The performance study of an electro-magnetic calorimeter for the LEPS2/BGOegg experiment

Yuji Matsumura
for the LEPS2/BGOegg collaboration

Research Center for Electron Photon Science , Tohoku Univ.

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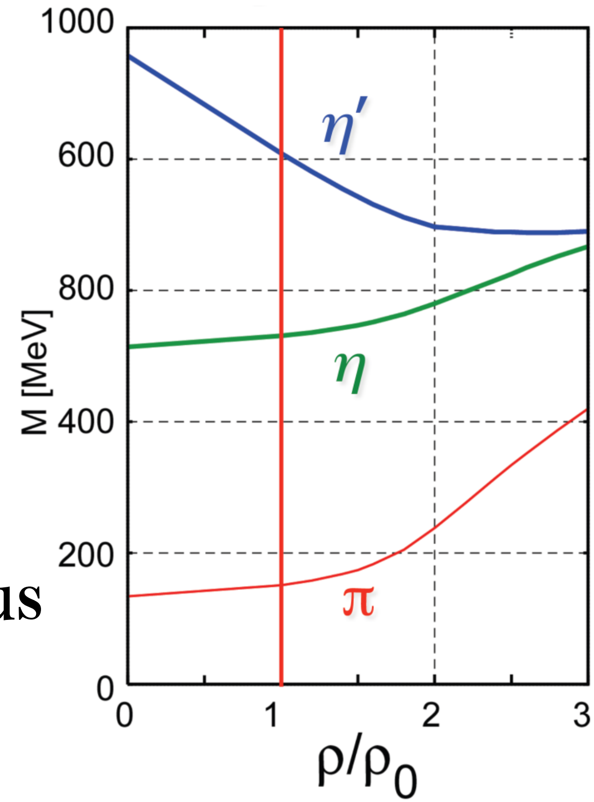
Contents

- physics motivation
- LEPS2/BGOegg experiment
- energy calibration of BGOegg
- timing calibration of BGOegg
- summary

η' mesic nucleus

- An η' meson has larger mass than other pseudo scalar mesons due to $U_A(1)$ anomaly.
  → The mass of η' meson is expected to decrease at the nuclear density.

- The decrease of the mass will cause a strong attractive potential in a nucleus.
- Absorption in a nucleus is estimated to be small.
  → Bound state of an η' and a nucleus is expected.
  : η' mesic nucleus

