Development of a new inorganic crystal GAGG for the calorimeter capable of the separation between neutrons and gammas

KEK IPNS Koji Shiomi

KEK[A], Yamagata University[B], National Defense Academy of Japan[c]
Tohoku University[D], C&A cooperation[E]

Togawa Manabu[A], Yasuhisa Tajima[B], Toru Matsumura[C]
Kei Kamada[D,E], Yasuhiro Shoji[D,E], Akira Yoshikawa[D,E]

Calorimeter for the High Energy Frontier 2019 Kyushu University
2019/11/25

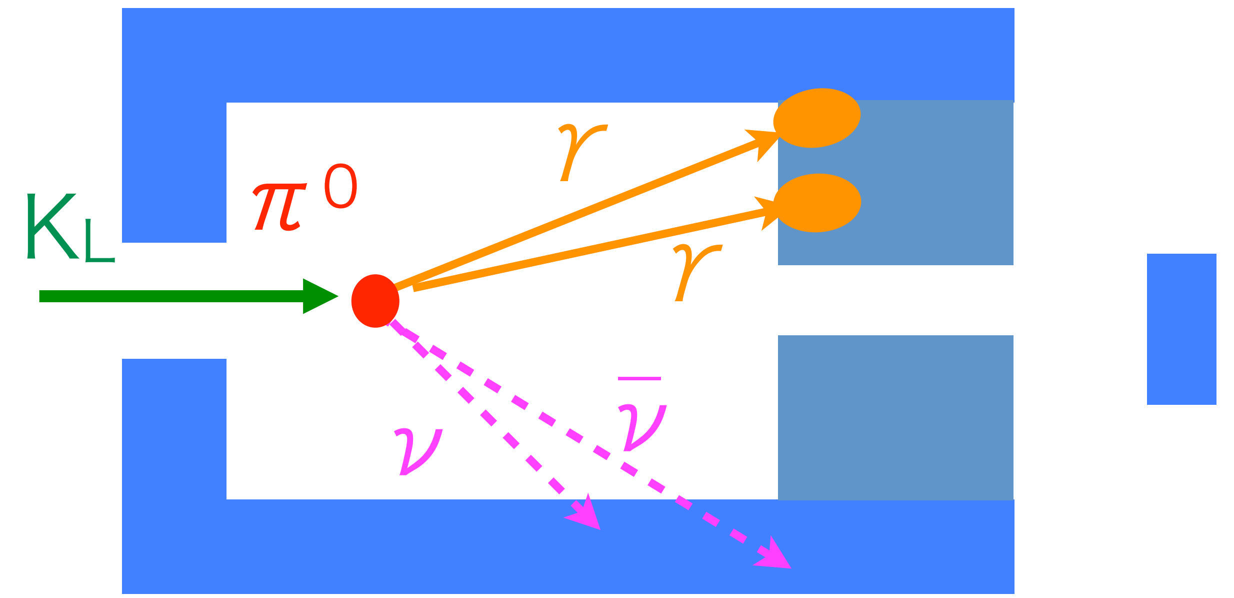
Contents

- Motivation for the calorimeter capable of the separation between neutrons and gammas
- Introduction of GAGG crystals
- Methods of the separation between neutrons and gammas by using GAGG crystals
- Electron beam test
- Neutron beam test
- Evaluation of the separation methods
- Summary

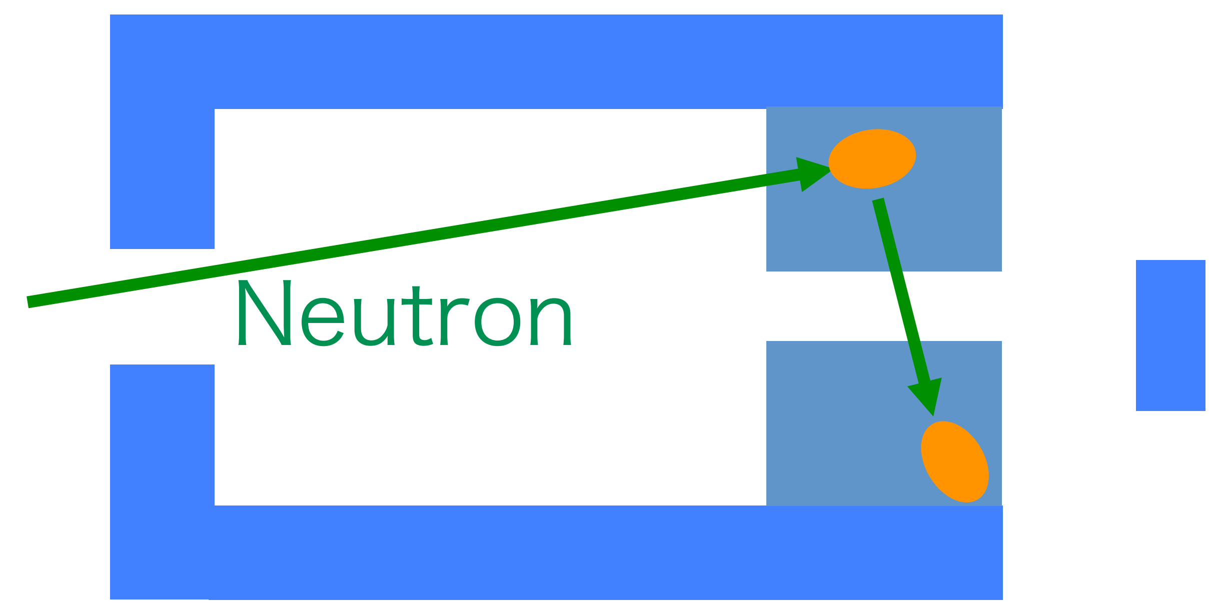
Motivation of the calorimeter capable of the separation between neutrons and gammas

- KOTO experiment
  - Search for $K_L \to \pi^0 \nu \nu$
    - Breaks CP symmetry directly.
      Suppressed in the standard model.
      -> Sensitive to New Physics
  - Signature for $K_L \to \pi^0 \nu \nu$
    「2γ + nothing」
  - Neutron is a main background source
    - The separation between neutrons and gammas is important
    - Neutron energy ～ 1GeV.

Signal event

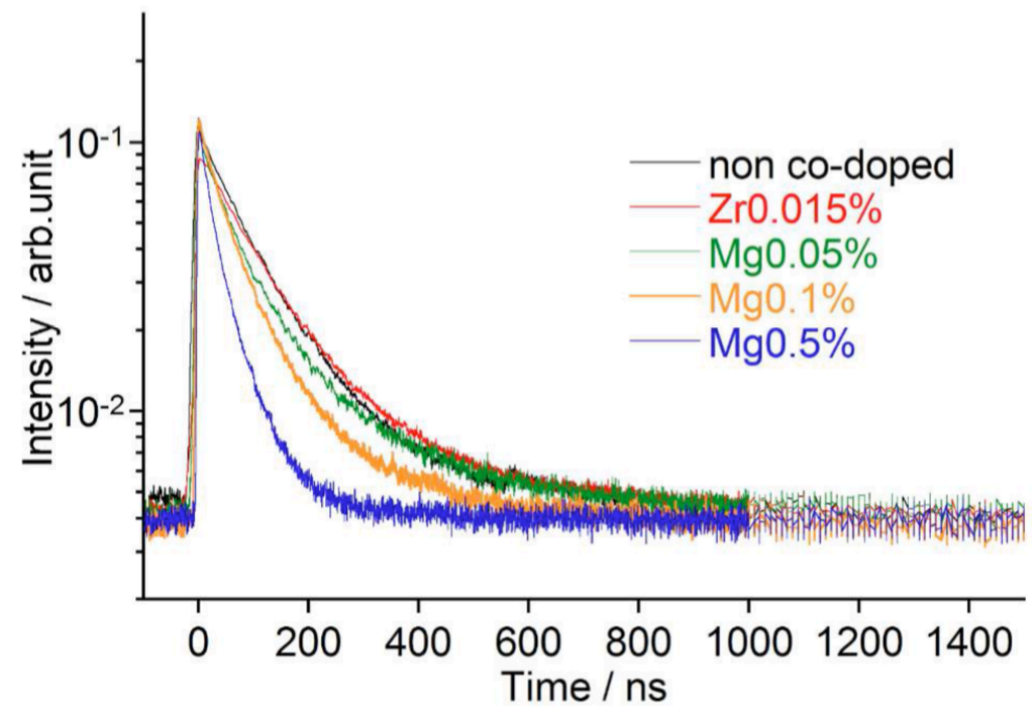


Neutron event



GAGG($Gd_3Al_2Ga_3O_{12}$(Ce)) Crystal

- High density
- High light yield (as high as NaI)
- Fast response

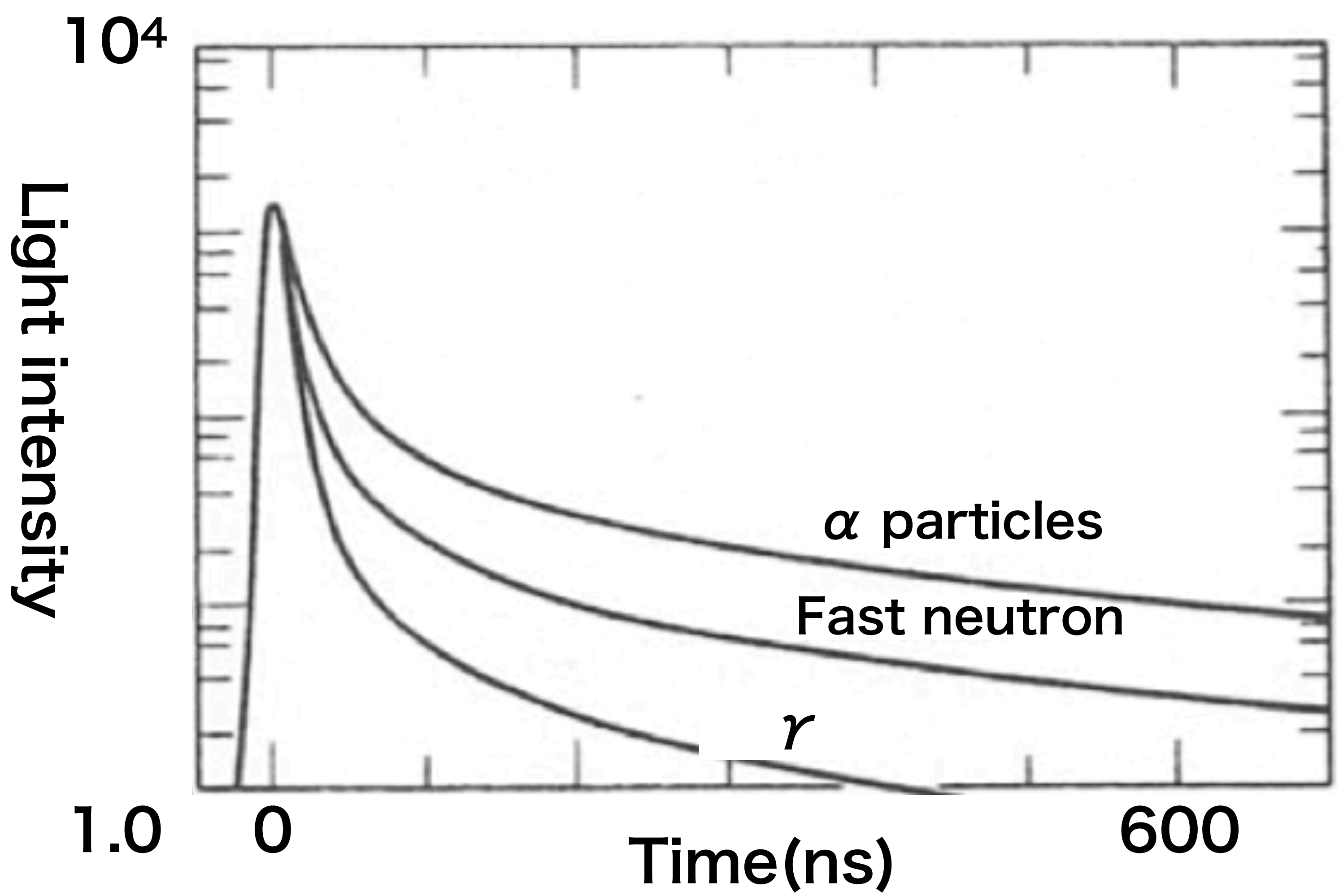


	GAGG(Ce)	Mg-doped GAGG(Ce)	Undoped CsI
Density(g/cm^3)	6.67	6.67	3.67
Light yield (NaI(Tl)=100)	127	100	1.1
Decay time(ns)	90	40	6
Peak emmision(mm)	520	520	310

