

NEutron-detection system for Breakup of Unstable-Nuclei with Large Acceptance (NEBULA) + γ Detector

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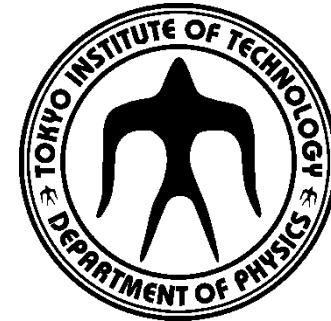
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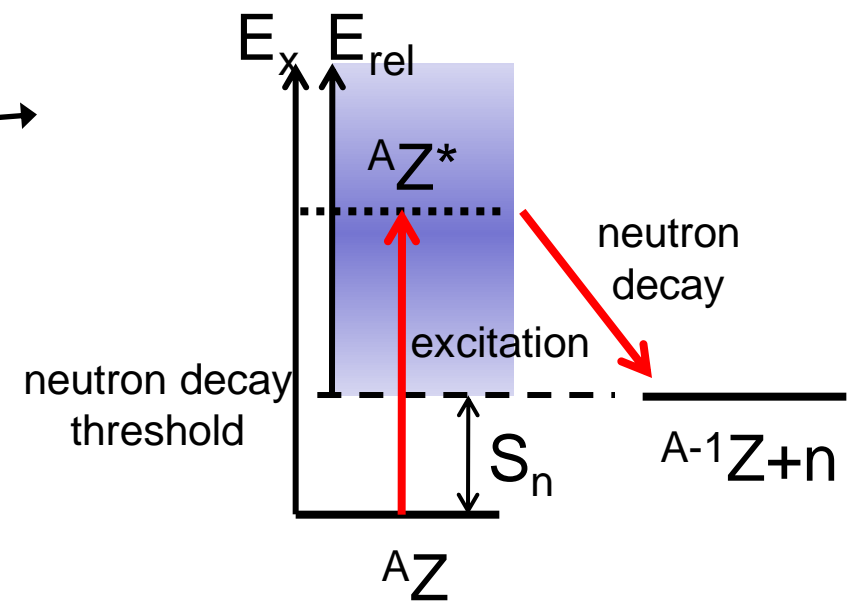
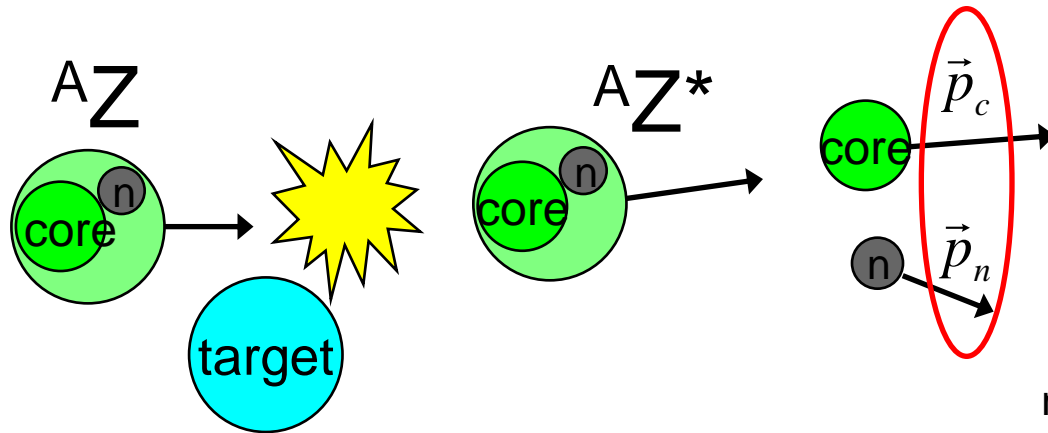
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Yoshiteru Satou^{2,3}



1. Tokyo Institute of Technology
2. RIKEN Nishina Center
3. Seoul National Univeristy

Physics Outline - Invariant-mass spectroscopy of neutron-rich nuclei



$$E_{rel} = \sqrt{(\sum E_i)^2 - (\sum \vec{p}_i)^2} - \sum M_i$$

Coulomb Breakup

- Soft E1 excitation(→T.Nakamura)
- Pygmy Mode(→T.Kobayashi)

Inelastic Scattering (Nuclear Breakup)

- (p,p'), (α,α'),(12C,12C),(p,n)

Unbound Nuclei, Unbound Resonances

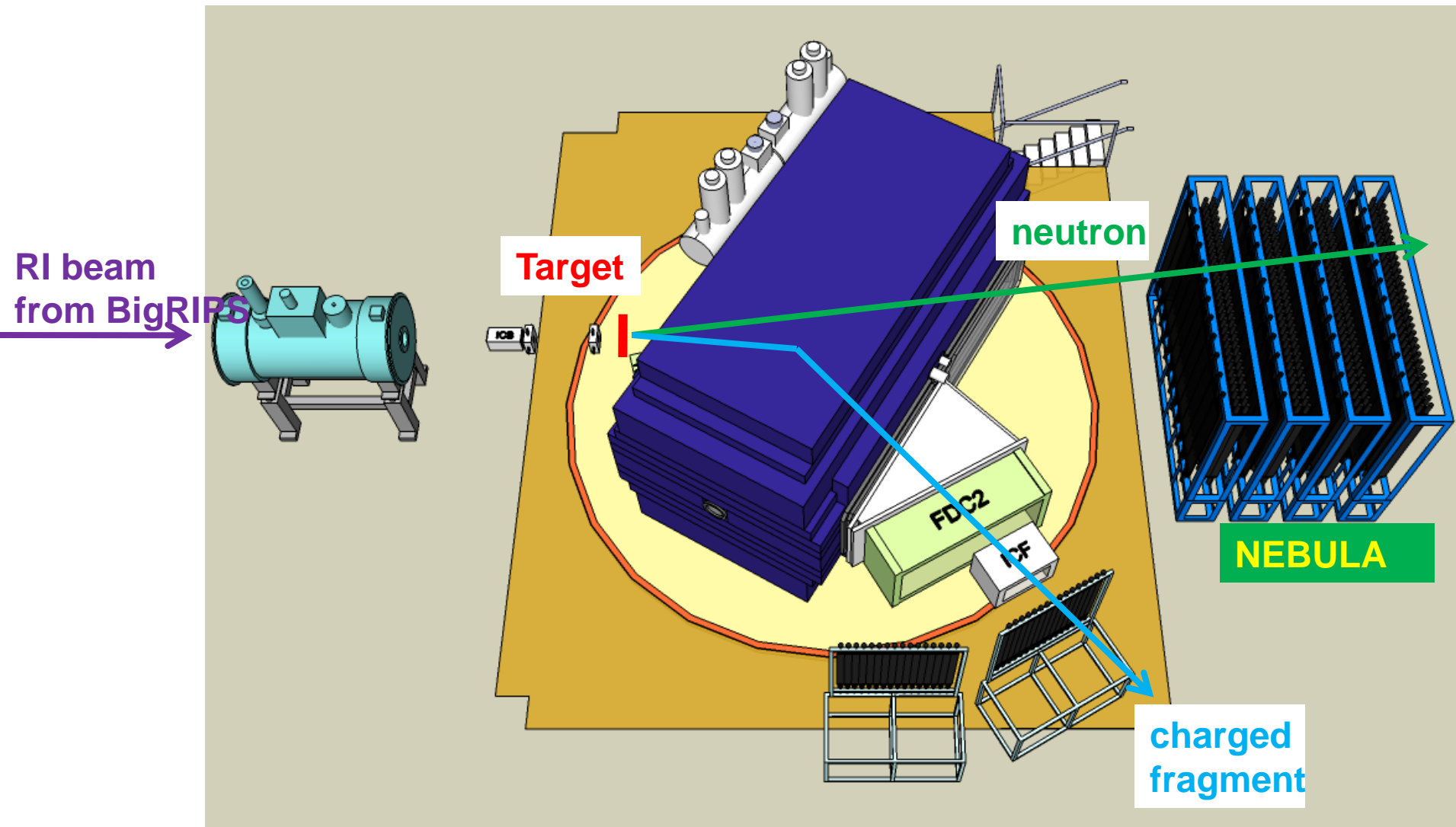
- Near/beyond drip-line(→Y.Kondo)

Neutron Measurement in heavy-ion collisions (EOS→Murakami/Lynch/Isobe)

Contents

- Physics Outline (Details presented tomorrow)
- Requirements for NEBULA
- Detector Specification
- Current Status
- Schedule
- Outlook

Typical Experimental Setup



Features (Requirements) of NEBULA

NEutron-detection system for **B**reakup of **U**nstable-Nuclei
with **L**arge **A**cceptance