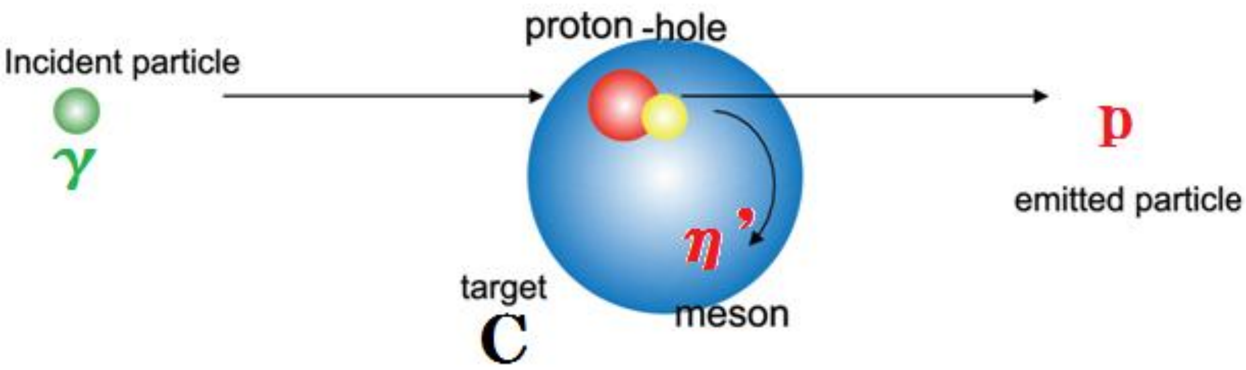


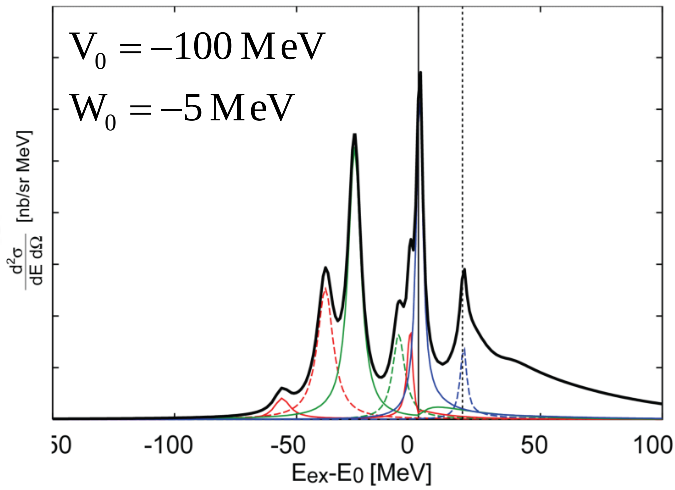
(based on NJL model + KMT interaction)

Nagahiro et al., PRC74, 045203 ,2006

Search for an η' mesic nucleus

- η' mesic nuclei are searched for in the missing energy spectrum of forward going protons in $C(\gamma, p)\eta' X$ reaction.





Nagahiro et al., PRC74, 045203 ,2006

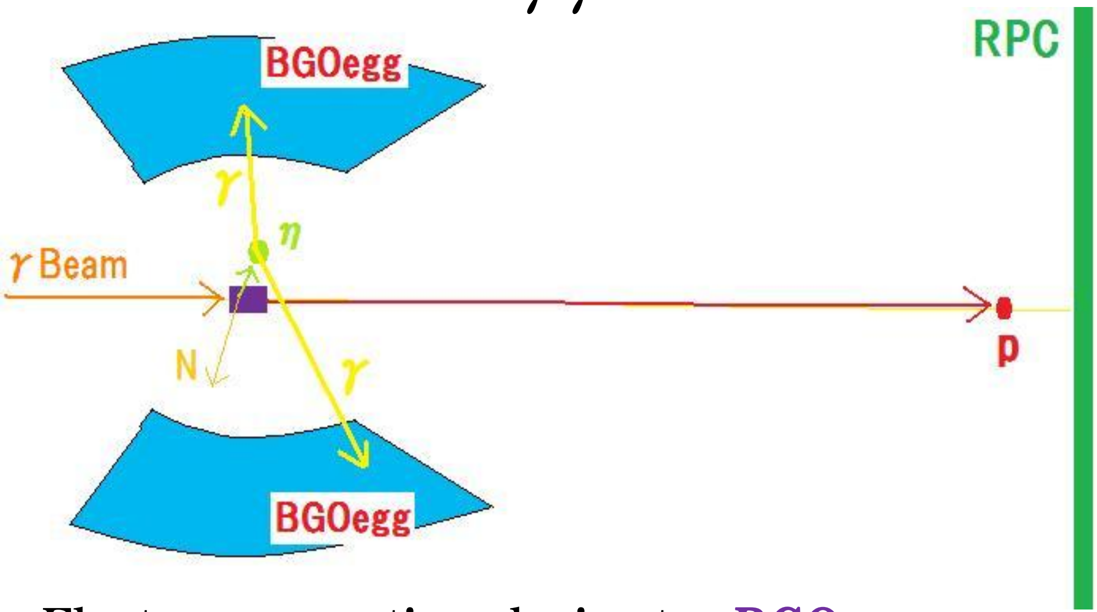
- There are a lot of background events with only proton detection. (multi π production etc.)

  $S/N \approx 0.005$

  → Tag of final state to reduce background.