Method of the separation between neutrons and gammas① (Separation by pulse shape)

The response of liquid scintillators depends on incident particles

Glenn F. Knoll Radiation Detection and Measurement ohmsha, 4th edition, 2013

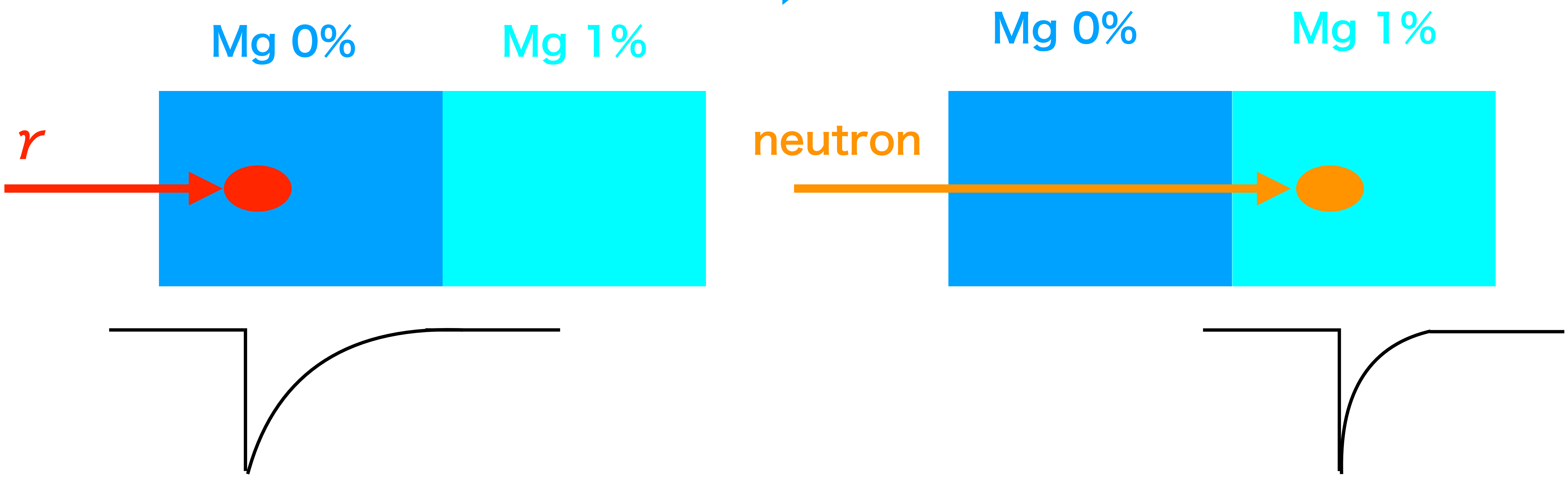


→Check whether the response of GAGG is different between neutrons and gammas

Method of the separation between neutrons and gammas② (Separation by interaction depth)

- Gammas : Radiation length
- Neutron : Interaction length

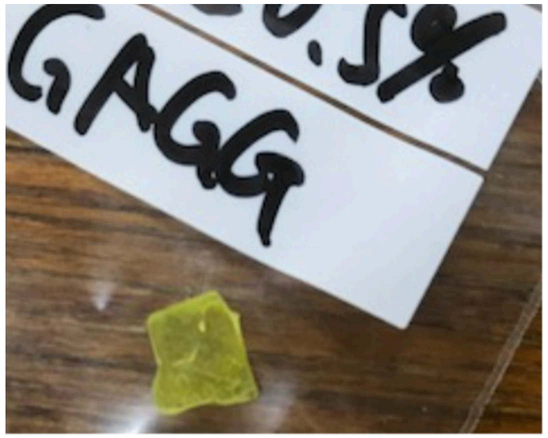
Make the difference of interaction depth in the crystal



- Glue two crystals with a different amount of doped materials
- Measure interaction positions by the observed pulse shape

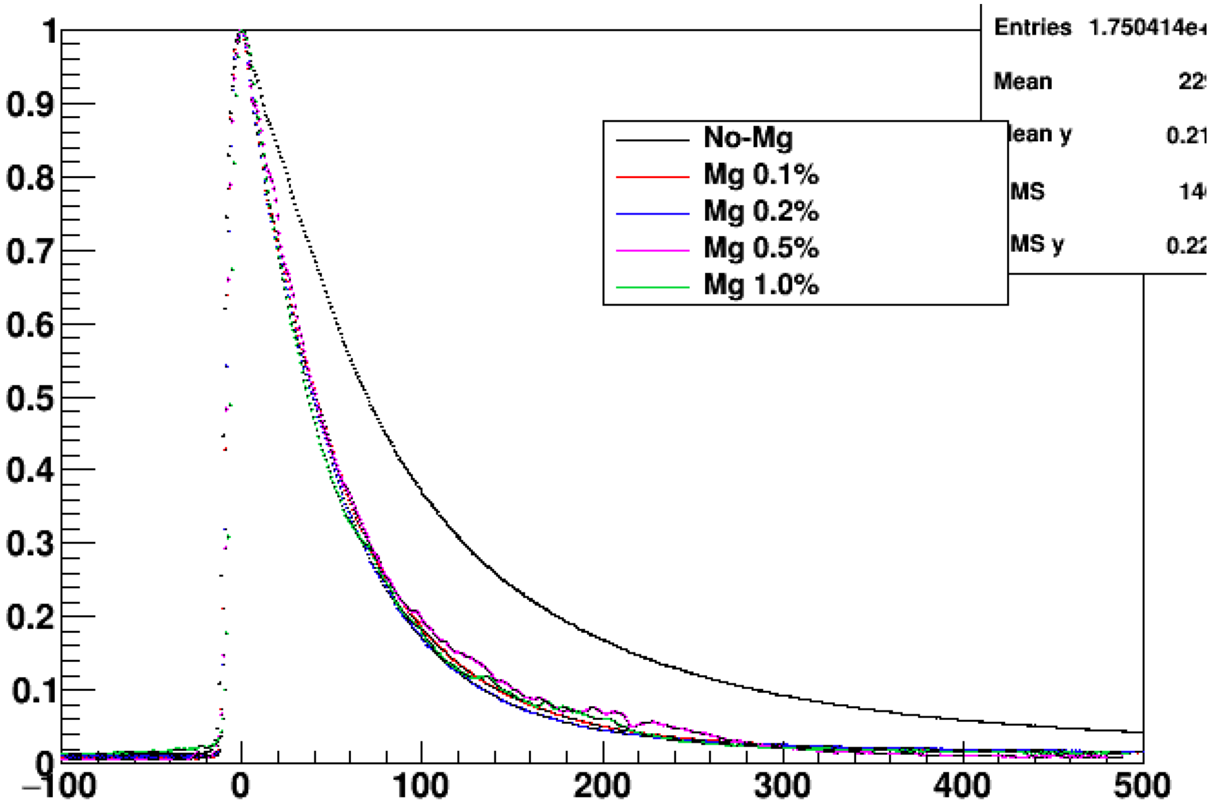
Dependence of light yield and decay constant on doped material