- Measure Four-Momentum Vectors of Fast Neutrons

100-300MeV

- Large Acceptance 50% at $E_{\text{rel}}=8\text{MeV}$

← *Kinematic focusing*

- High Intrinsic Detection Efficiency

60% for 1n, 20% for 2n

- Good Energy(E_{rel}) Resolution

ΔE_{rel} 0.3~0.4MeV (FWHM) at $E_{\text{rel}}=1\text{MeV}$

ΔE_{rel} 1 MeV (FWHM) at $E_{\text{rel}}=8\text{MeV}$

- Multi Neutron Detection 1n,2n,3n,4n

- Flexibility of setup configuration

Acceptance/Resolution/Multi-neutron

Specification of NEBULA

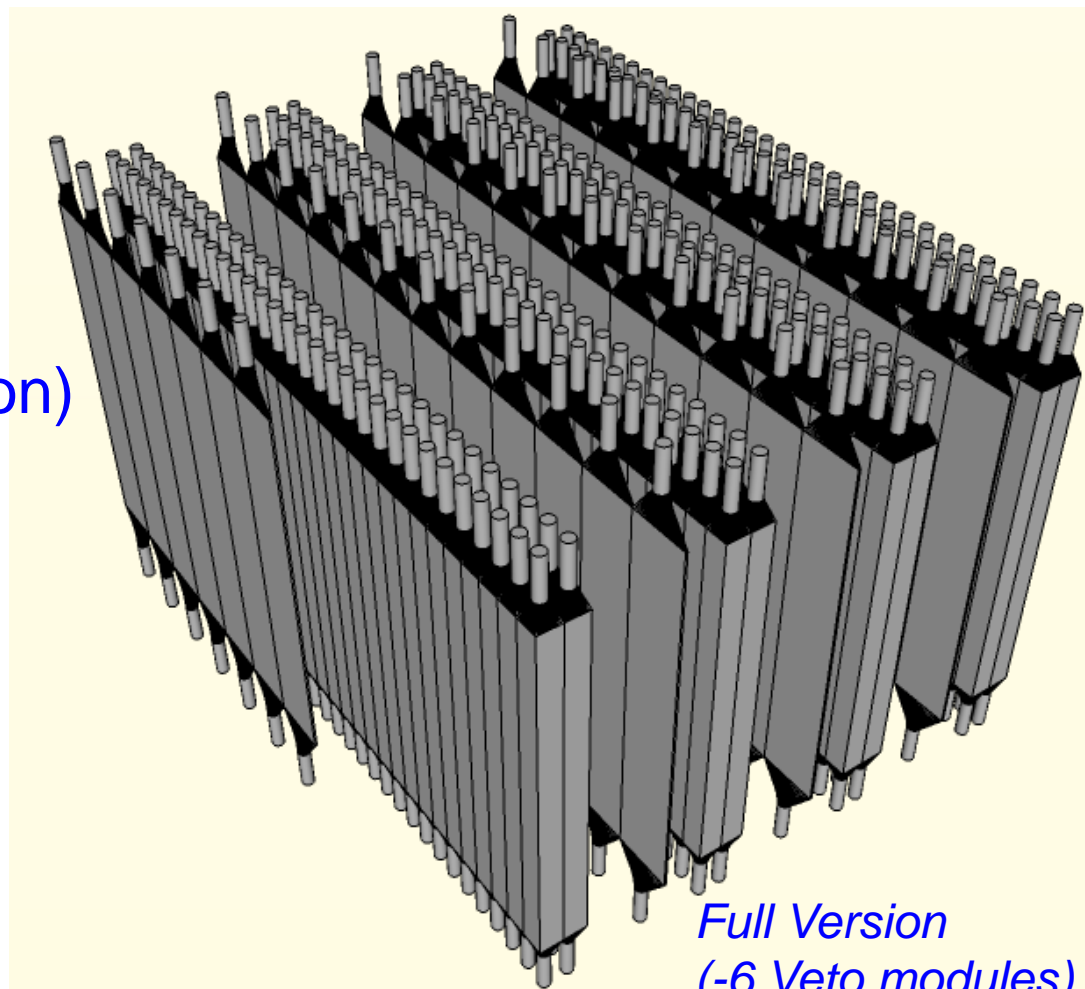
(Neutron-detection system for Breakup of Unstable-Nuclei with Large Acceptance)

Full Version

- 240 Neutron counters
(60 modules x 4 layers)
- 48 VETO counters
(12modules x 4 layers)

Half Version (Current Version)

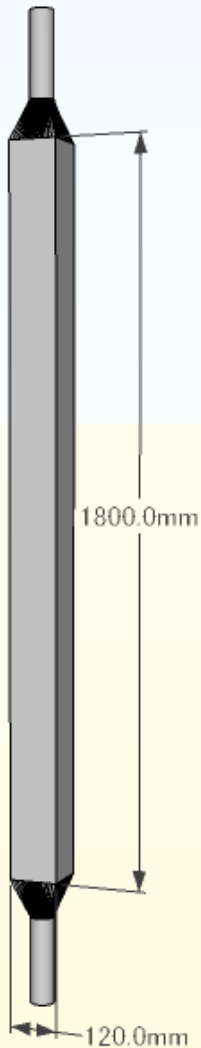
- 120 Neutron counters
(60 modules x 2 layers or
30 modules x 4 layers)
- 48 VETO counters
(12modules x 2 layers)



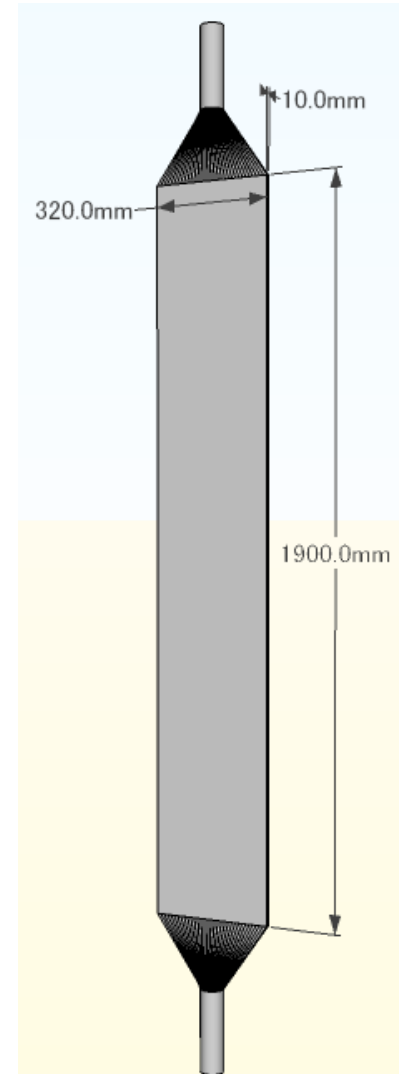
Full Version
(-6 Veto modules)

NEBULA

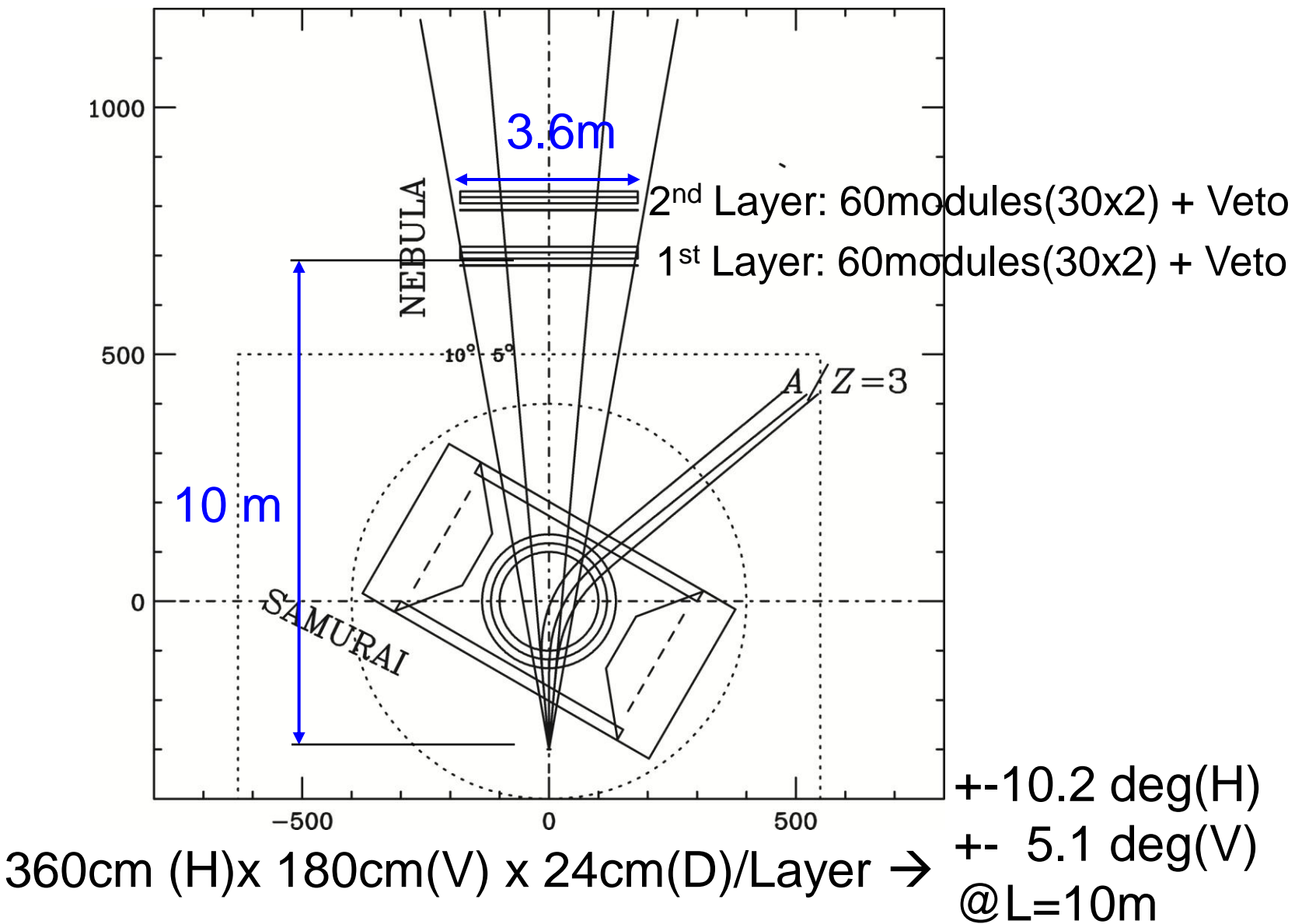
(Neutron-detection system for Breakup of Unstable-Nuclei with Large Acceptance)



