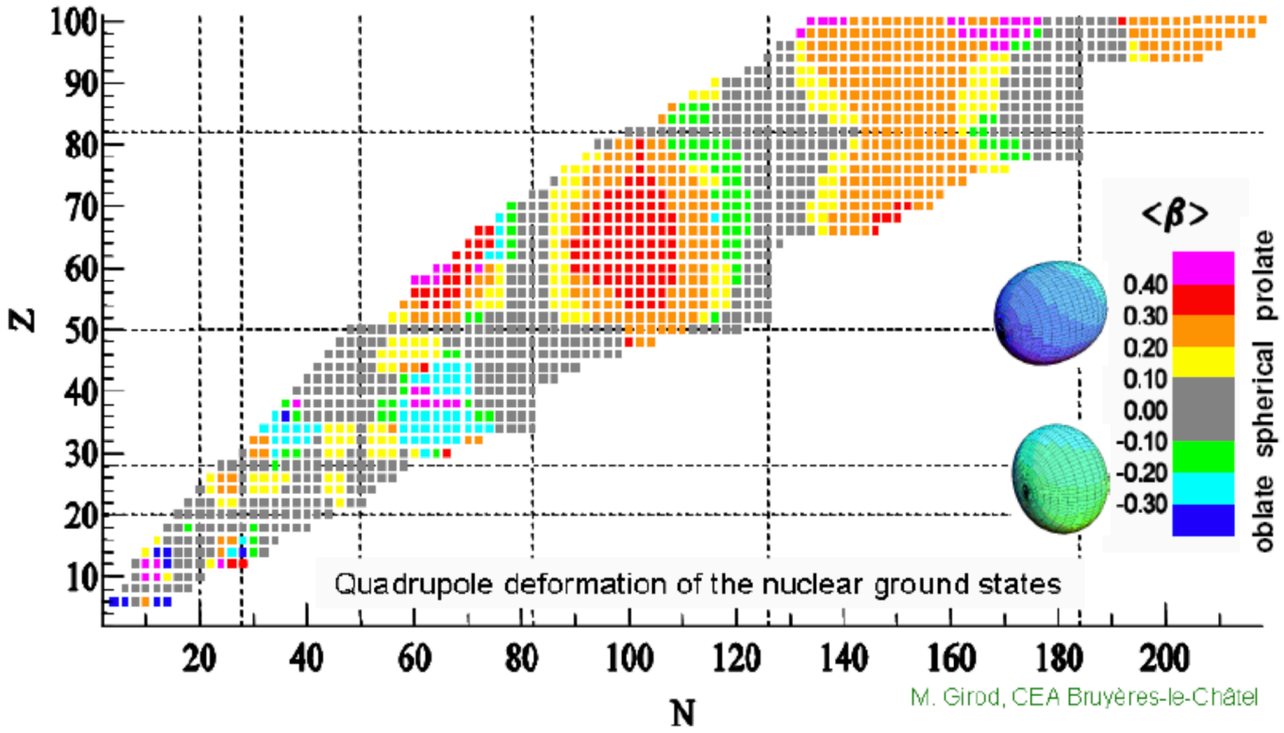
Proposal of MINIBALL project with $LaBr_3(Ce)$ array

Byul Moon
Department of Physics, Korea University

Motivation



	$B(E2;2_1^+ \rightarrow 0_1^+)$ $[e^2fm^4]$	$B(E2;4_1^+ \rightarrow 2_1^+)$ $[e^2fm^4]$	$Q_s(2_1^+)$ $[efm^2]$	$Q_s(2_2^+)$ $[efm^2]$	$Q_s(4_1^+)$ $[efm^2]$	$Q_{RM}(2_1^+)$ $[efm^2]$
^{138}Nd	1736	2853	-30	+31	-31	±84
^{140}Sm	2055	3344	-12	+12	-15	±92
^{142}Gd	2376	3847	14	-17	8	±99
^{144}Dy	2743	4476	37	-44	29	±106

Table 1. B(E2) values and spectroscopic quadrupole moments from the configuration-mixing calculations with Gogny D1S interaction. The last column shows the spectroscopic quadrupole moment of the 2_1^+ states calculated from the B(E2) values using the rotational model.

A. Gorgen et al., "Study of oblate nuclear shapes and shape coexistence in neutron-deficient rare earth isotopes", ISOLDE LOI (2009).