Search for an η' mesic nucleus

- Signal events are tagged to reduce background.
  - tagged process
    : $\eta' N \to \eta N$, $\eta \to \gamma\gamma$



- TOF-RPCs
  - forward proton detection
  - 12.5 m flight length
  - forward 6.8° coverage
  - ～80 ps time resolution

- missing energy resolution
  ～20 MeV @ $E_\gamma = 2$ GeV

- Electro-magnetic calorimeter **BGOegg**
  : γ (and a nucleon) detection in final state

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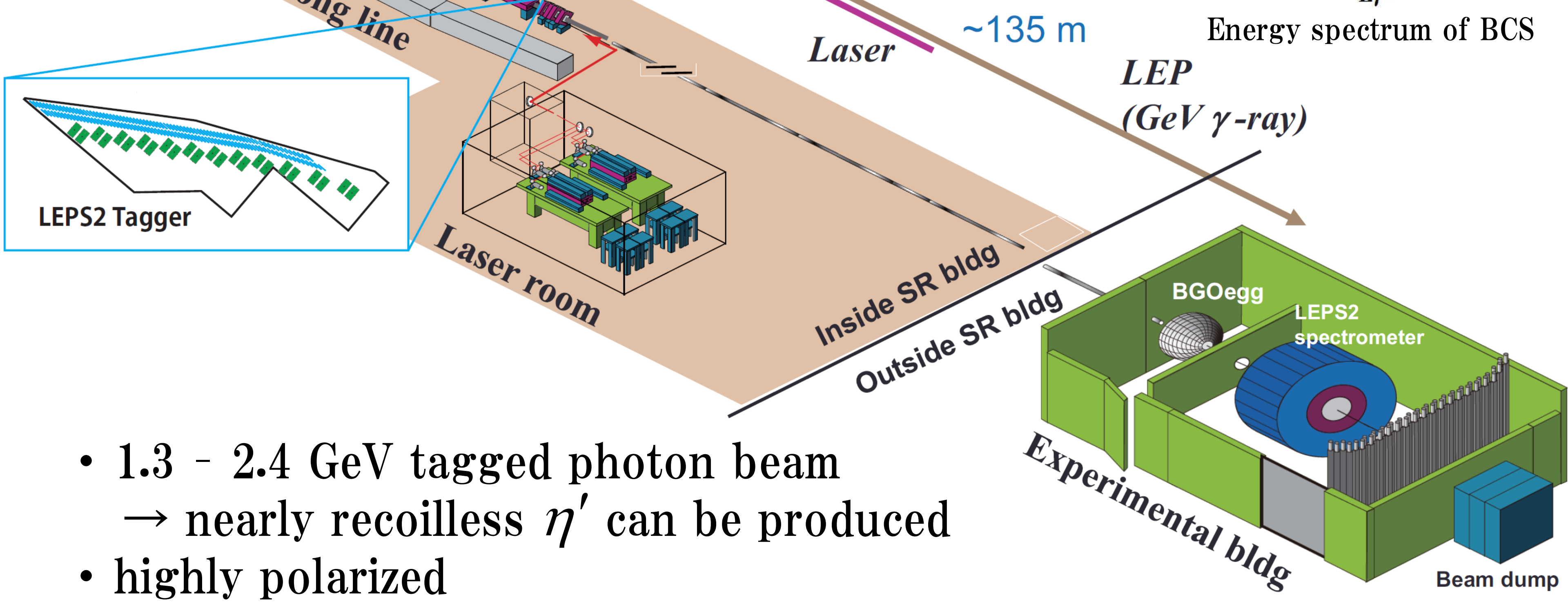
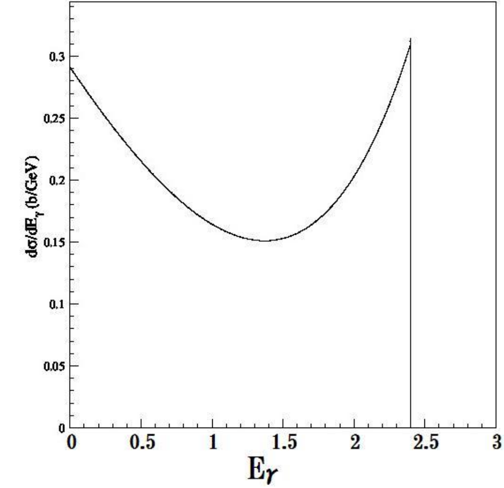
This talk：calibration status and performance of BGOegg