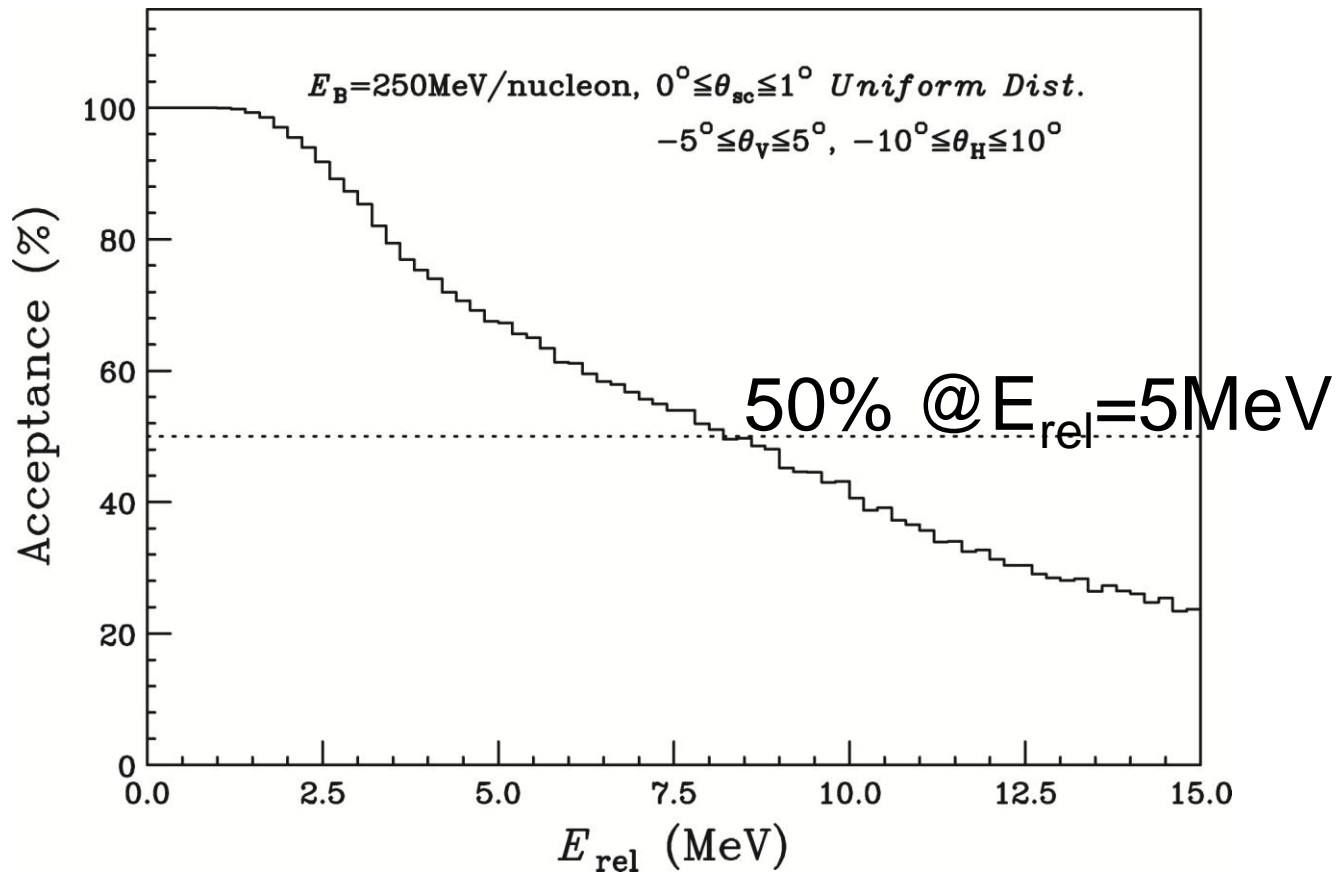
- Neutron counter
 - scintillator
 - BC408
 - 12cm x 12cm x 180cm
 - PMT
 - R7724 (both ends)
 - vertical position is determined by time difference
- VETO counter
 - 1cm-thick scintillator
 - used to identify the charged particles



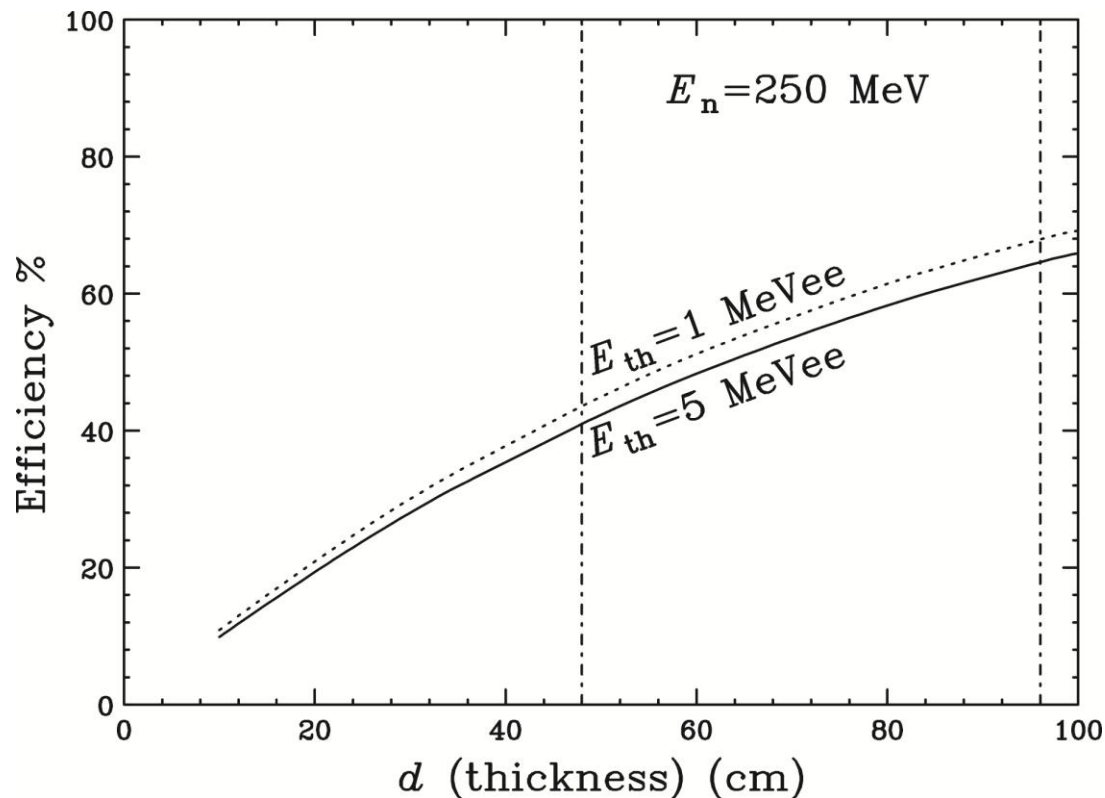
2-Layer Setup (*Day-1 Setup*)