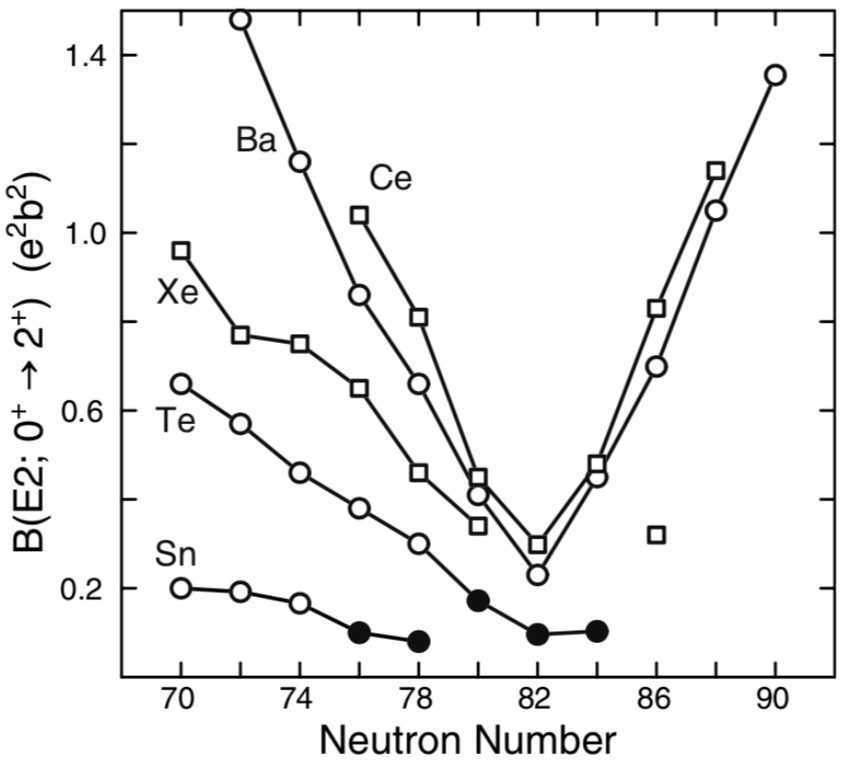
Electromagnetic transition rates provide one of the most sensitive probes of nuclear structure: lifetime of quantum state.

1. Lifetime → **Γ**, intrinsic width according to Heisenberg uncertainty principle: crucial information on wavefunctions.
2. Lifetime → $B(\lambda L)$, reduced matrix element (transition rate): direct information on deformation.

Strength comparison between $M1$ and $E2$ transitions: Quadrupole? Mixed-symmetry?

Lifetime measurement of specific levels, i.e., first 2^+, second 2^+, first 4^+, etc., extend our understanding on the nuclear structure regarding the deformation and nuclear matter.