- Measured with a small crystal

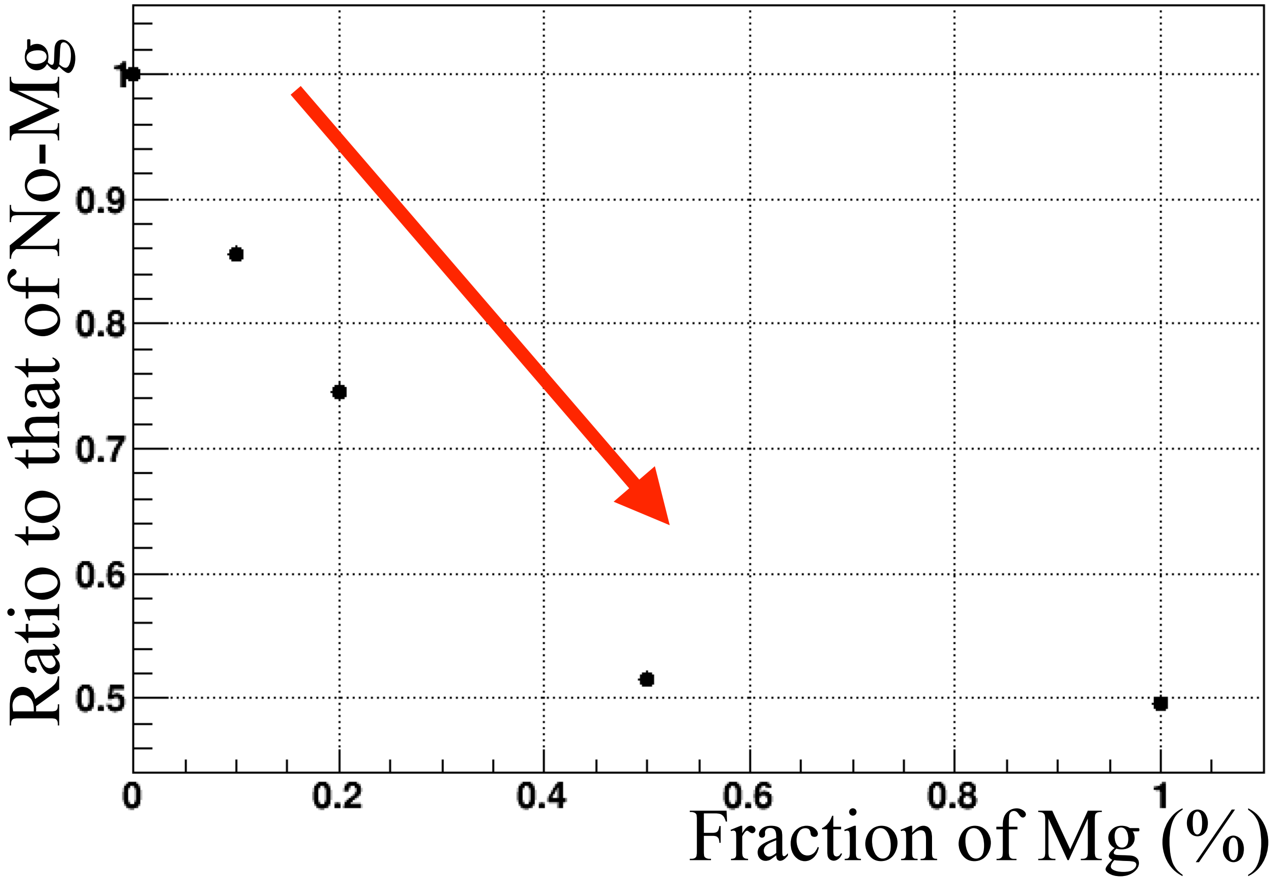


~1 mm thickness

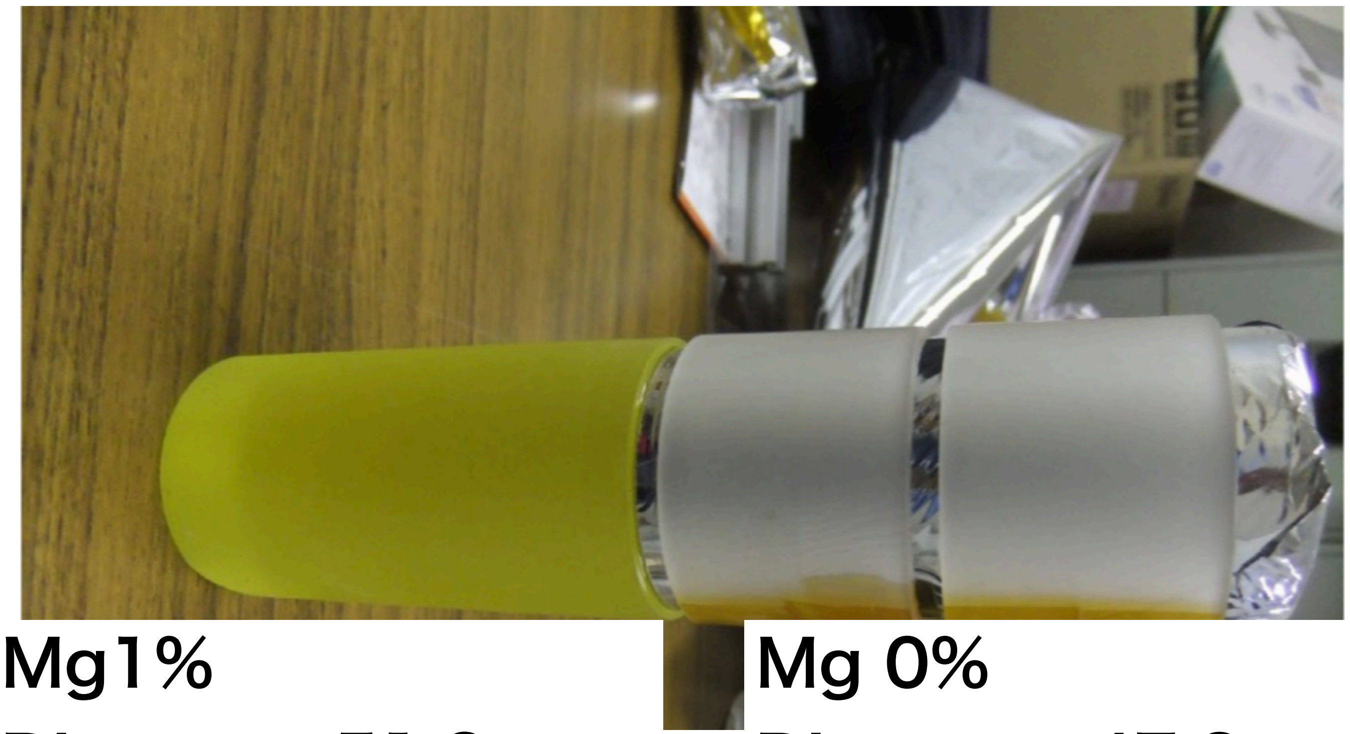
Profile



Relative light yield



Positron/neutron beam tests with a prototype module



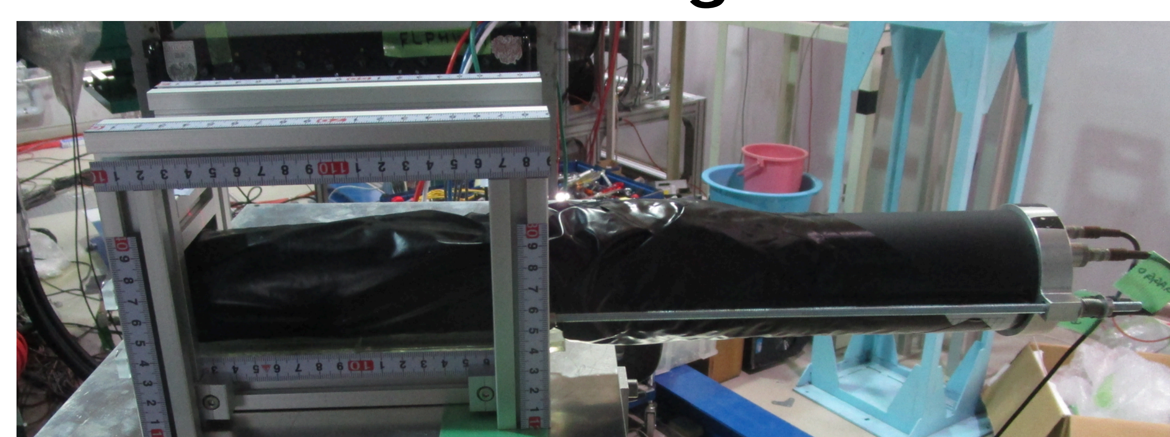
Attach a 2inch-PMT to this side

Mg1%
Diameter:51.3mm
Length:100.2mm
($6.4X_0$)

Mg 0%
Diameter:47.2mm
Length:99.9mm
($6.3X_0$)

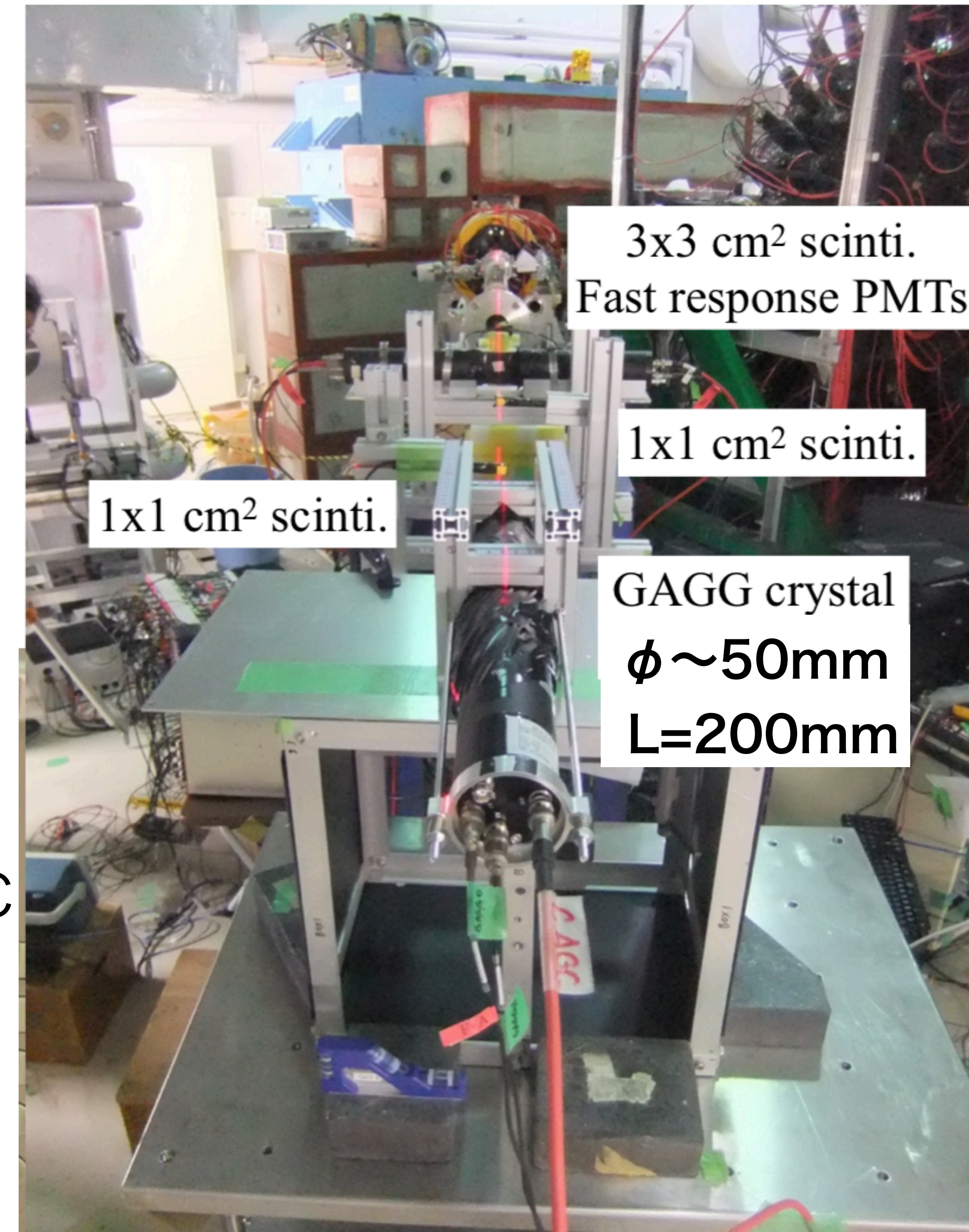
Glued two crystals with optical cement(BC-600)