SPring-8/LEPS2 beamline

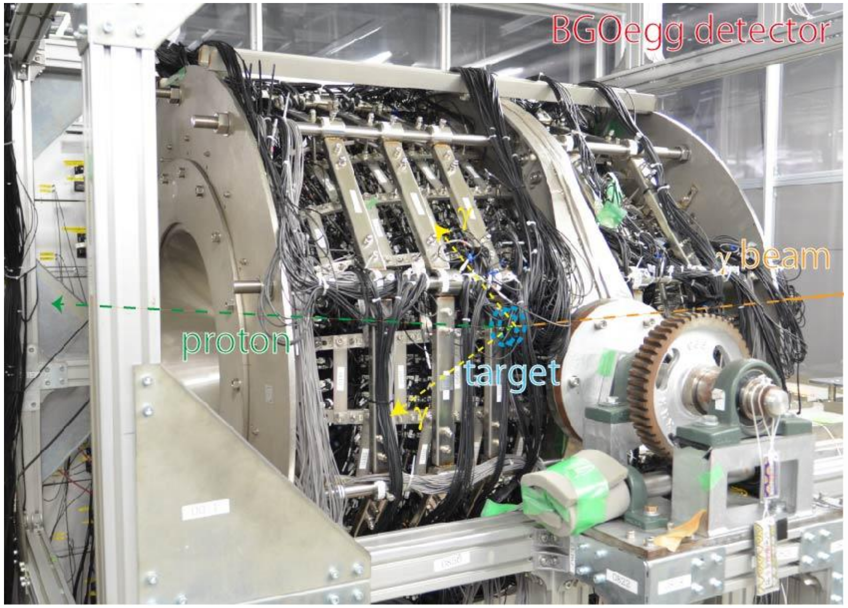


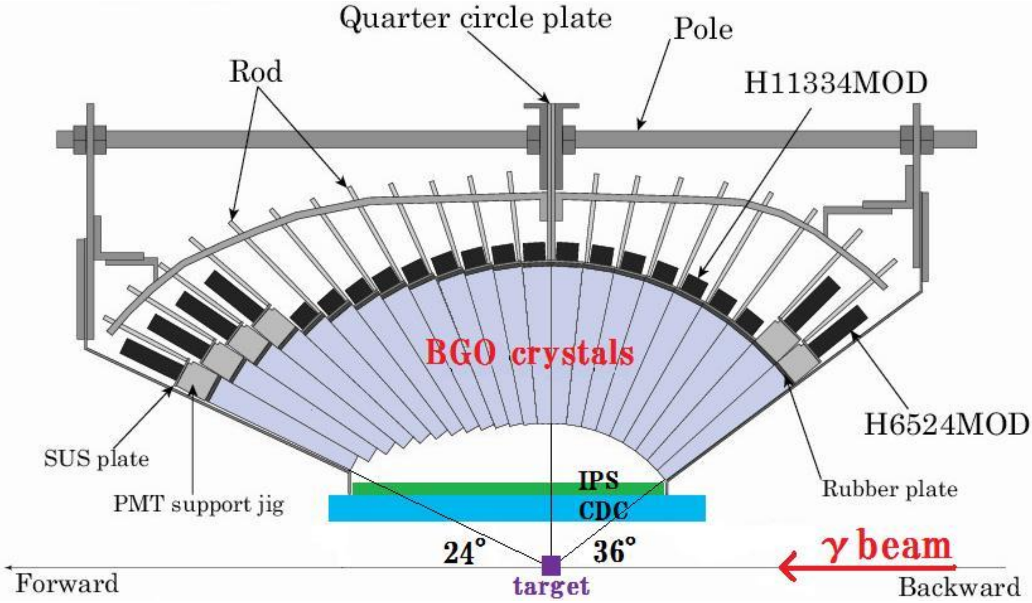


Energy spectrum of BCS

- 1.3 - 2.4 GeV tagged photon beam
  → nearly recoilless η' can be produced
- highly polarized
- ~2 Mcps beam intensity