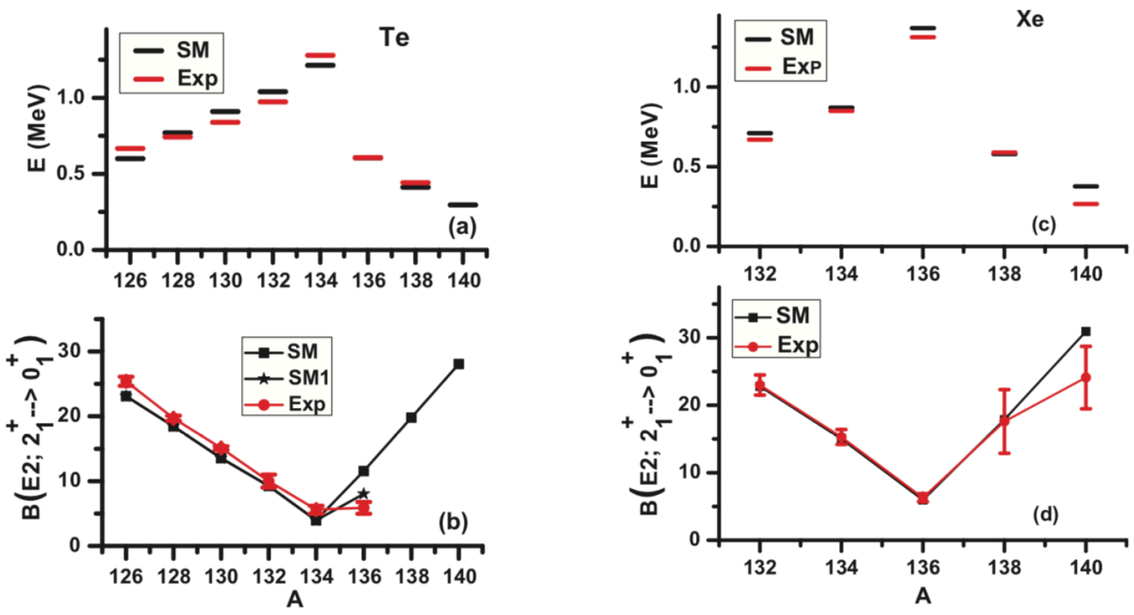
Motivation

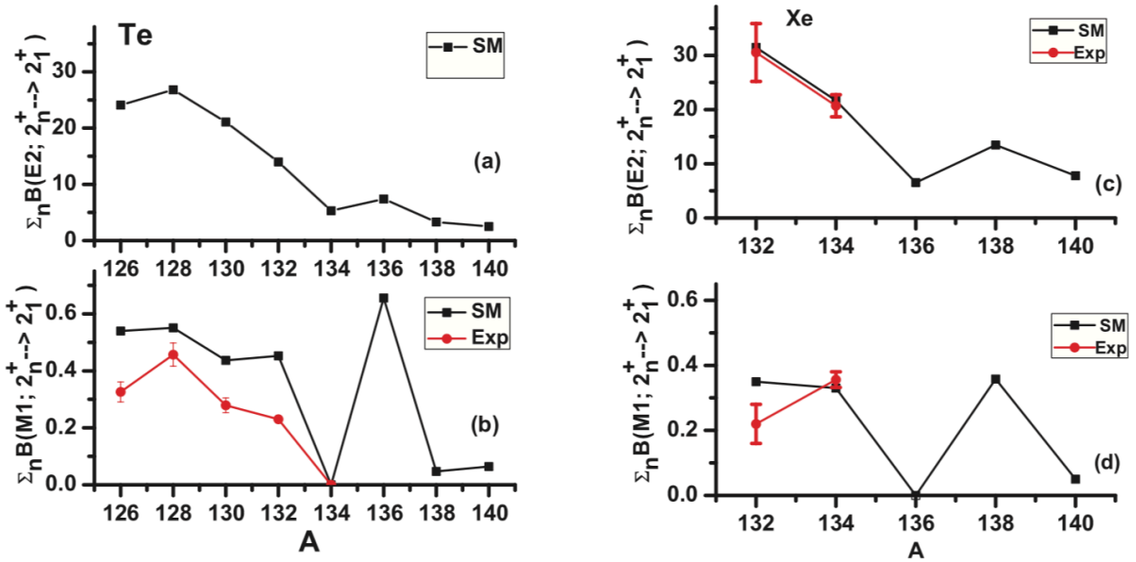


D. C. Radford et al., Phys. Rev. Lett. 88, 222501 (2002).

Abnormal $B(E2)$ value found in the first 2^+ state in ^{136}Te:
Neutron dominance and weakened pairing.
Mixed-symmetry state occur in the second 2^+ state in Te with $N > 82$.
Direct information on the deformation.

Strong evidence on NEUTRON MATTER!
Related to the purpose of CENUM.

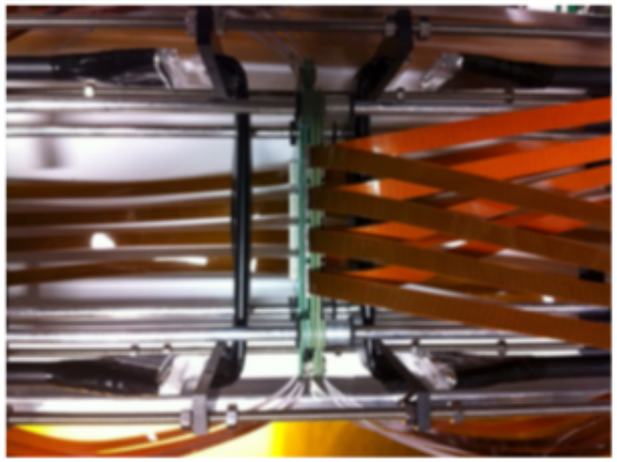




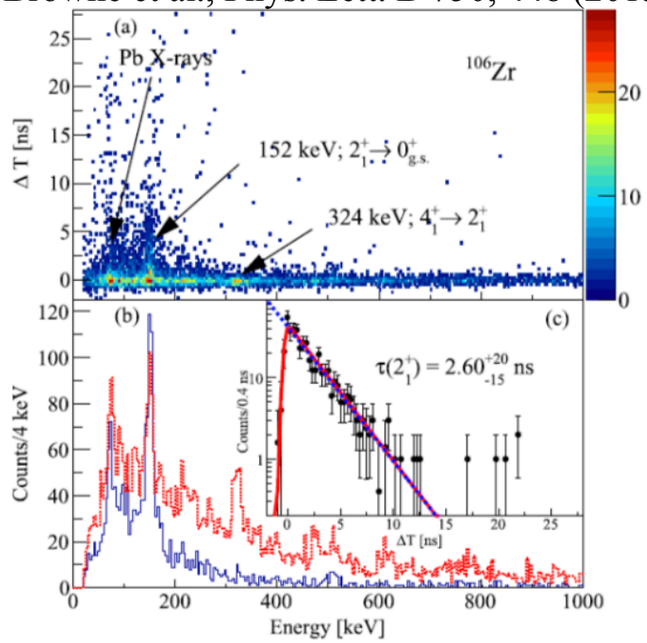
D. Bianco et al., Phys. Rev. C 88, 024303 (2013).