Acceptance



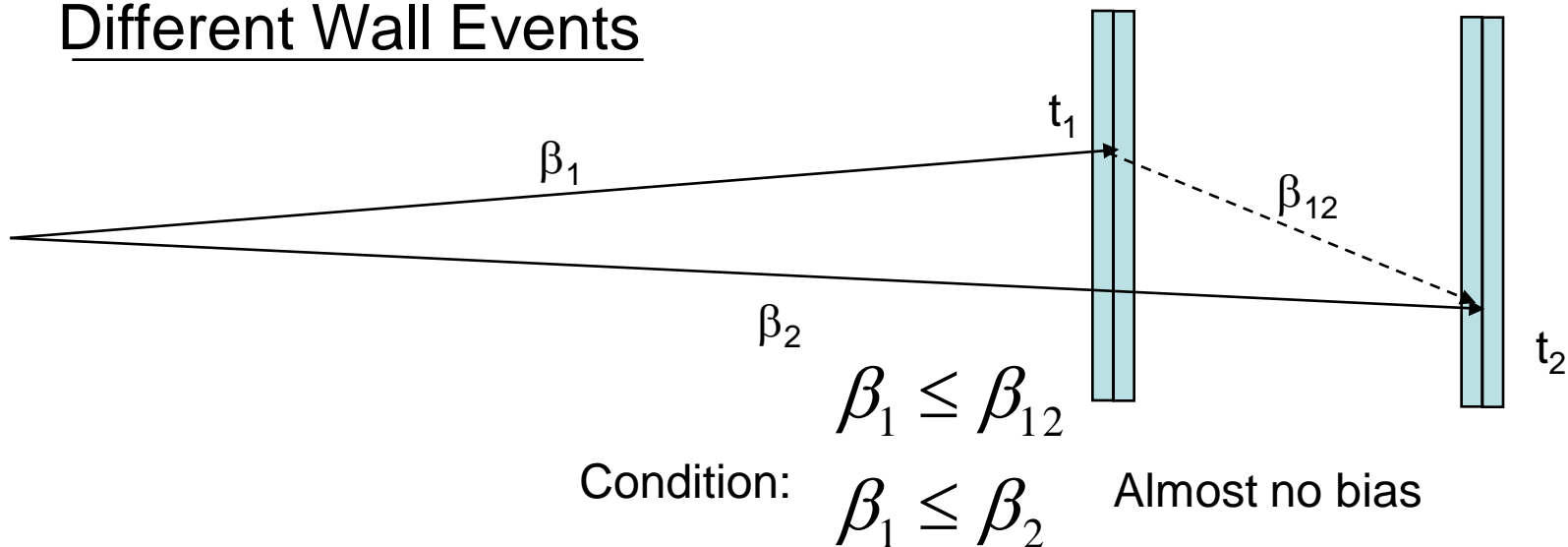
Intrinsic Efficiency (1n detection)



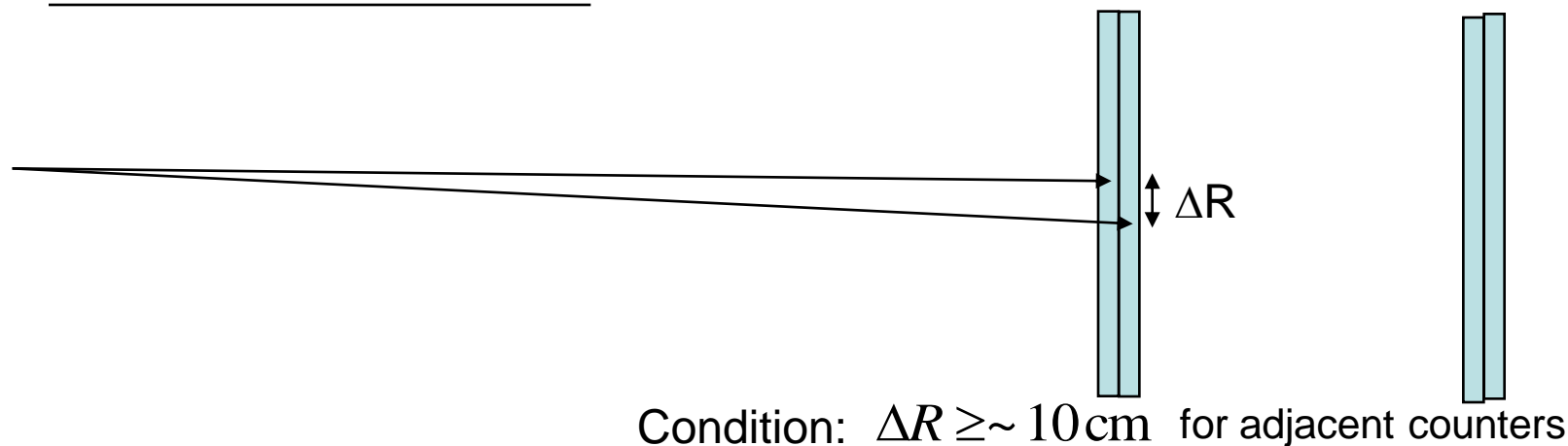
	Eff_1n(%)	Eff_2n(%)	Eff_4n(%)	
24cm x 2Layer	41.0	12.6		Half Version
12cm x 4Layer	41.0	10.5	0.011	Half Version
24cm x 4Layer	64.6	26.6	0.056	Full Version

Exclusion of Cross Talk Events for 2n or more neutron detections

Different Wall Events



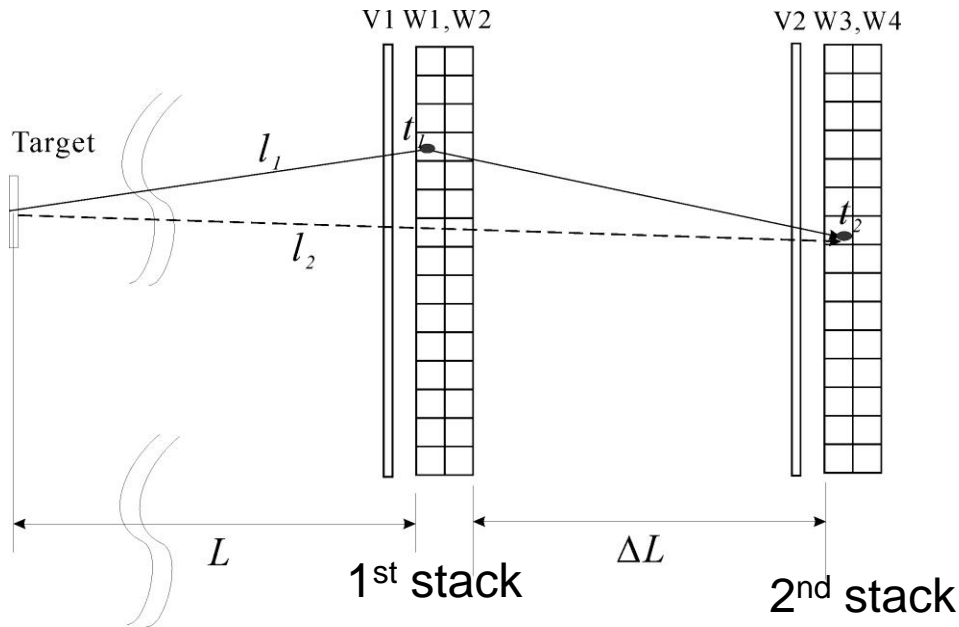
Same Wall Events



$E_{\text{th}}=5\text{MeVee}$ to avoid any gamma related events

■ Different Wall Setting (Simulation)

→ Nearly perfect rejection of crosstalk events



$$\beta_1 \leq \beta_2$$

Finite timing resolution →

ΔL should be about 1m

for 12cmx12cm

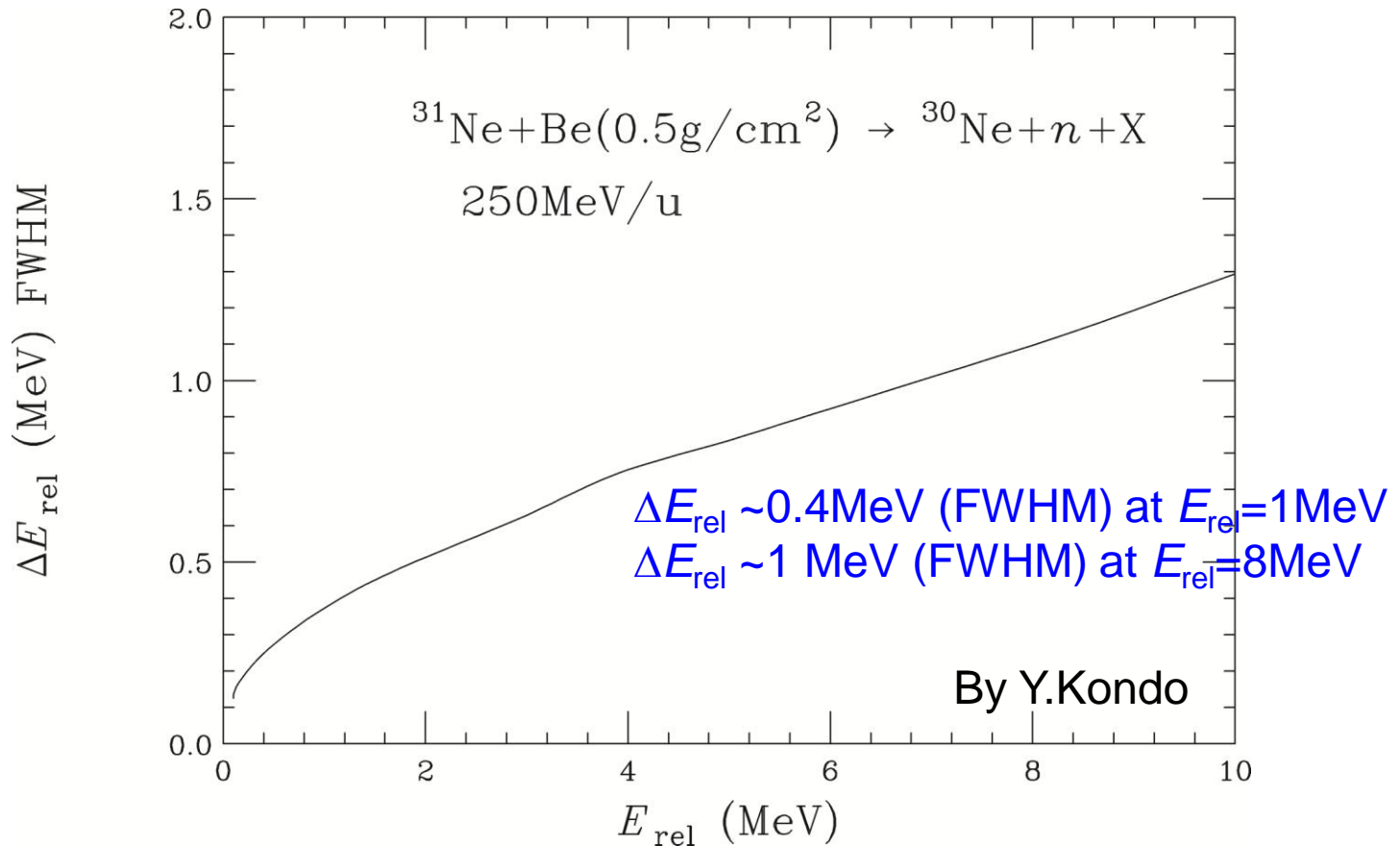
(Non-distinguishable events ~ 2%)

