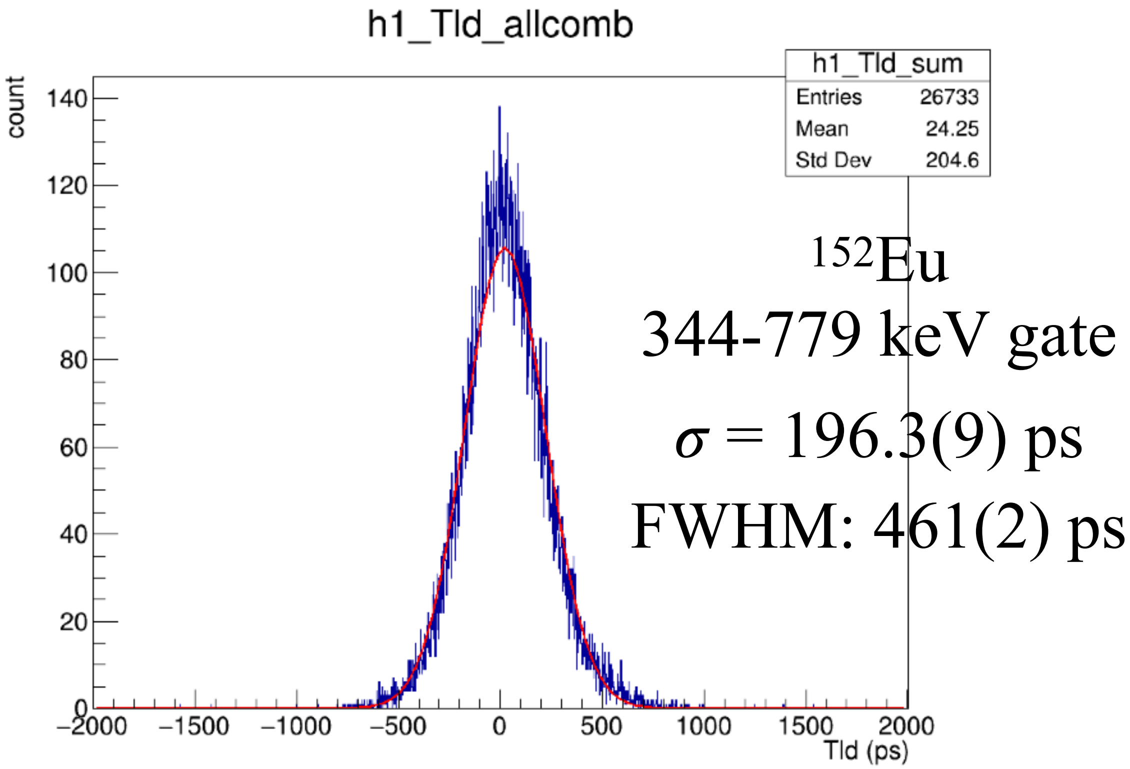
Supply voltage: 1500 V, K: Cathode, Dy: Dynode, P: Anode, G: Grid, Acc: Accelerating electrode
Acc to be connected to Dy8 with a protection resistor in series. (recommended resistance: 10 MΩ)