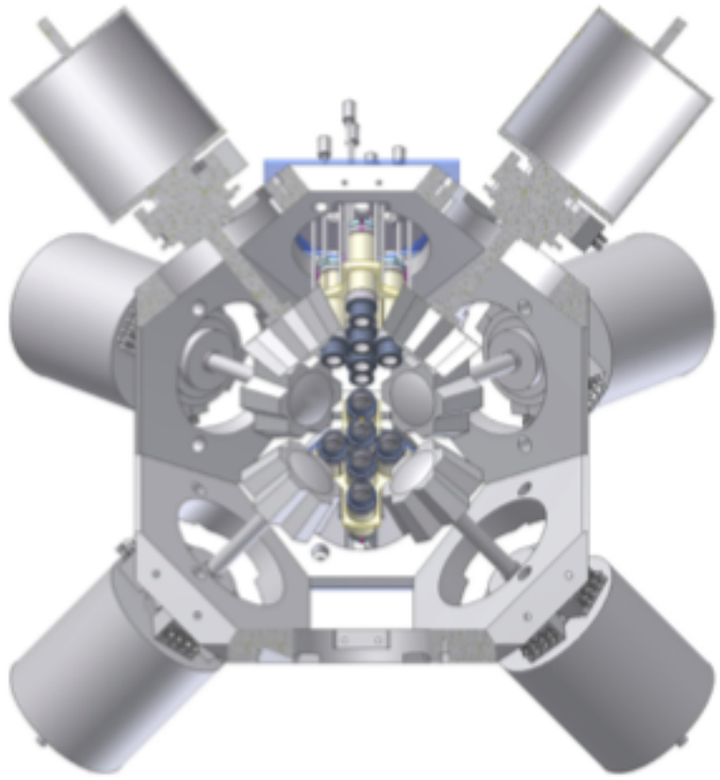
Benchmarking

- EURICA Campaign



F. Browne et al., Phys. Lett. B 750, 448 (2015)





$LaBr_3$(Ce) detectors Z. Patel et al., RIKEN Accel. Prog. Rep. 47, 13 (2014)

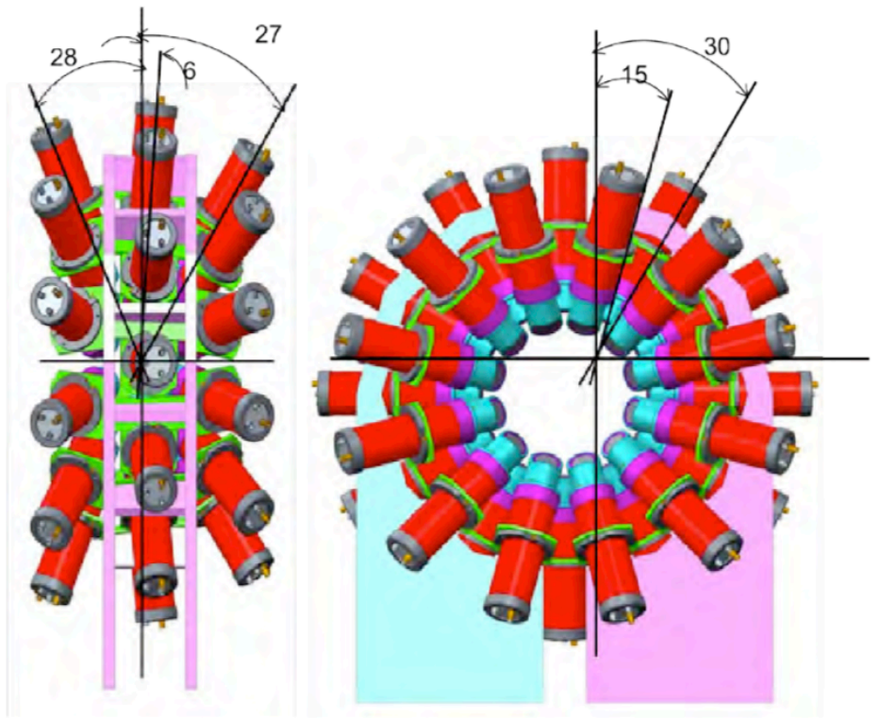
1. 18 LaBr3(Ce) scintillators w/ 5-mm lead shielding.
2. ø1.5 inch. × 2 inch. size.
3. Efficiency of 2 % @ 662 keV.