■ Need of veto for each wall:

For high energy neutrons > 200MeV

To remove cross-talks from recoil protons

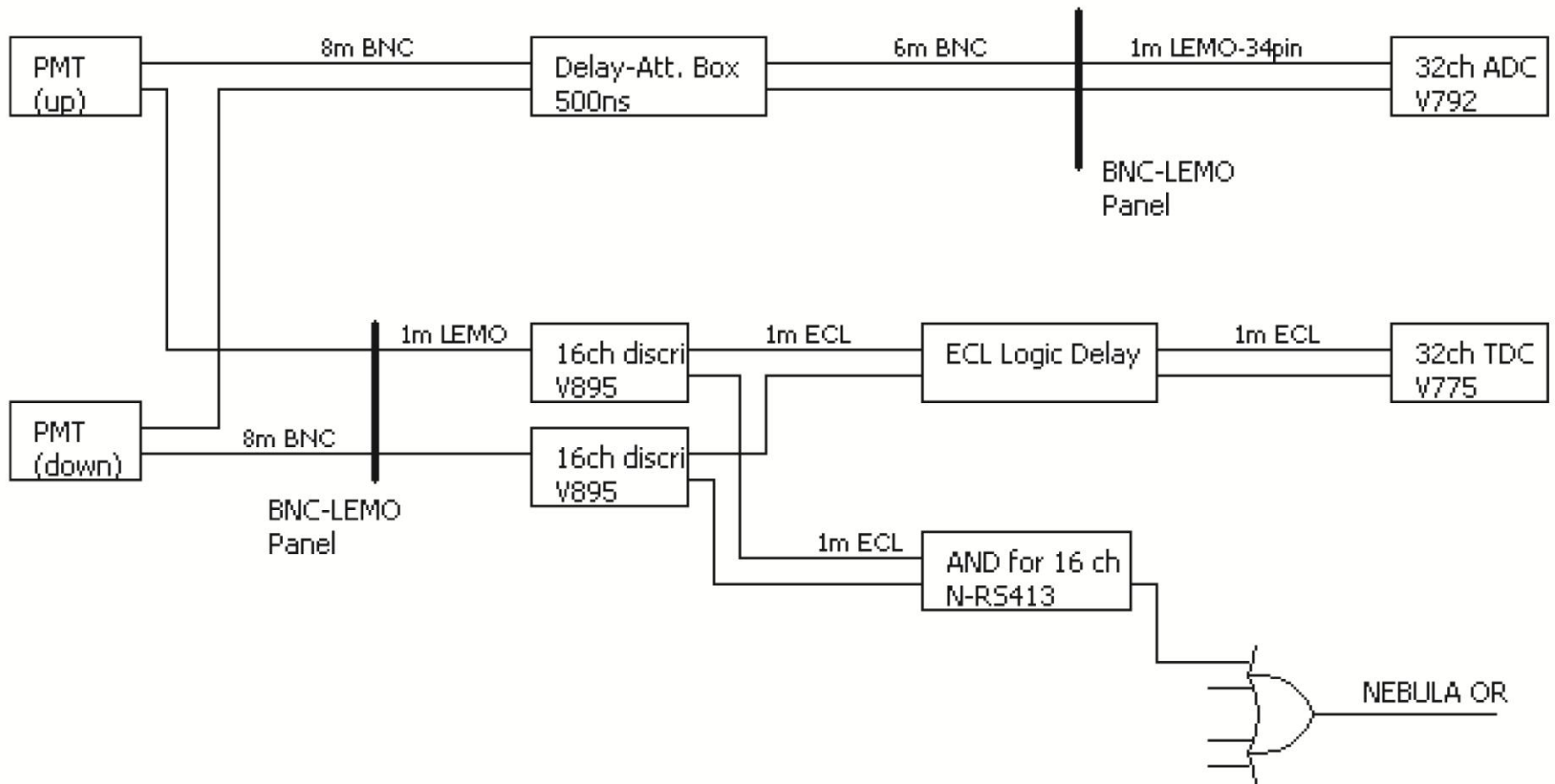
Energy Resolution



$$\sigma_y = 3\text{cm}$$
$$\sigma_t = 0.1\text{ns}$$

$$\frac{\sigma(P_{30})}{P_{30}} = \frac{1}{700}$$

ELECTRONICS



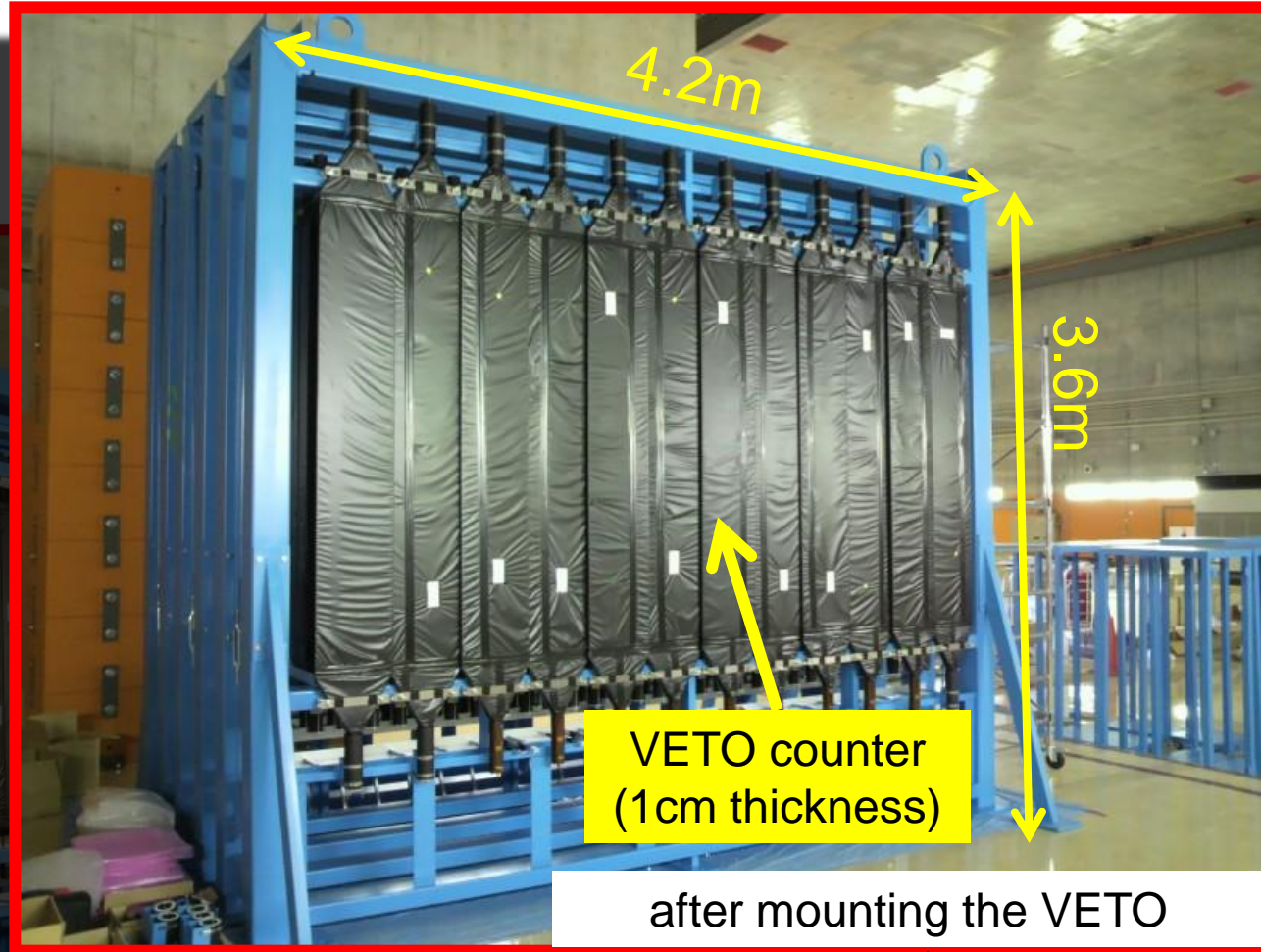
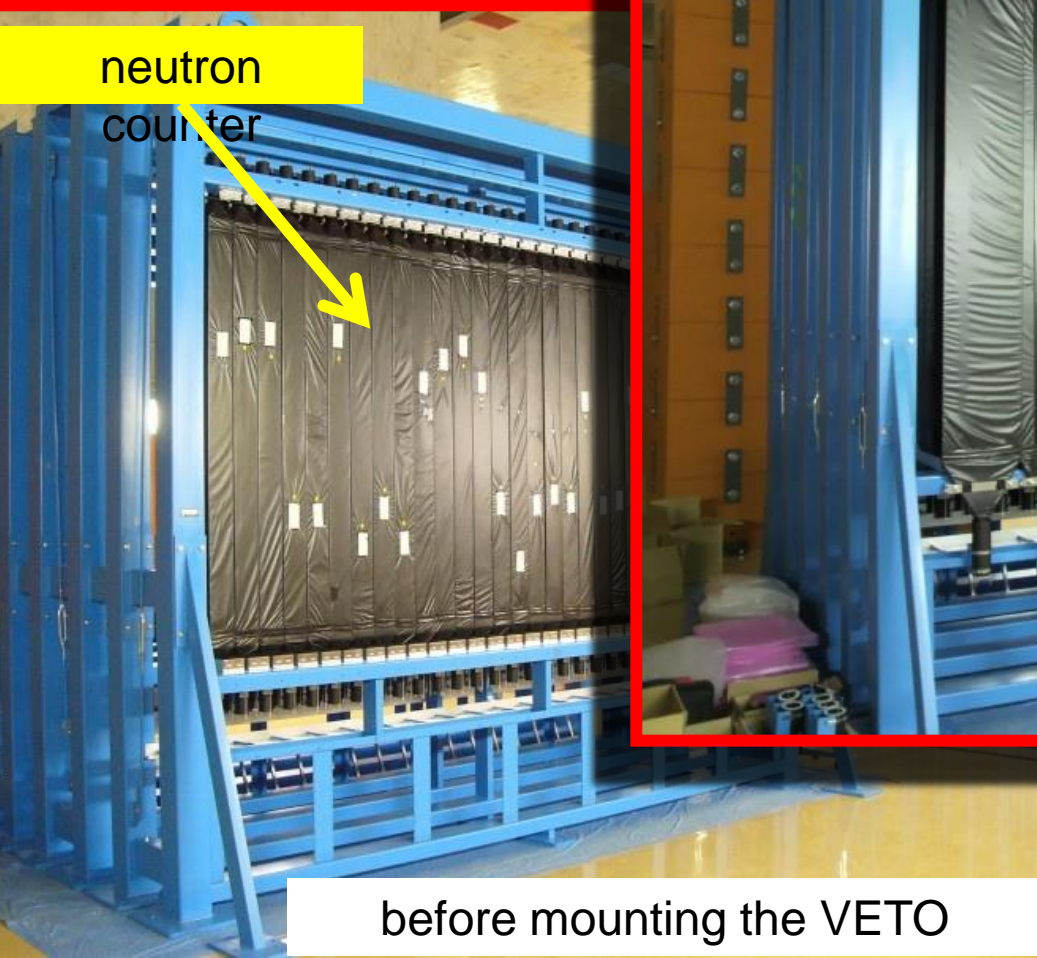
Current Status and Schedule

- **Half** of the neutron detector modules(120)
+Full Veto Modules (48) are funded

For the funded part,