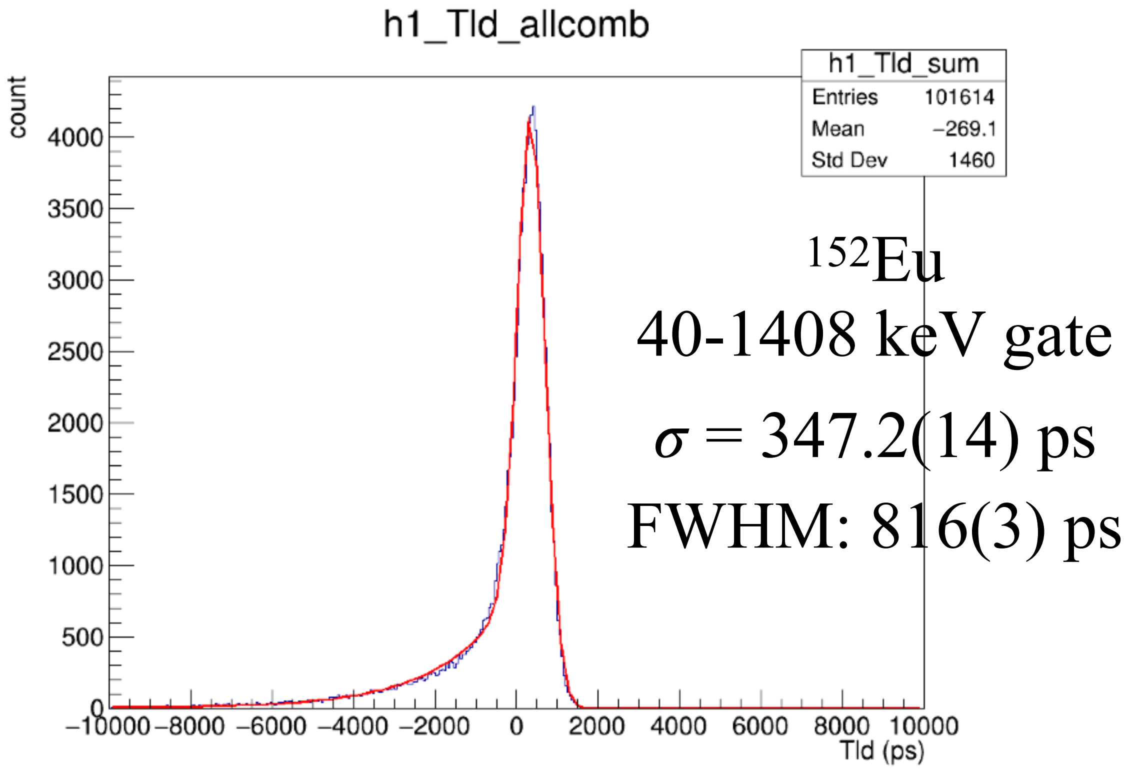
● R13408

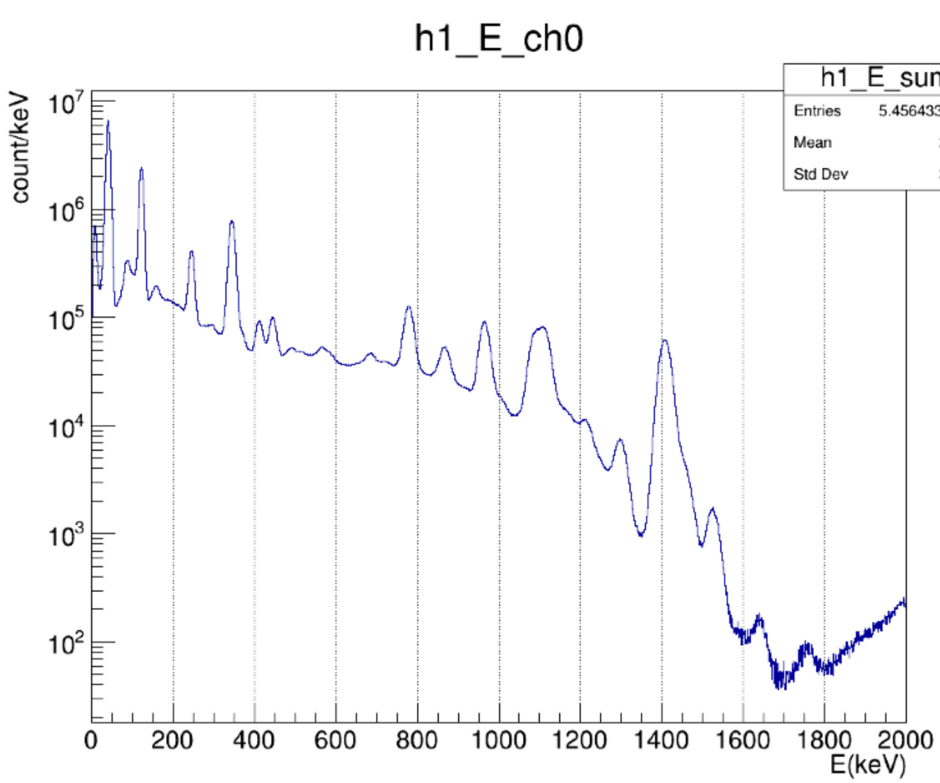