After shielding the crystals and attaching the PMT

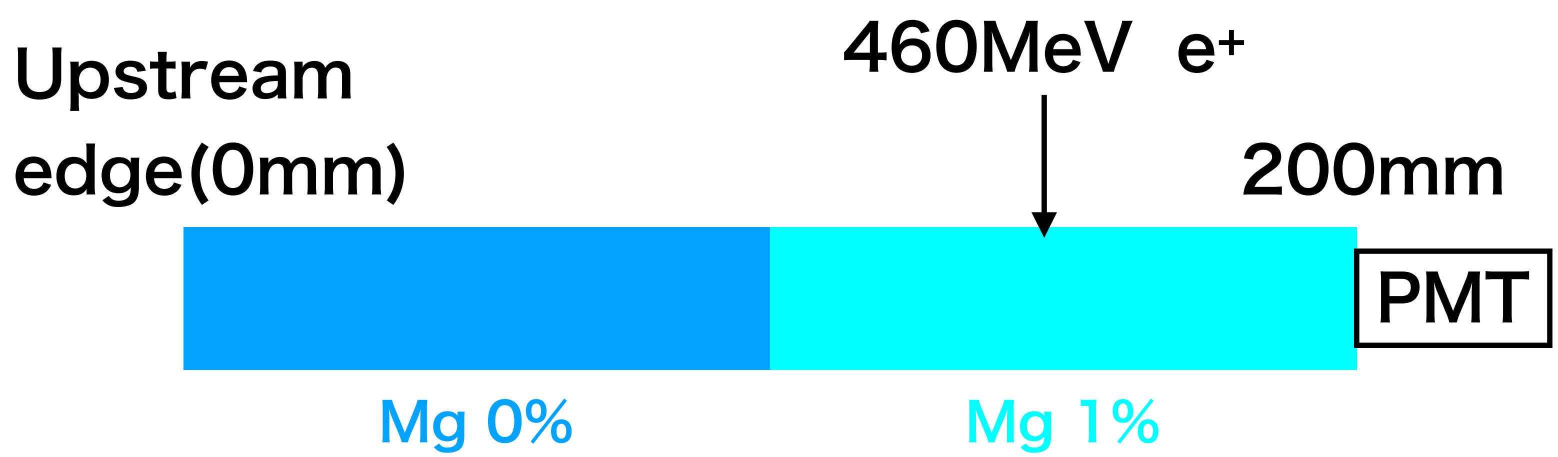


Positron beam test

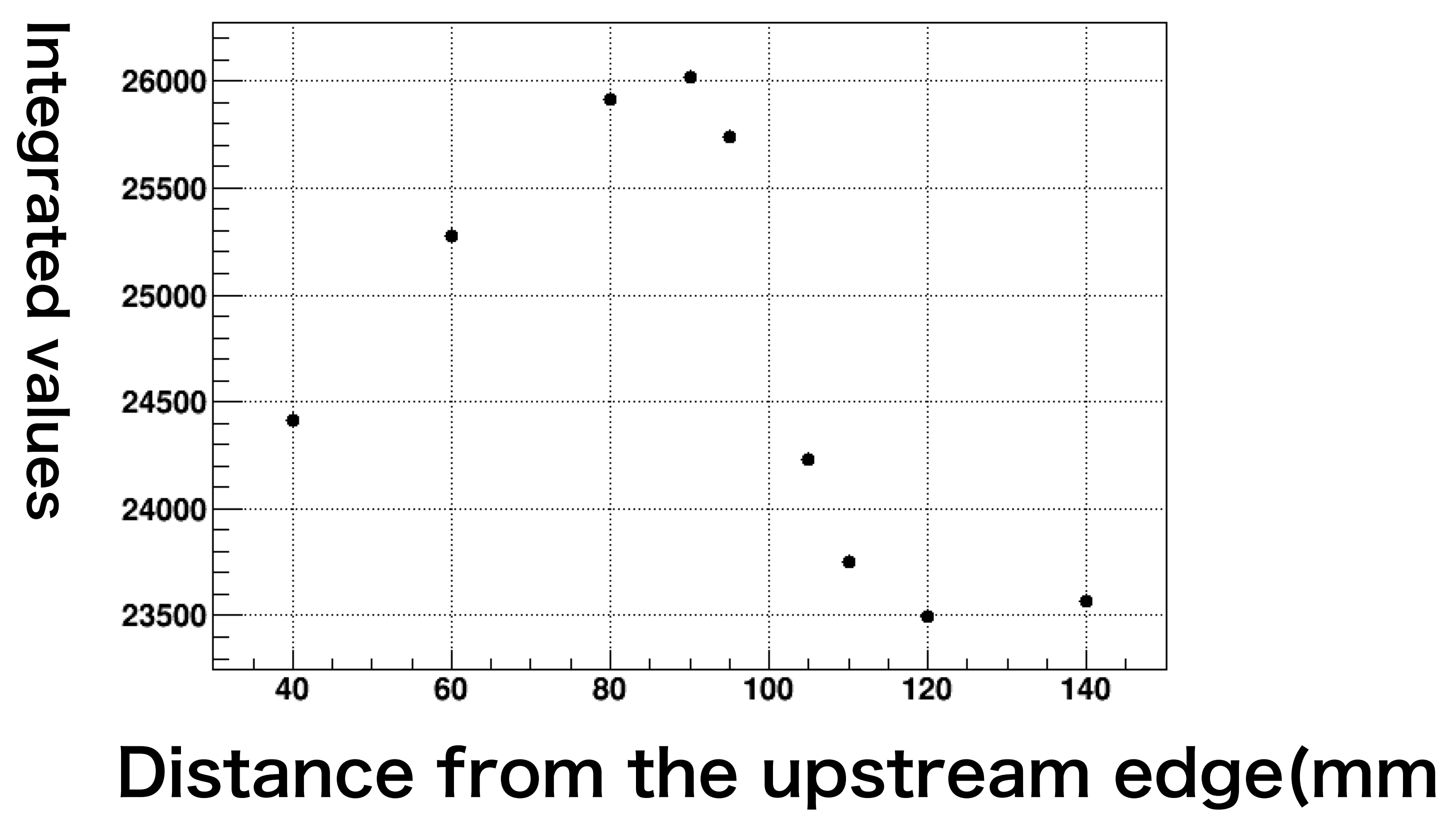
- ELPH @ Tohoku University
  - 200-800MeV positron
  - Beam size@GAGG crystal
    - ～1x1cm^2
  - Recorded waveforms of the GAGG crystal with a 500 MHz FADC
  - Irradiated the positron beam to the GAGG crystal in parallel or vertical



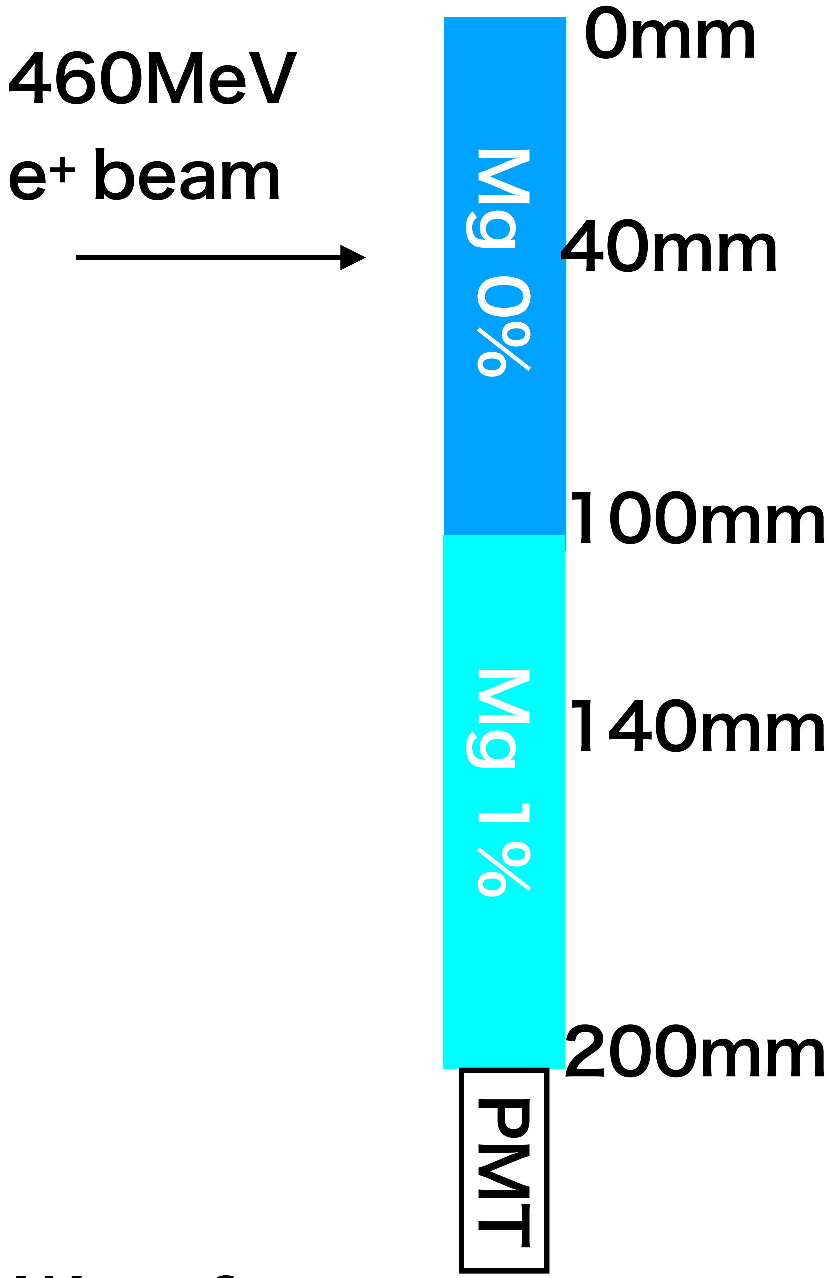
Response to longitudinal direction

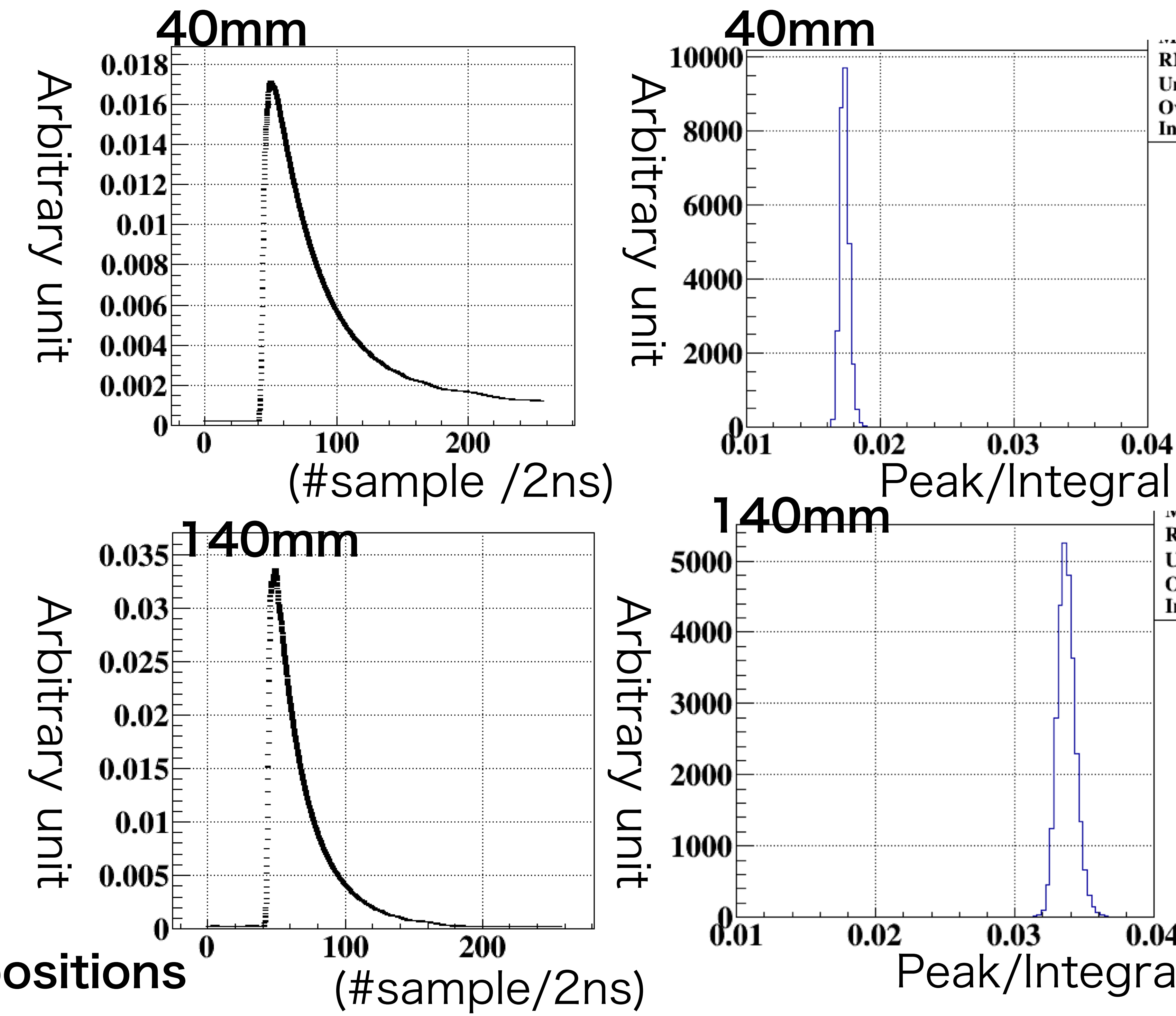


- Light Yield of GAGG Crystals
  - (Mg 0%) ～ (Mg 1%) x 2
- Deviation of light yield is within 10%.
  -> Due to loss at
  the connection surface.