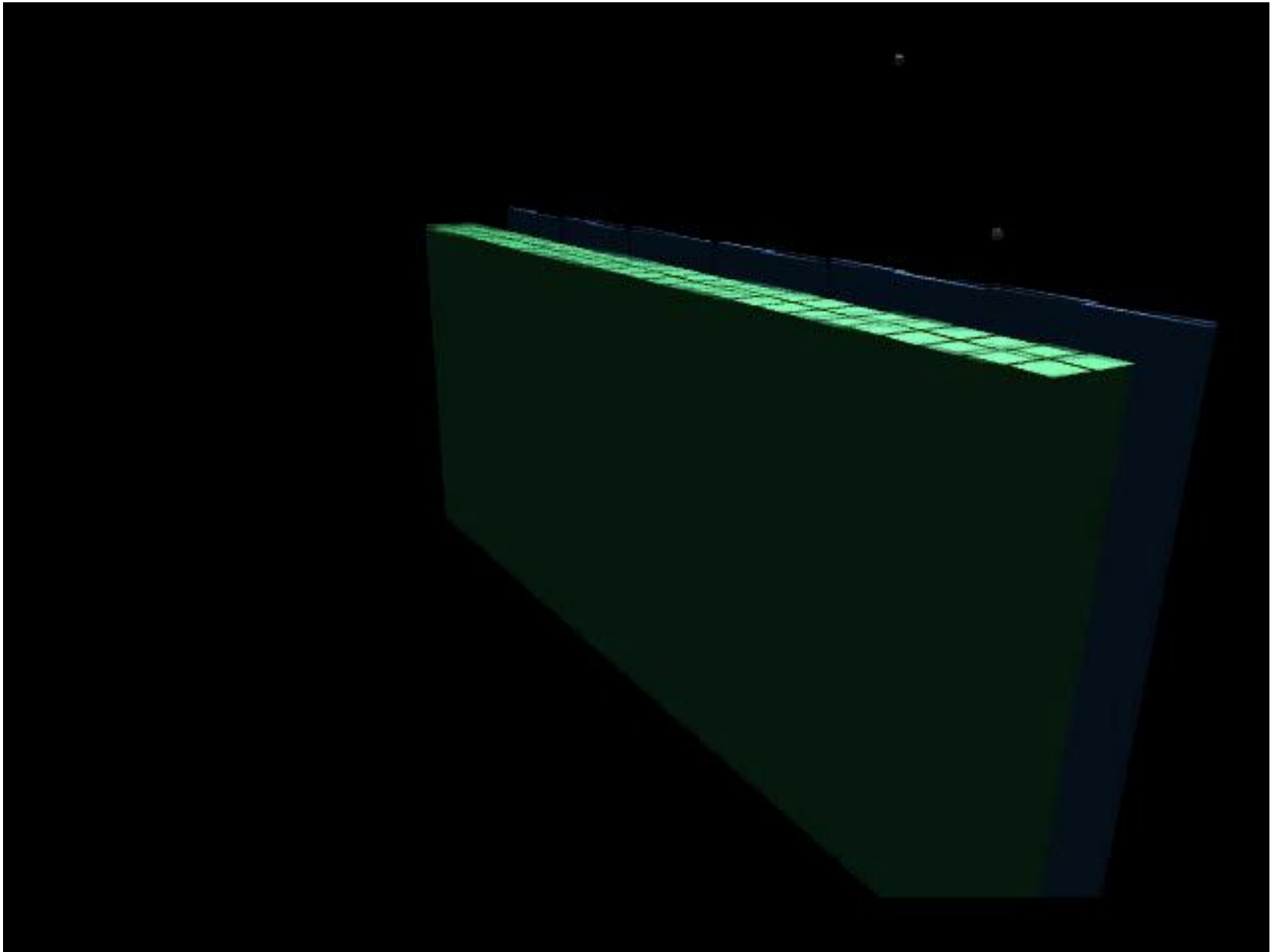
- Plastic Scintillators+PMT's have been delivered to RIBF and installed to the frame
- Part of the Electronics modules have been delivered, and the remaining will be delivered by the middle of 2011
- Test Experiments with Cosmic Rays have been started.
- Test experiment (p,Ar@250-400MeV) has been proposed at HIMAC; To test NEBULA detectors with HI beams in 2011 ${}^7\text{Li}(p,n){}^7\text{Be}, \pi^0 \rightarrow \gamma + \gamma$
(Establish slew correction, TOF calibration)