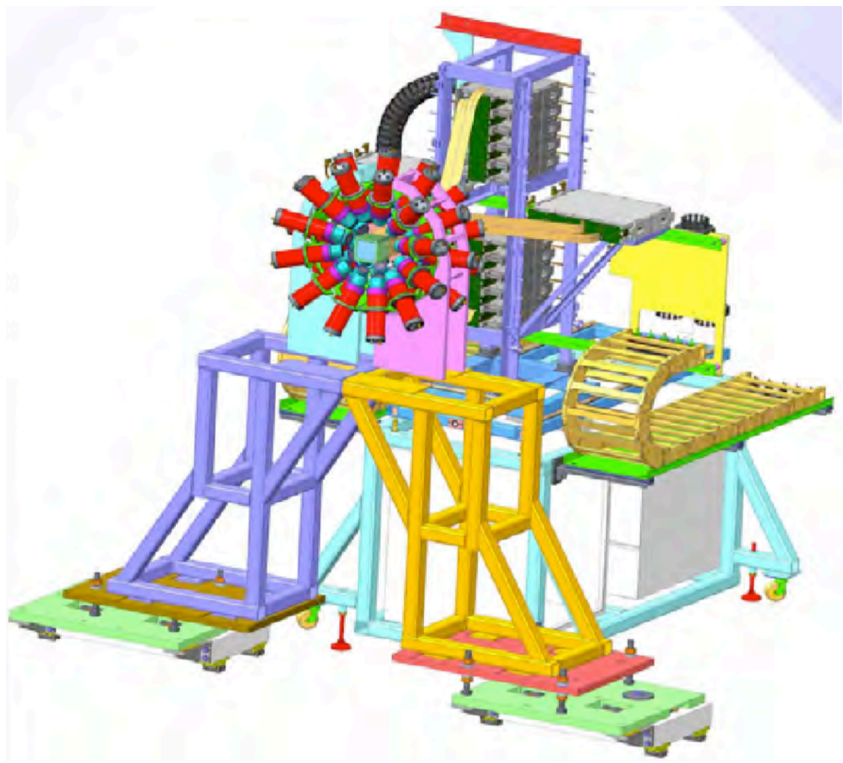
Fast timing trigger counters

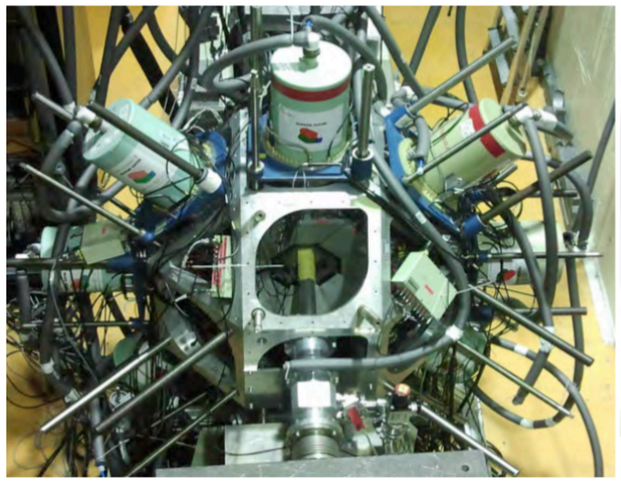
1. 2 BC-418 fast timing plastic scintillators.
2. 2-mm thickness.
3. Efficiency around 50 %.

Benchmarking

- FATIMA (FAst TIMing Array)







Technical Report for Design, Construction and Commissioning of FATIMA, the Fast TIMing Array, March 2015.

FATIMA

1. 40 $LaBr_3(Ce)$ scintillators.
2. DESPEC @ FAIR.
3. Prototype test with ROSPHERE, EXOGAM, and EURICA.