Response to longitudinal direction



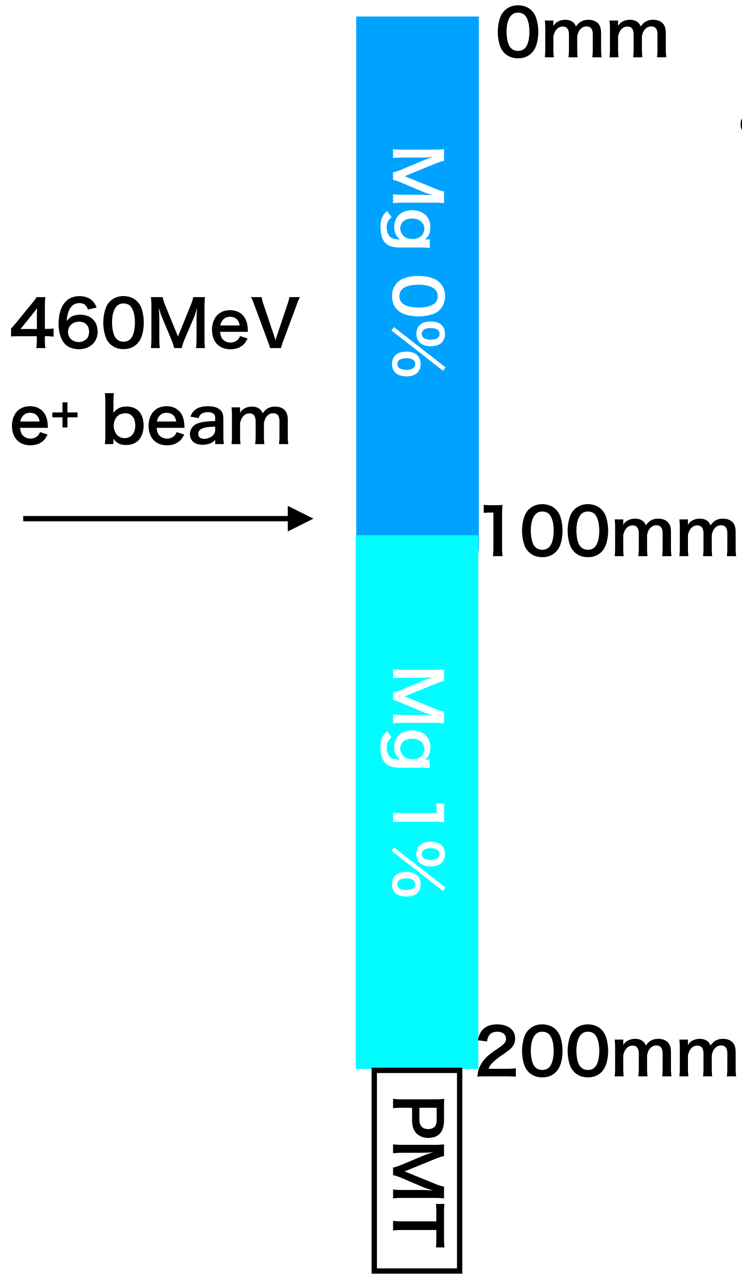


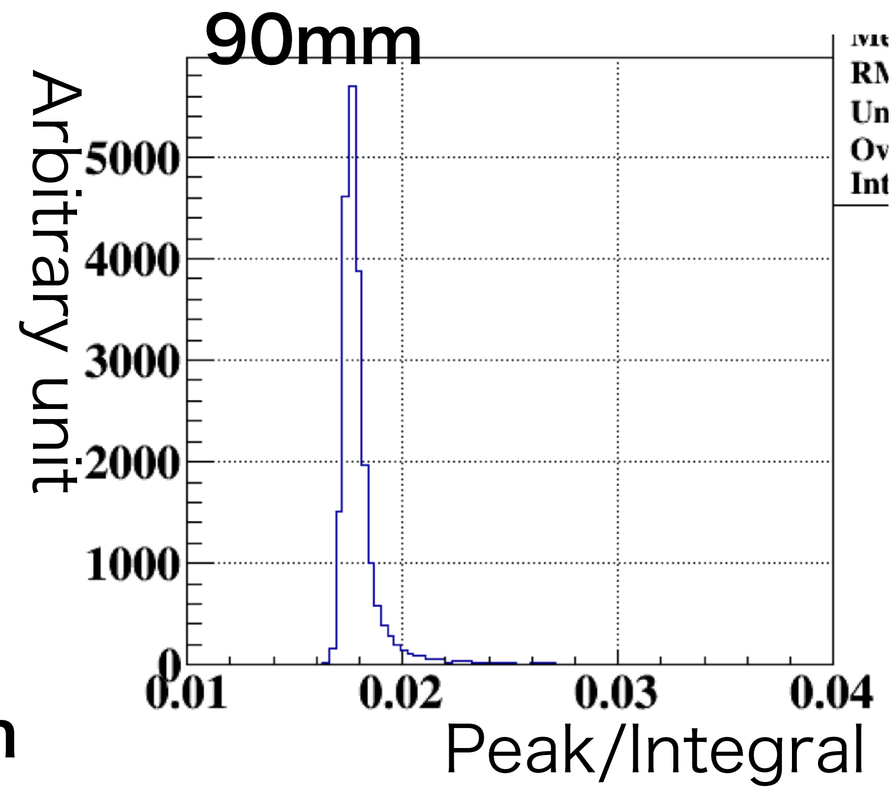
-Waveforms

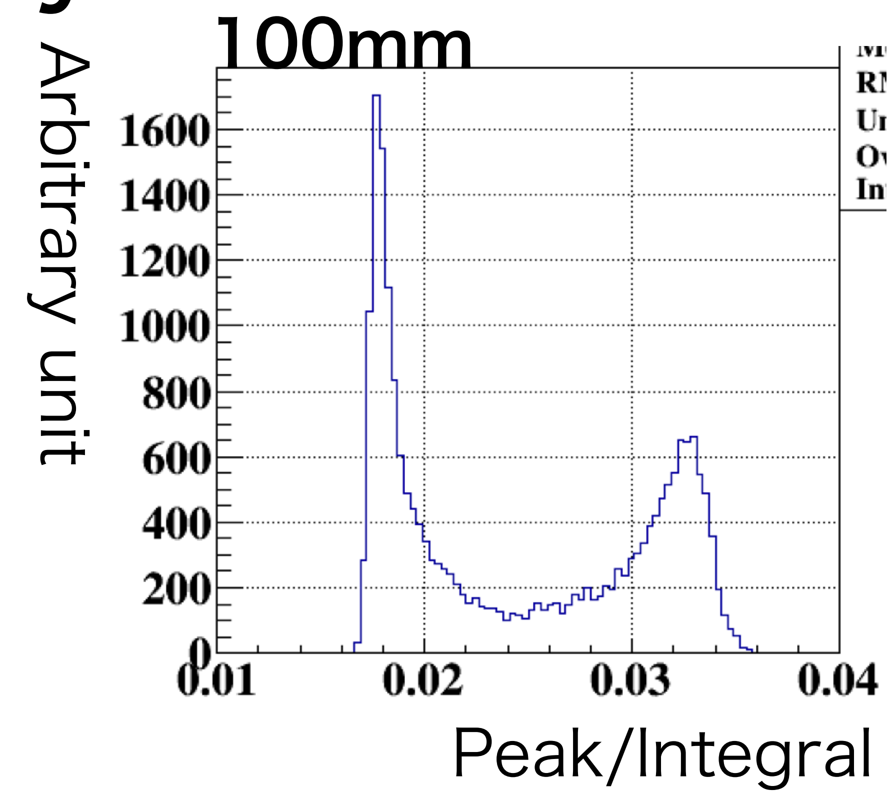
-Depend on incident beam positions

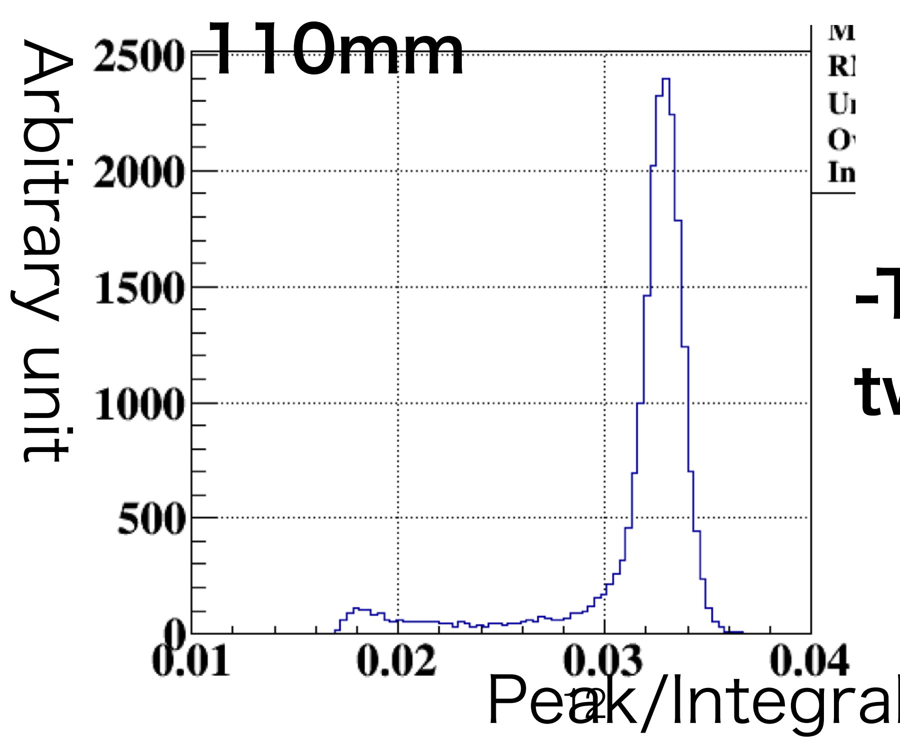
-Can be separated by Peak/Integral

Response around connection surface of two crystals





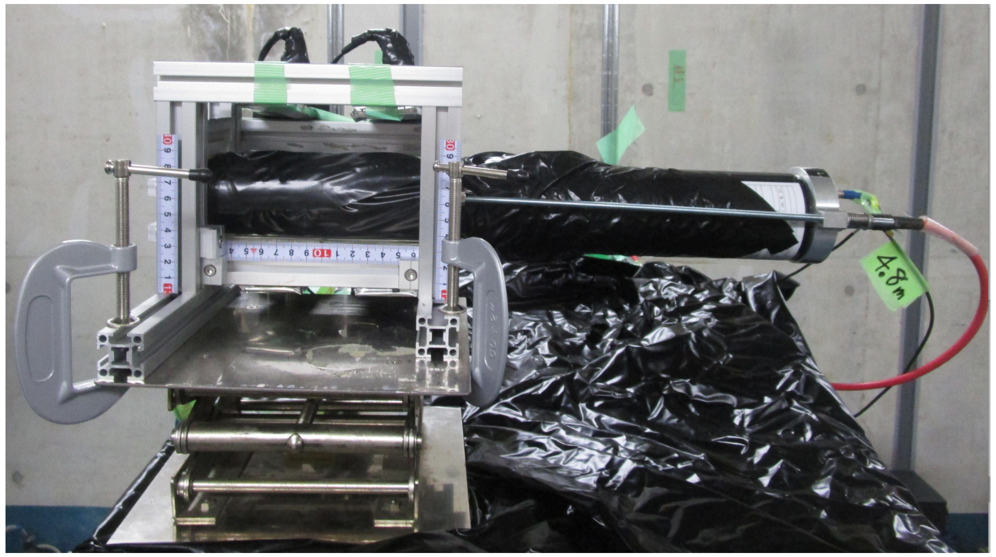


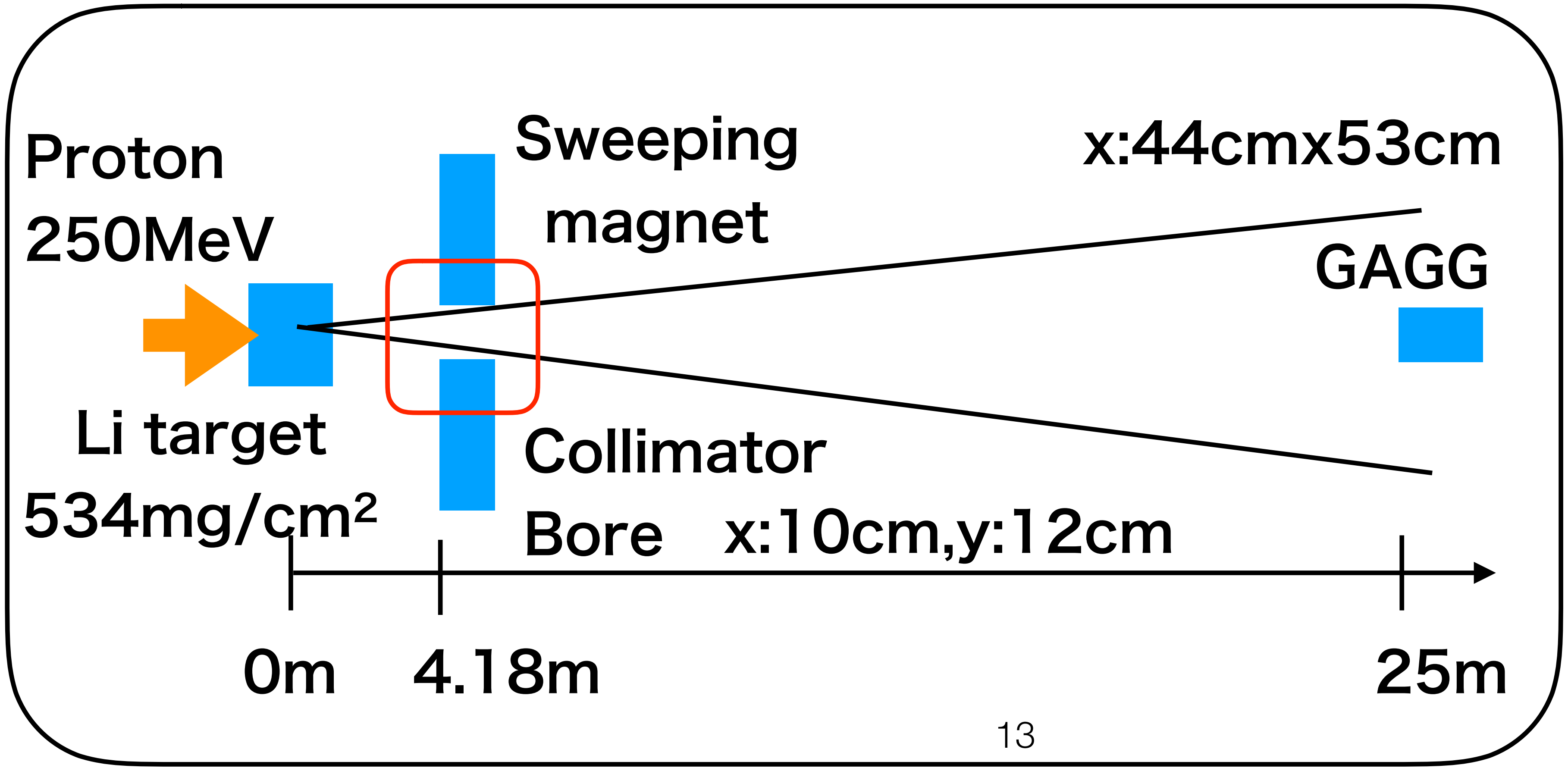


-The waveforms from two crystals seem to be mixed.

Neutron beam test