BGOegg calorimeter





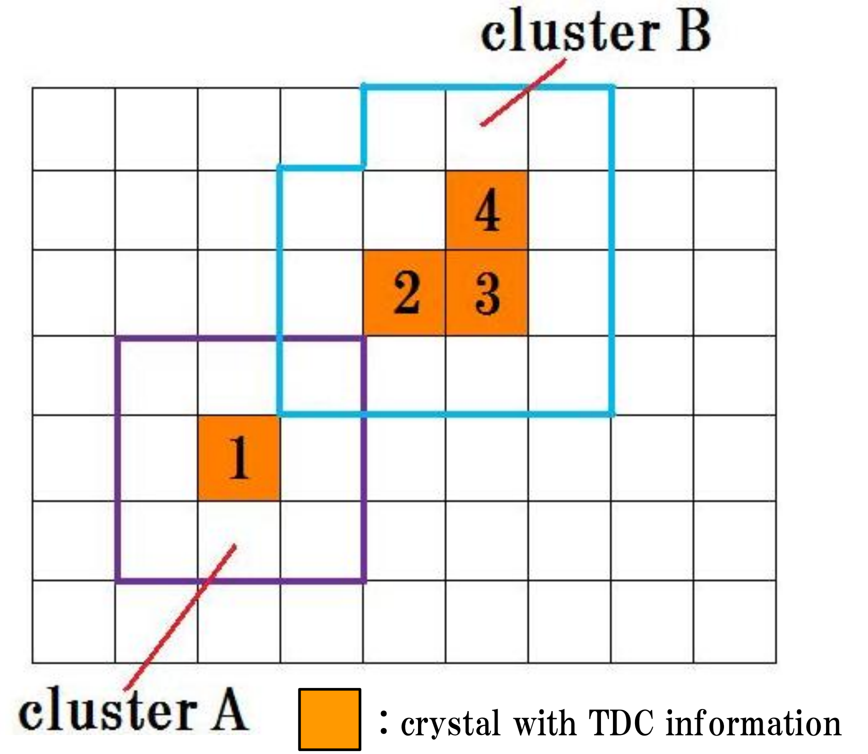
- 1320 BGO crystals
- polar angle : 24° ~ 144°
  azimutial angle : 360°
- homogenious
- no housing material
- energy resolution : 1.3% @ 1GeV
- position resolution : 3.1mm @ 1GeV

Energy measurement

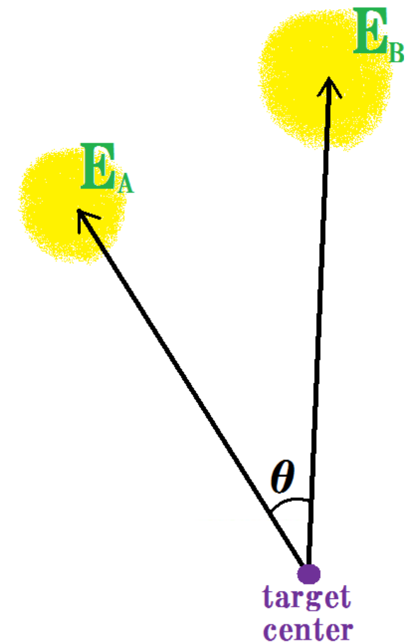
- **energy deposit for a crystal**

$$E_i = \alpha_i (A_i - A_{0i})$$

α_i : gain factor
A_i : ADC value   for crystal i
A_{0i} : pedestal value



- **clustering**
  - Crystals in which photon energy was deposited is put together into a cluster.
  - Sum up energy deposit of all crystals in a cluster to reconstruct the photon energy.