Detector Design

- $LaBr_3(Ce)$ 1.5-inch crystal

Specification

1. Crystal dimension: diameter 38 mm x 38 mm
2. Shell dimension: diameter 45.4 mm x 45 mm
3. Encapsulated with aluminum housing and optical window
4. Energy resolution: <3.5% with cesium 137 by using Hamamatsu R6231

Advantage

1. Fast timing measurement: < 200ps @ 662 keV
2. Fine energy resolution: < 3.5% @ 662 keV

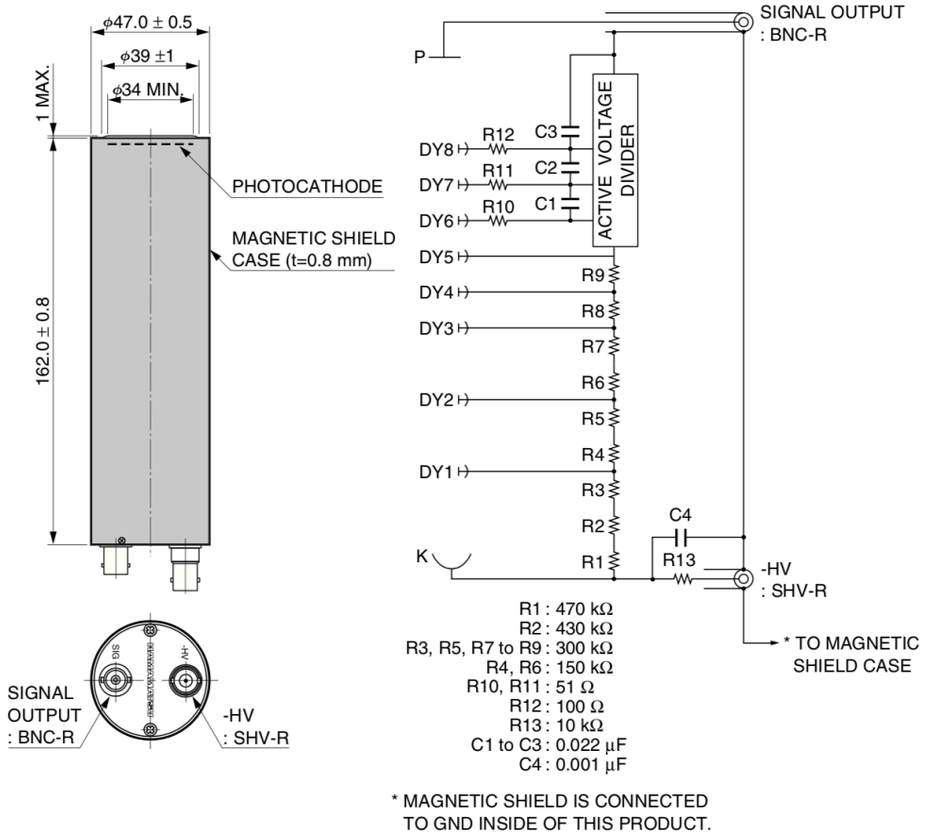
Disadvantage

1. Expensive: ~$5,000/crystal
2. Self-radioactive: ~1470 keV
3. Actinide contamination

Detector Design

- H10828 (R9420) PMT: Fast time response

⓫ H10828



GENERAL

Parameter		Description / Value	Unit
Spectral Response		300 to 650	nm
Wavelength of Maximum Response		420	nm
Window Material		Borosilicate glass	—
Photocathode	Material	Bialkali	—
	Minimum Effective Area	ϕ34	mm
Dynode	Structure	Linear focused	—
	Number of Stages	8	—
Base		JEDEC No. B12-43 / Flying lead type	—
Operating Ambient Temperature		-30 to +50	°C
Storage Temperature		-80 to +50	°C
Suitable Socket		E678-12A (supplied)	—

MAXIMUM RATINGS (Absolute Maximum Values)

Parameter		Value	Unit
Supply Voltage	Between Anode and Cathode	1500	V
Average Anode Current		0.1	mA