- RCNP @ Osaka University
  - Proton beam: Energy 250MeV, Mean current 85nA
    RF cycle: 68ns, Chopping: 1/9
  - $^7Li(p,n)^7Be$: Quasi mono-energetic neutron
    250MeV proton -> 250MeV neutron

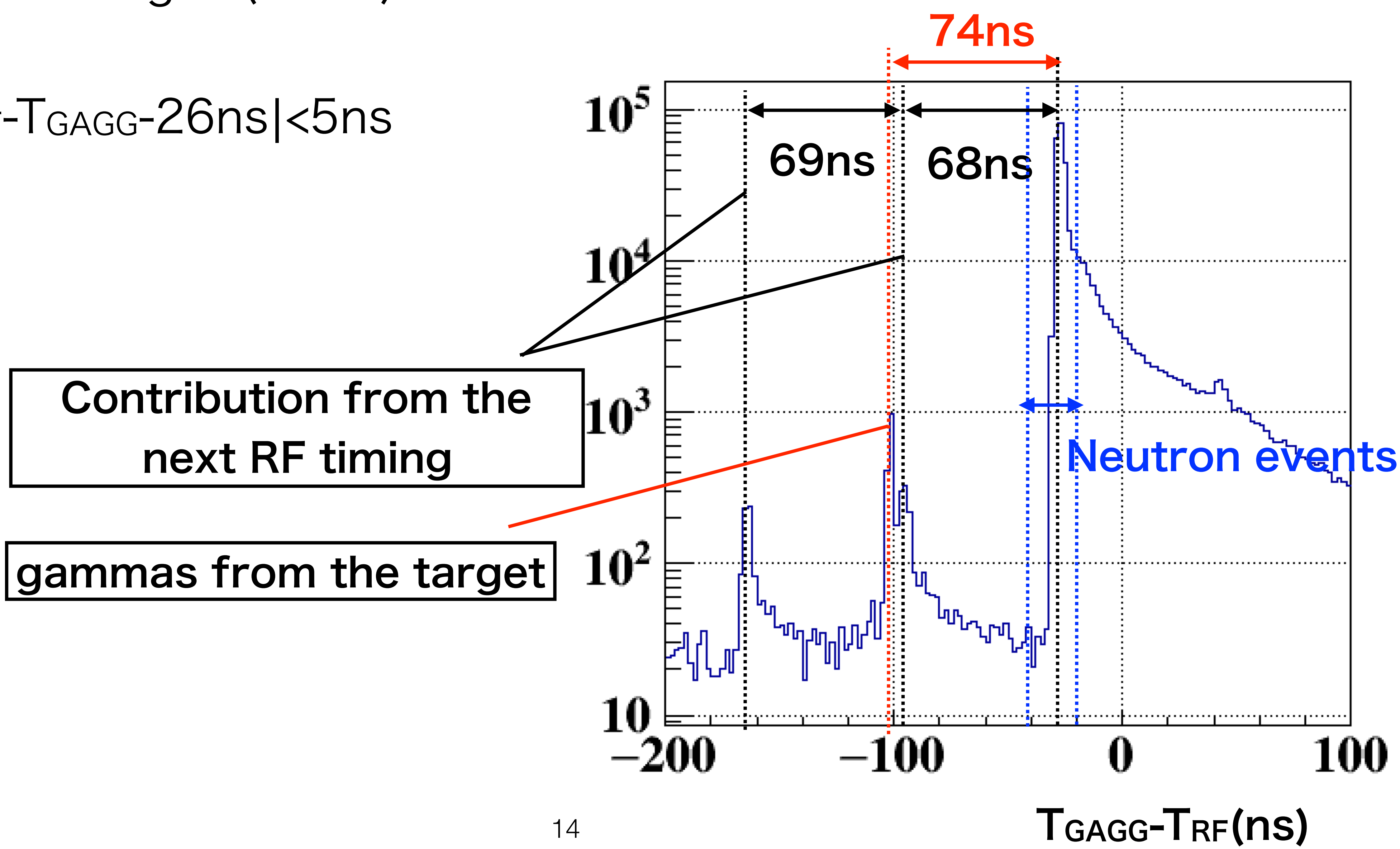




- Data taking
  -Self-triggered
  by GAGG
  -Recorded waveforms
  by a 500MHz FADC

Neutron identification

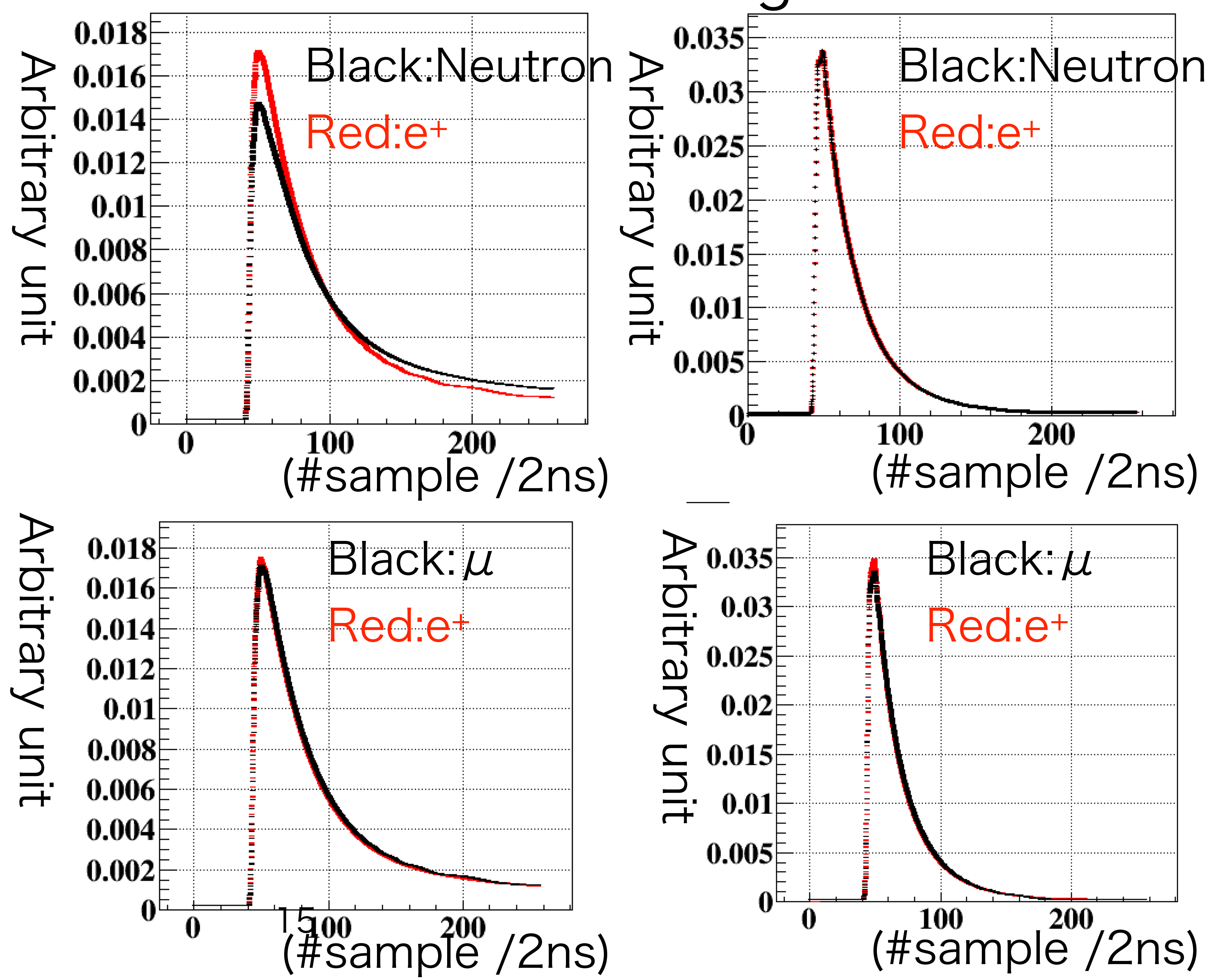
- Use time difference between RF signal(T_{RF}) and GAGG signal(T_{GAGG})
  - $|T_{RF}-T_{GAGG}-26ns|<5ns$