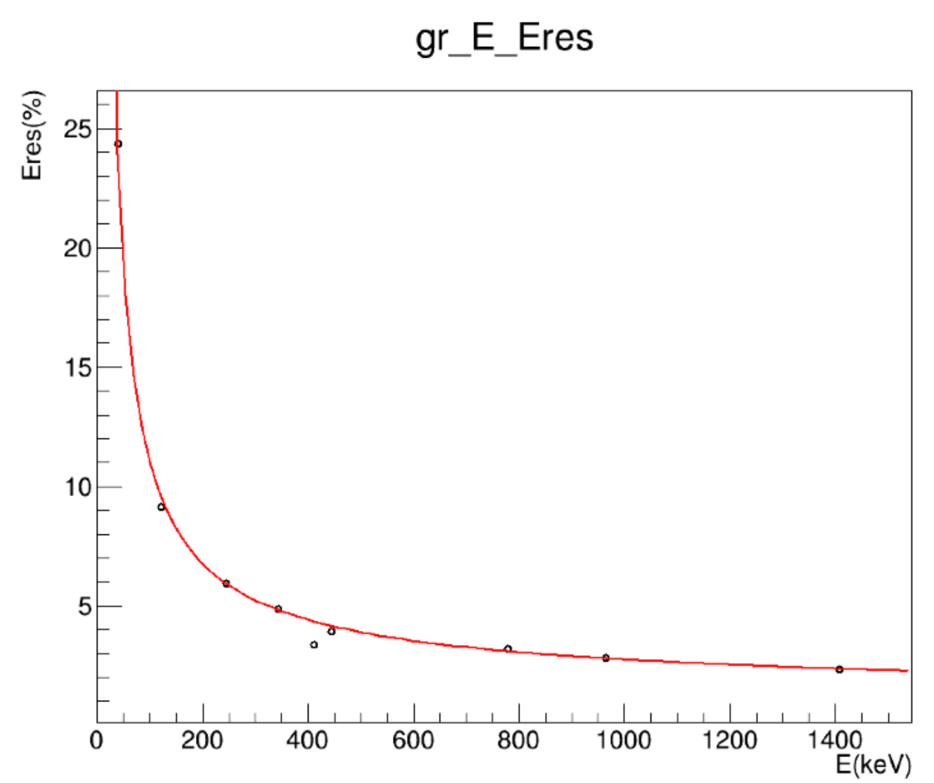
- Manufactured by Hamamatsu
- Specialized in fast-timing performance
- Diameter: 1.5 inch