Photo



Off-Line Test Experiments Using Cosmic Rays

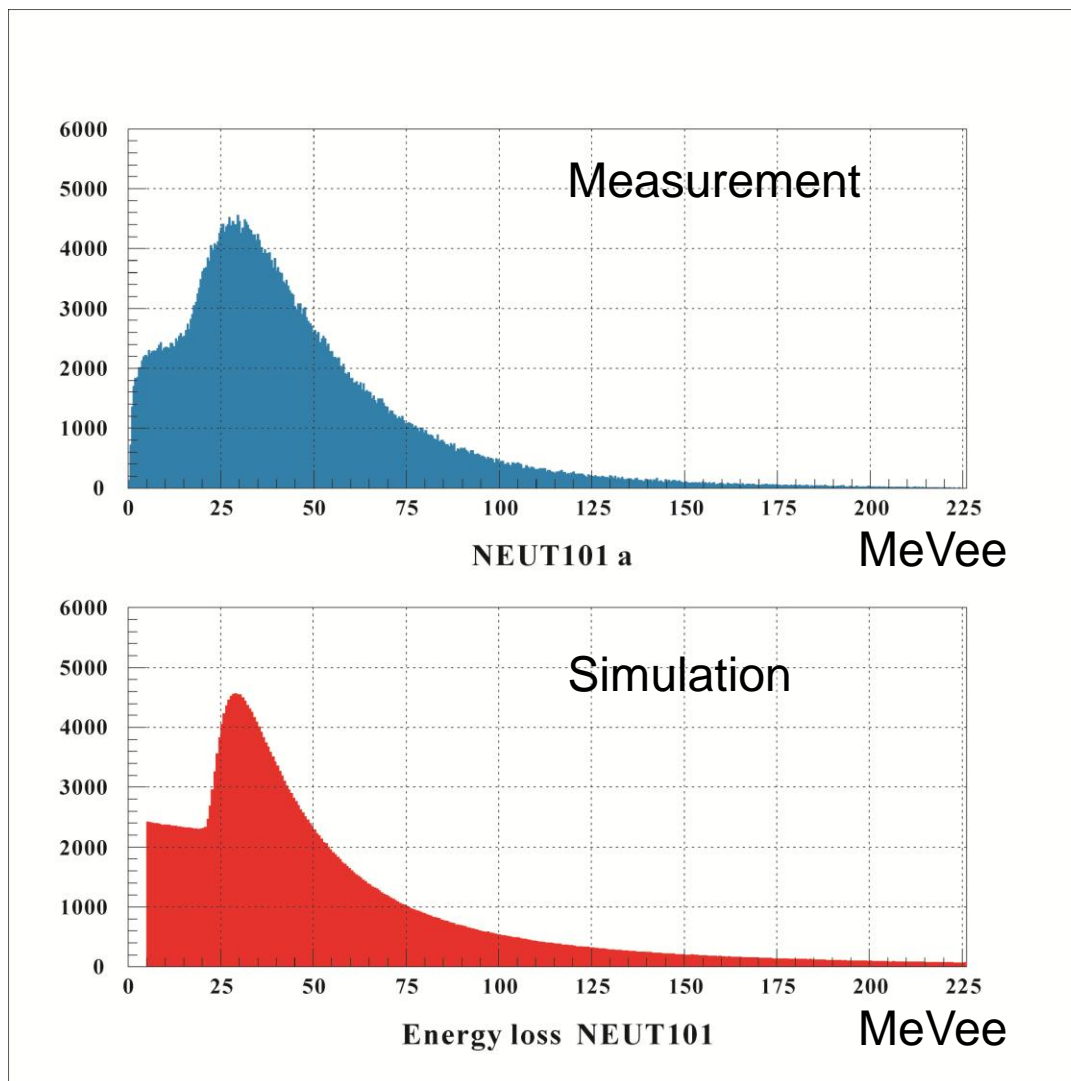
- Check Basic Functions of Plastic Scintillators, PMT's, Electronics
- Check Timing Resolution
- Check Position Resolution



Movie “NEBULA with Cosmic Ray” by Takayuki Sako (佐古貴行)

First Result from Cosmic Ray Measurement

Yosuke Kawada(河田鷹介), Takayuki Sako(佐古貴行)



Neut:30 modules
Veto:6 modules
 $M \geq 3$

Budget Summary

(current half version)

Items	kJPY (~12USD)
Scintillators	36,287
PMT, Light Guide, inc. fabrication	48,440
Electronics	50,810
Cables, Delay-Attenuator Boxes	30,000
VME Controllers	1,680
Sum	167,217

1.67oku-JPY ~2M USD

Future Issues

- Other half of Neutron detectors
- High efficiency Gamma ray detectors
- Next Generation Neutron Detectors for multi-neutron detection
- Collaboration