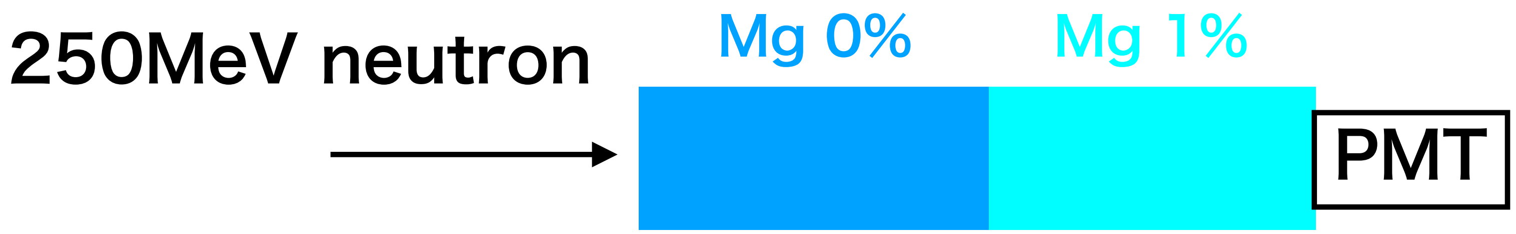
Waveforms for different particles

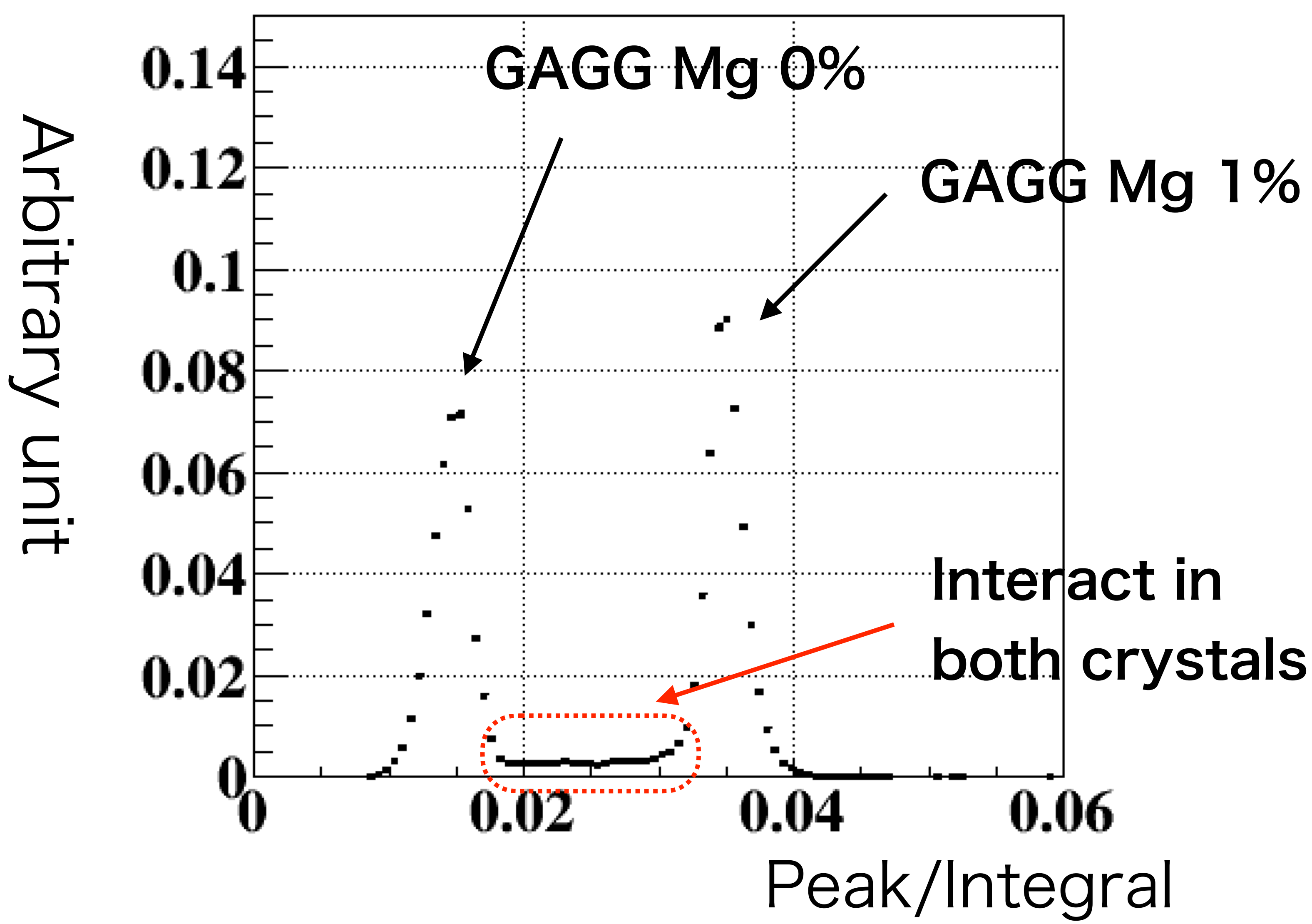
- Mg 0%
  - Neutrons have wider width
  - No difference between e^+/μ
- Mg 1%
  - No difference

Mg 0% Mg 1%

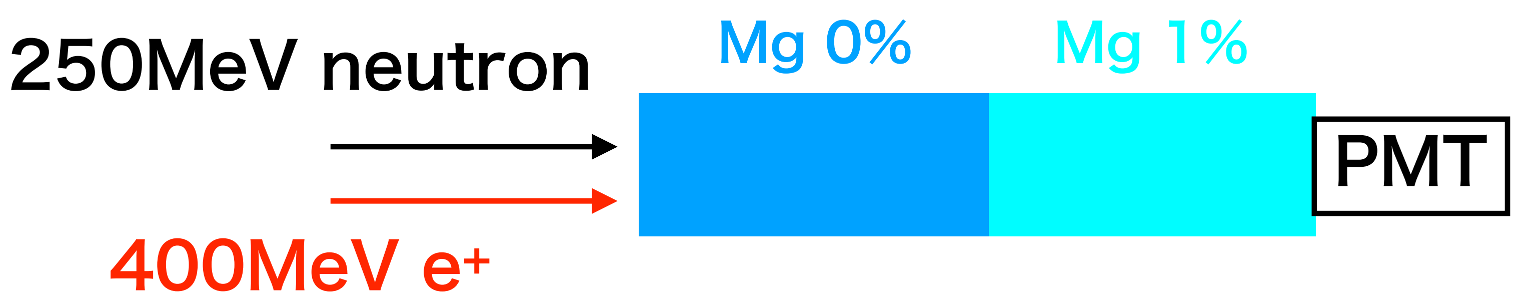


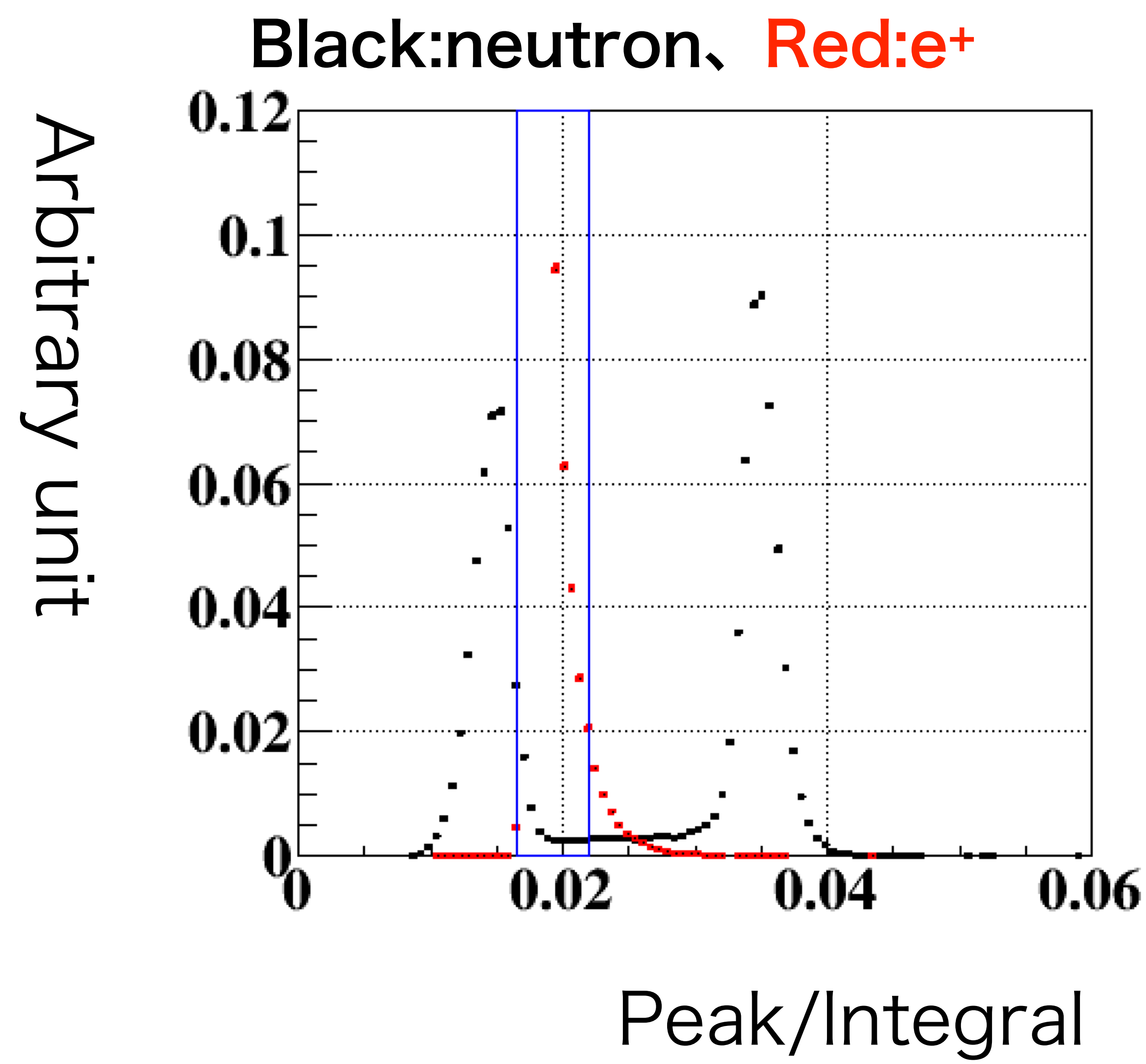
Peak/Integral for neutron events





Evaluation of neutron/gamma separation





- -Mg 0%
  - -Waveforms are different between neutrons and e^+
- -Select events inside the blue region
  - -Achieve 94% efficiency for e^+ while 95% of neutrons can be rejected.