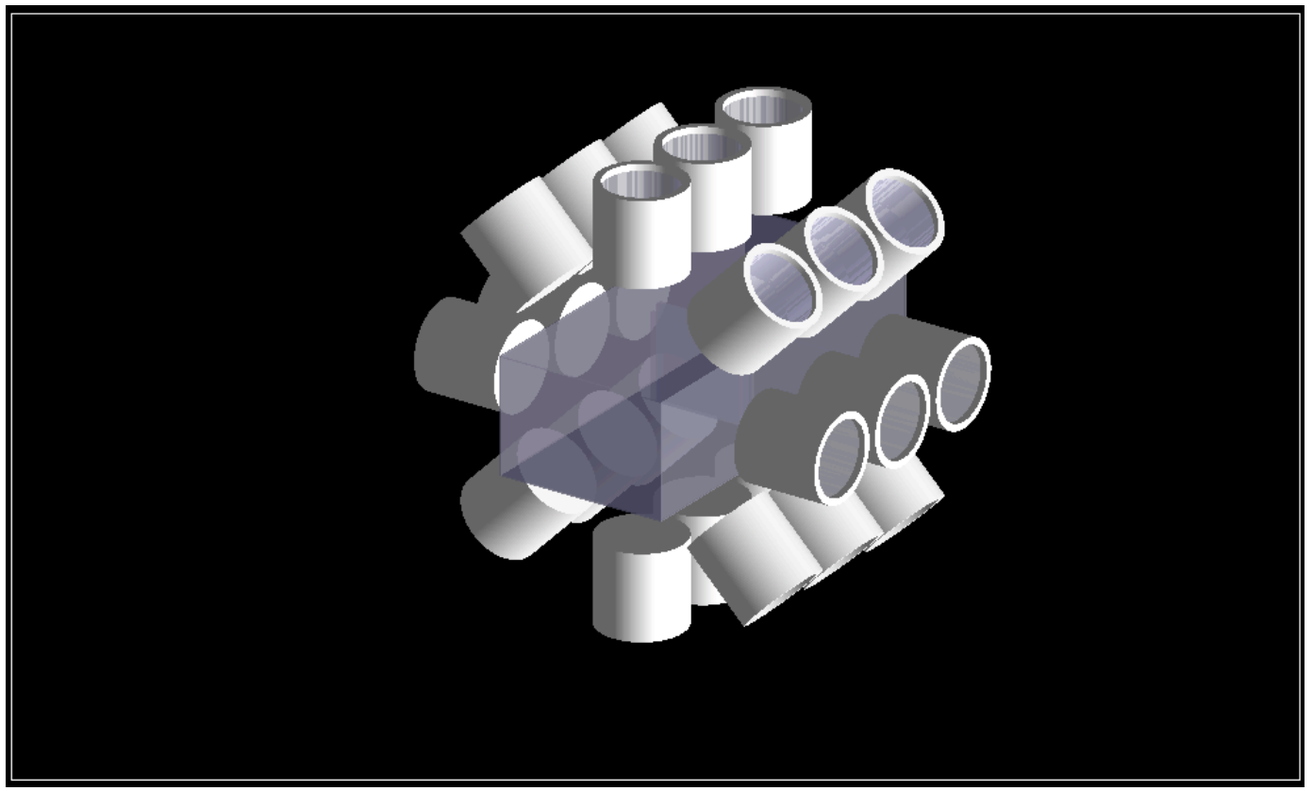
CHARACTERISTICS (at 25 °C)

Parameter		Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous (2856 K)	70	95	—	μA/lm
	Blue Sensitivity Index (CS 5-58)	9	11	—	—
Anode Sensitivity	Luminous (2856 K)	5	47	—	A/lm
Gain		—	5.0×10^5	—	—
Anode Dark Current (After 30 minute storage in darkness)		—	10	100	nA
Time Response	Anode Pulse Rise Time	—	1.6	—	ns
	Electron Transit Time	—	17	—	ns
	Transit Time Spread (FWHM)	—	550	—	ps
Pulse Linearity (±2 % deviation)		—	30	—	mA

NOTE: Anode characteristics are measured with a voltage distribution ratio and supply voltage shown below.