Performances

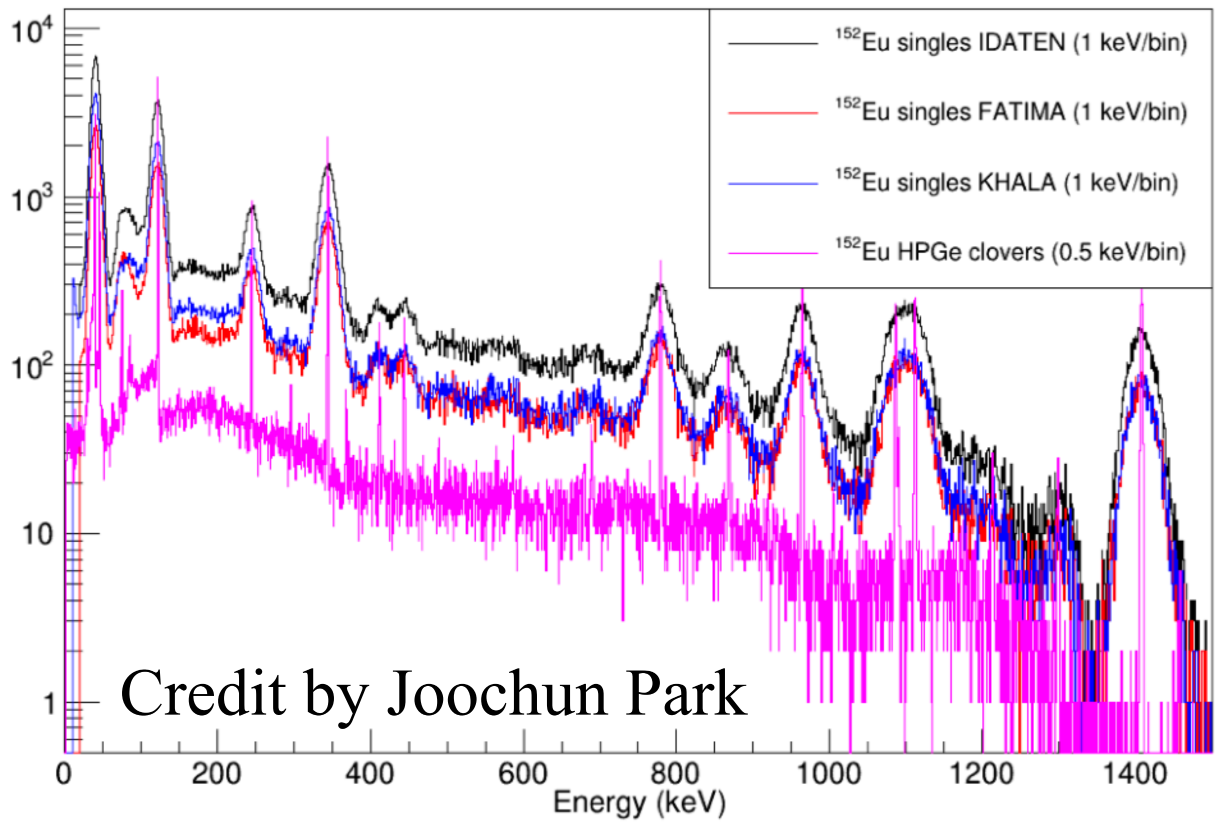


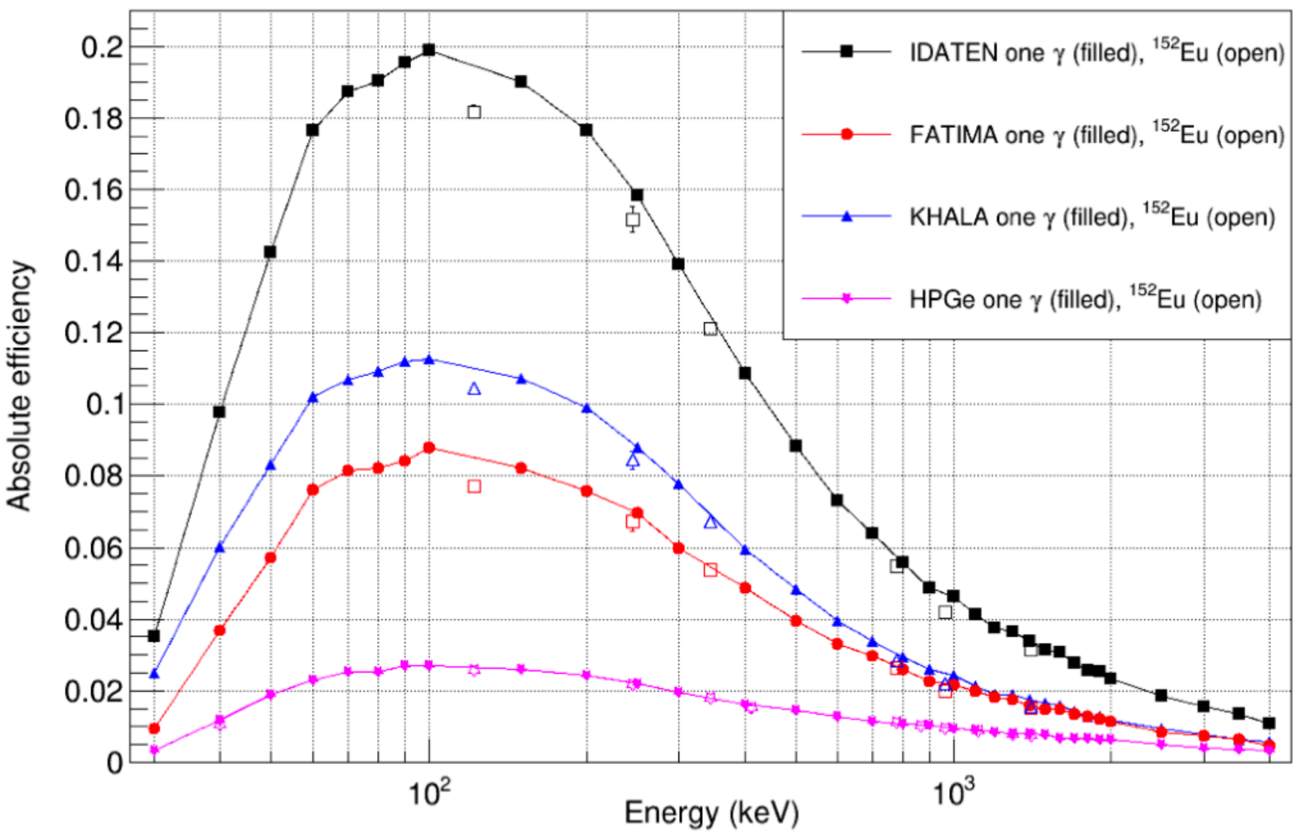






IDATEN simulation





- Simulation based on NPTool
- Source data simulated with IDATEN-82 array
- Atomic and self-radioactive backgrounds are planned to be implemented.
- All proponents are strongly recommended to do the simulations for the PAC proposal.