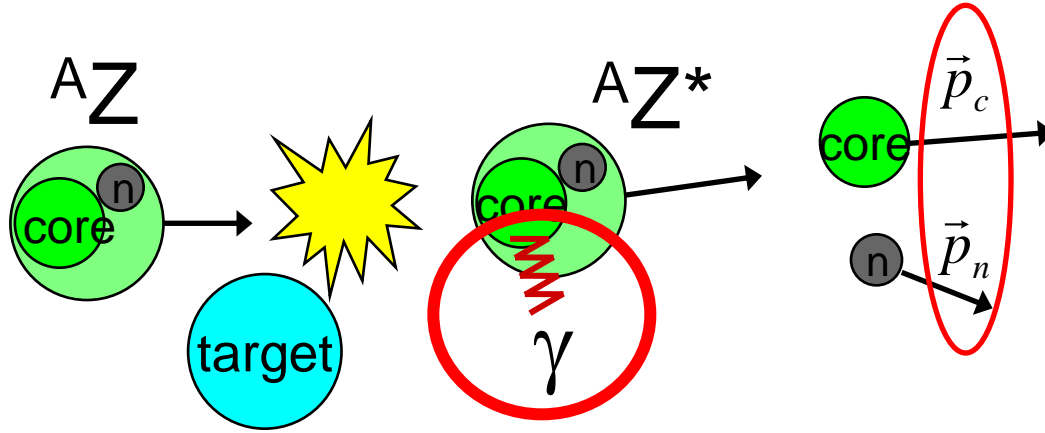
NEBULA Collaboration

Tokyo Tech. T.Nakamura, Y.Kondo, Y.Kawada, T.Sako,
R.Tanaka, N. Kobayashi

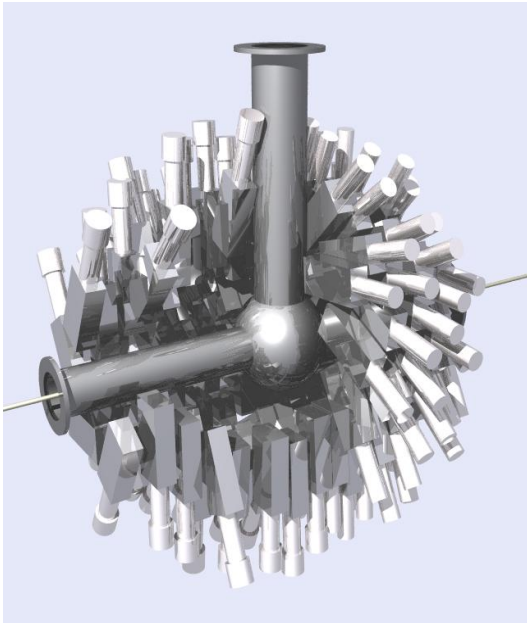
Seoul N. Univ. Y.Satou

Possible Collaboration CNS, LPC-CAEN, GSI, MSU

Need of Gamma ray detection

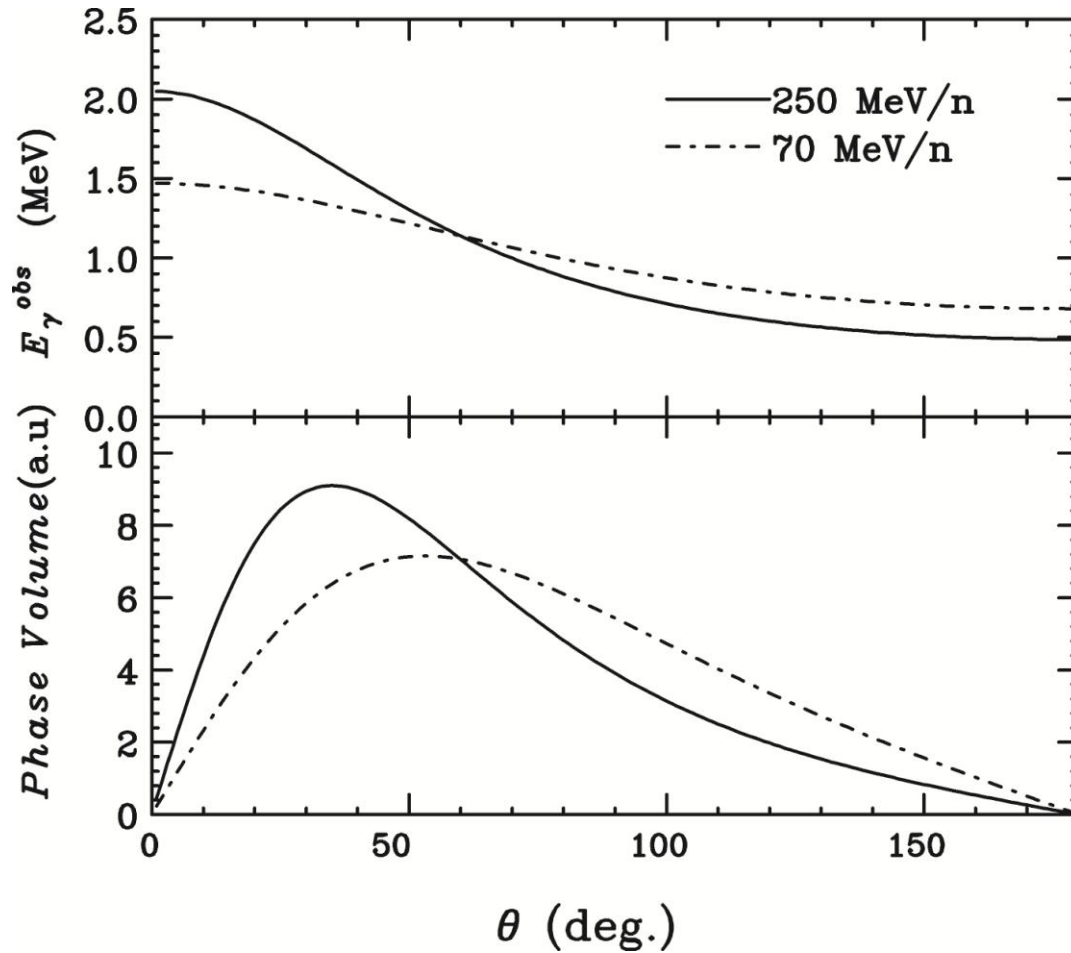


Core fragment could be in the excited state \rightarrow Emit γ rays



182 NaI detectors
Efficiency :
26% @ 0.7MeV
Energy resolution:
11% @ 0.7MeV (FWHM)

DALI2
 \rightarrow Efficiency Low



$E_\gamma = 1 \text{ MeV}$

$$\frac{d\sigma}{d\theta_{Lab}} = \frac{d\sigma}{d\Omega} \frac{2\pi \sin\theta}{\gamma^2 (1 - \beta \cos\theta)^2}$$

10—170deg \rightarrow 97% of 4π

Issues

Choice of Configuration and **Crystal**

PMT or APD? (Magnetic fringing field)

Consider (gamma,gamma') type experiment.

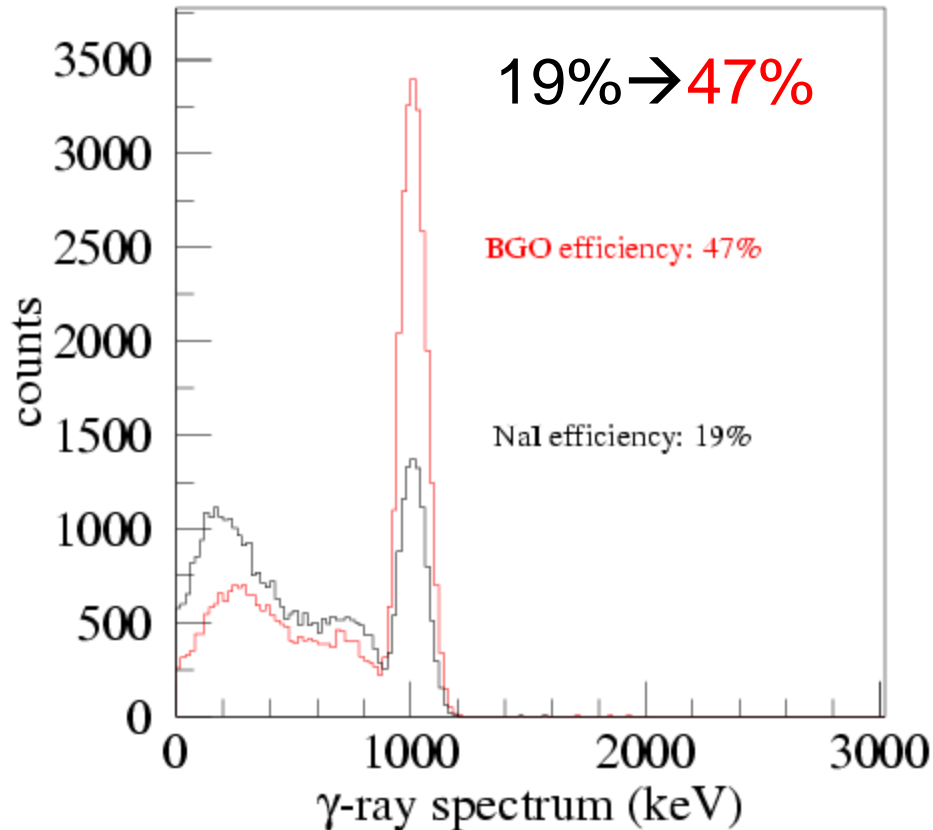
Funding

	Density (g/cm ³)	Ref. index	Rad. Length (cm)	Decay Const. (ns)	Light Yield(%) NaI(Tl)	Peak wave length (nm)	Hygro- scopic
NaI(Tl)	3.67	1.85	2.59	230	100	415	Yes
CsI(Tl)	4.51	1.75	1.86	1000	85	565	Weak
LaBr ₃	5.1	1.9	1.77	16	160	380	Yes
GSO	6.7	1.87	1.38	50-60	11-18	350	No
BGO	7.13	2.15	1.10	300	10-14	480	No
LYSO	7.3	1.82	1.82	40-44	20-30	375	No

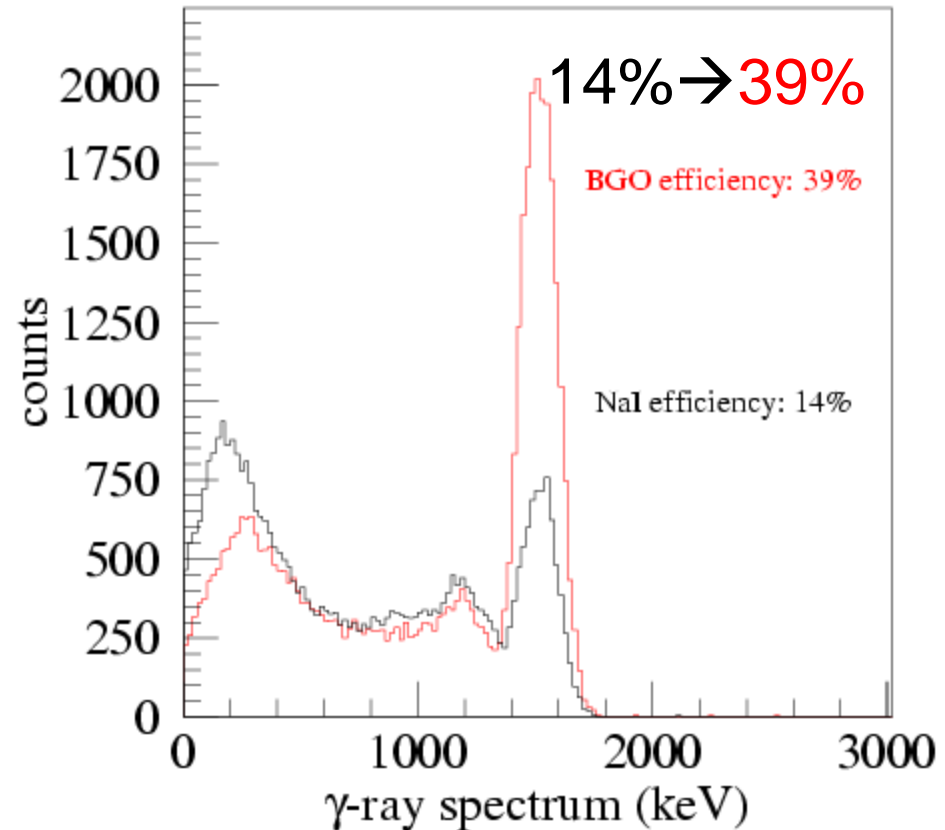
How about BGO?

If all the NaI(Tl) crystals of DALI2 are replaced by BGO crystals... (resolution is not considered)

1 MeV γ ray (50000 events)



1.5 MeV γ ray (50000 events)



250 MeV ^{31}Ne beam on 3.37g/cm² Pb

By Nobuyuki Kobayashi (小林信之)
(GEANT4, coded by Pieter Doornenbal)

Summary

- Half of NEBULA has been funded:
 - All the Scintillators+PMT (Half version) are delivered.
 - Off-line measurement of cosmic rays have been started.
 - 2011: Remaining electronics will be delivered.
 Test experiment at HIMAC (before summer)
 - 2012: Commissioning experiment
 - 2012: Day-1 experiment
-
- The other half?
 - We have started consideration for the gamma-ray arrays
 - Next Generation Neutron Detectors (R.Tanaka 田中隆己)