Simulation

- GEANT4 geometry

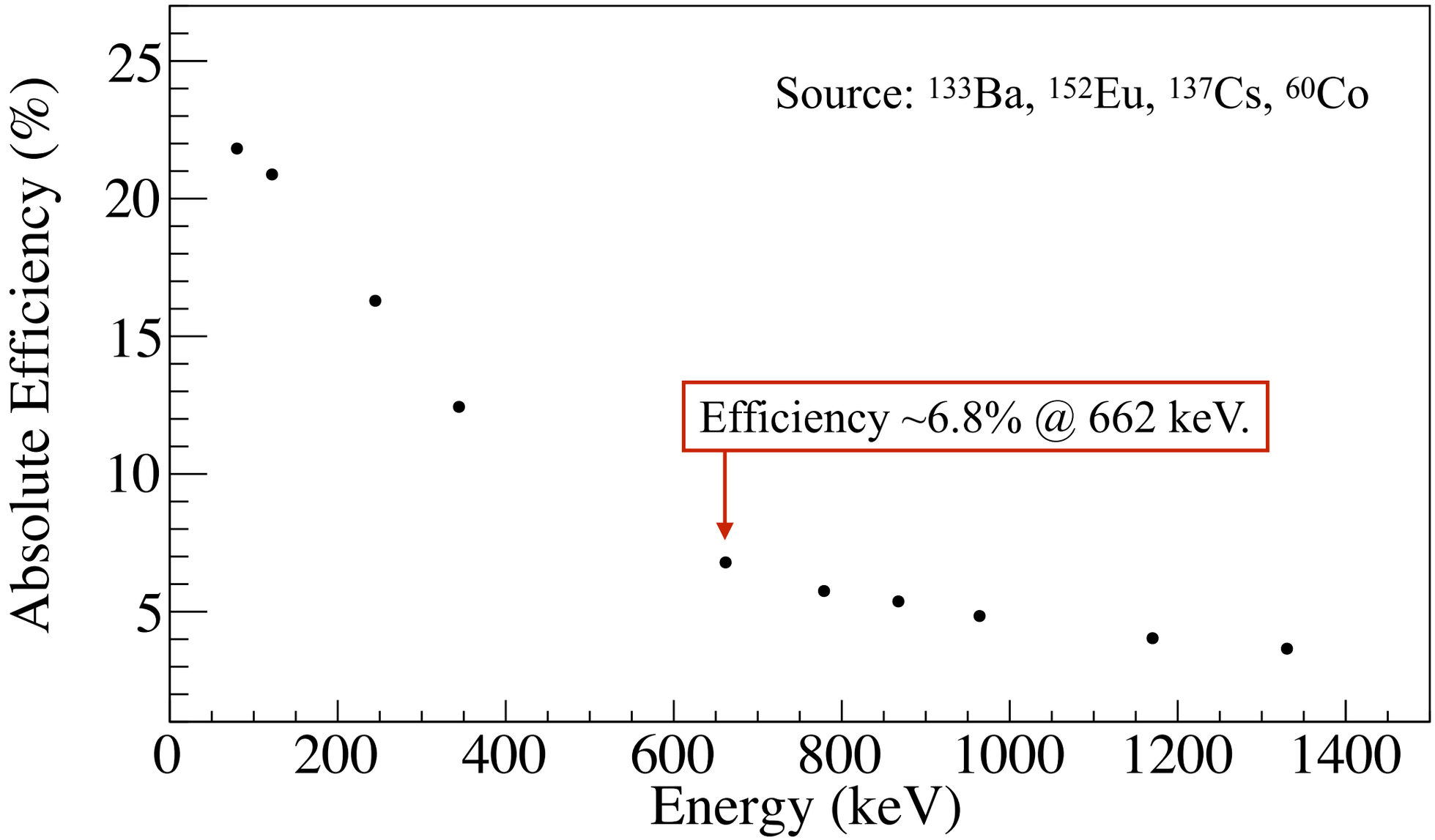


	Geometry	Quantity
$LaBr_3$(Ce) crystal	ø38mmX38mm	24
Encapsule (Al)	ø45.4mmX45mm	24
DSSSD (Si)	50mmX50mmX1mm	3
Plastic scintillator (C_9H_{10})	50mmX45mmX2mm	2
Gas (N_2)	90mmX60mmX200mm	1
Chamber (Al)	Surrounding N_2 gas with 0.5-mm thickness	1

HPGe clover type detectors are not considered.

Simulation

- Gamma-detecting efficiency



Expected Achievements

EURICA Campaign (2012-2016)
Articles: totally 47 articles so far.
(PRL: 12, PLB: 10, PRC: 19, EPJA: 1, PTEP: 2, JPSJ: 1, NIMB: 1)
More articles in preparation.
Thesis: totally 19 theses so far.
(PhD: 16, Master: 3)

MINIBALL (tentative) (2020-?)
Expected number of articles: ~ 25 articles.
Expected number of theses: ~ 10 theses.
Only at RIBF, RIKEN.
Extend campaign to RAON, IBS.

Budget

	Manufacture	Price	Quantity	Total
$LaBr_3$(Ce) crystal	EPIC	$4,920	24	$118,080
H10828 (R9420)	HAMAMATSU	$1,370	24	$32,880

* Tax is not included.

Electronics should be studied both with digital-type DAQ and analog-type DAQ to compensate the timing resolution, energy resolution, and price.

Milestone

	2019				2020				2021				2022			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Performance test of respective detectors.	■	■														
Construction of supporting structure.		■	■	■												
DAQ preparation.		■	■	■												
Call for collaborators and proposals.			■	■												
Conveyance.				■	■											
Construction of systems.					■	■	■									
Commissioning experiment.							■									
Beamtime experiment.							■	■	■	■	■	■	■	■	■	■

Summary

- Lifetime measurements of quantum states play crucial roles in the nuclear structure study.
- Several frontier experiments with fast-timing measurements have been performed and being prepared.
- MINIBALL campaign with 24 $LaBr_3(Ce)$ scintillators at RIBF, RIKEN.
- Efficiency ~6.8 % at 662 keV.
- Expecting plenty of articles and PhD theses.
- Plan to launch and start the campaign from 2020.
- Future experiments at RAON, IBS.