Summary

- GAGG crystals have high density and fast response.
  ->suitable for calorimeters in high energy physics experiments

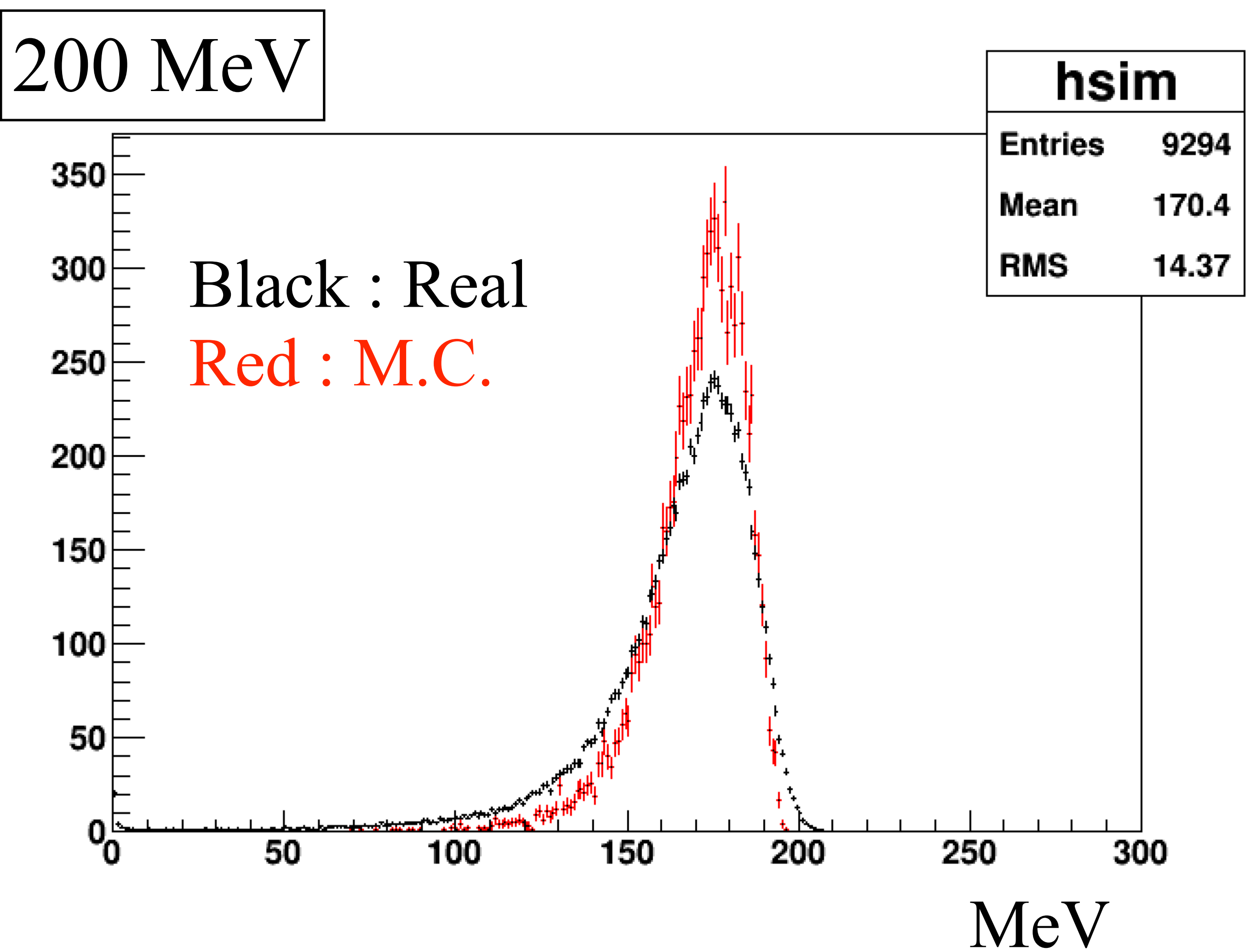
- Evaluated the capability of separation between gammas and neutrons with the prototype module consisting of two GAGG crystals with a different amount of doped materials

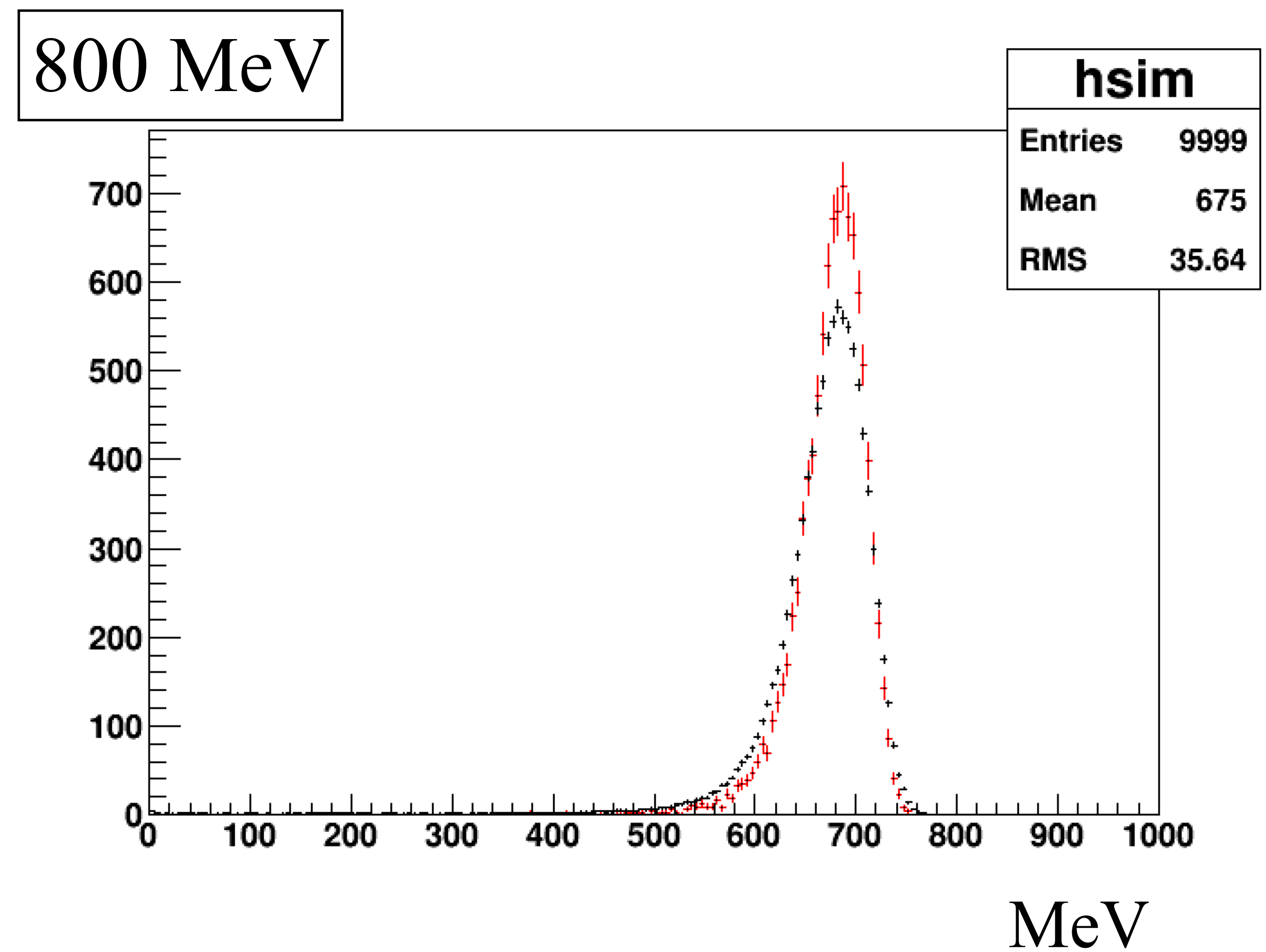
  - Found response of GAGG crystals are different between gammas and neutrons.

  - Can reject 95% of neutrons while keeping
    95% efficiency for positrons.

- Backup

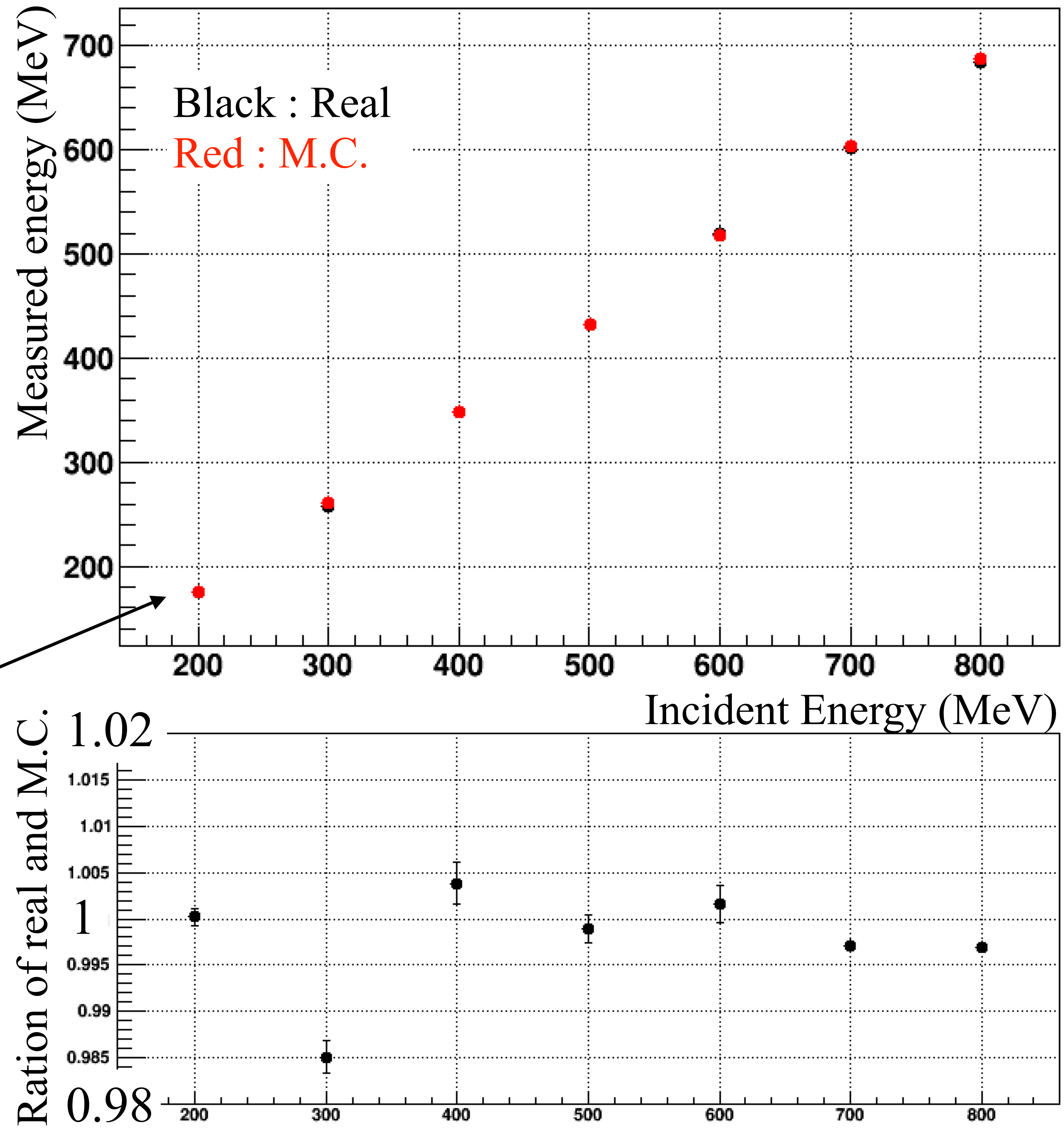
Incident in Longitudinal





Calibration was done by peak position of 200 MeV

Linearity



Calibration was determined by 200 MeV

Peak position is reproduced by M.C.