- **2γ invariant mass**

$$M_{\gamma\gamma} = \sqrt{2E_A E_B (1 - \cos\theta)}$$

Energy calibration

- **decide gain factor α by successive approximation**

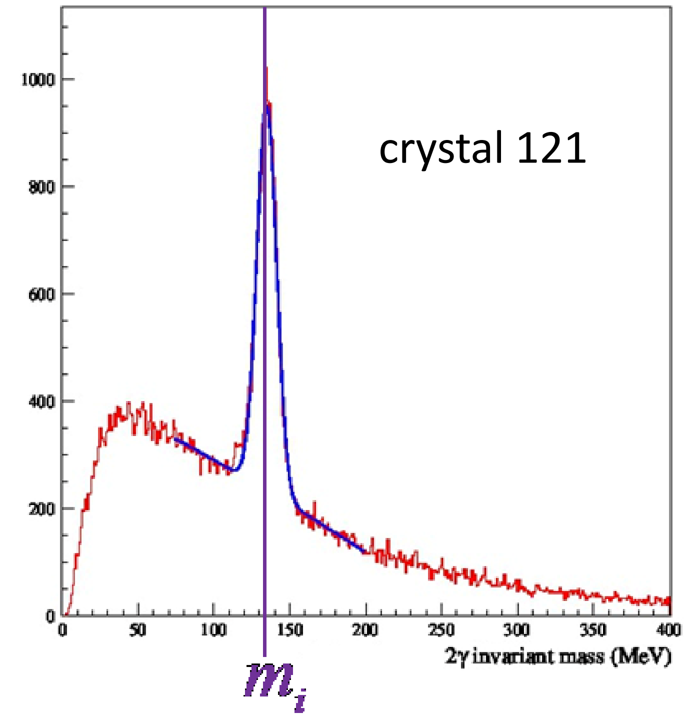
1：get mean values of π^0 peak m_i in $\gamma\gamma$ invariant mass distribution for each crystal ($i = 1 \sim 1320$)

2：adjust gain factors

$$\alpha_i \rightarrow \alpha_i \left(\frac{m_\pi}{m_i} \right)$$

($m_\pi = 134.977$ MeV: π^0 mass)

3：reconstruct $\gamma\gamma$ invariant mass distribution using new gain factors



- **iterate 1 ～ 3 until converged**

Check convergence

$$\chi^2 = \sum_{i=1}^{1320} \left(\frac{m_i - m_\pi}{\delta m_i} \right)^2$$

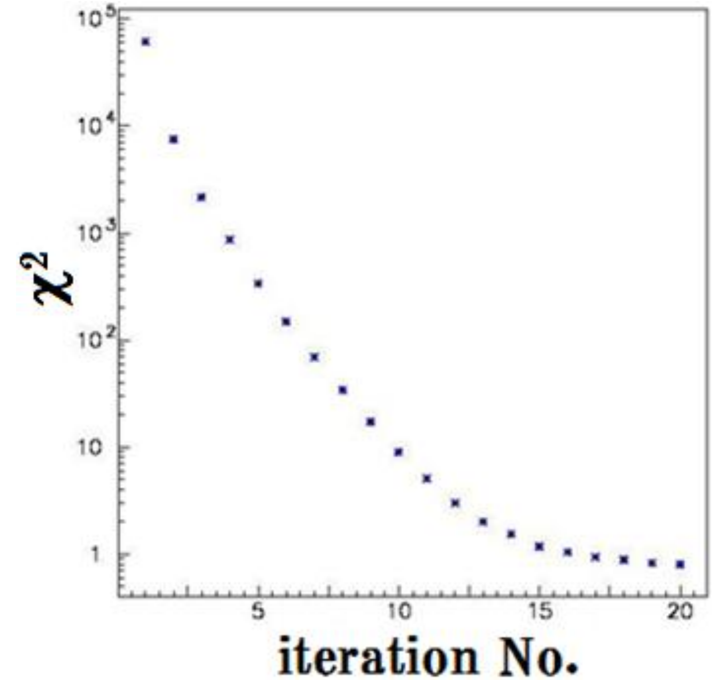
m_i ： mean value of π^0 peak

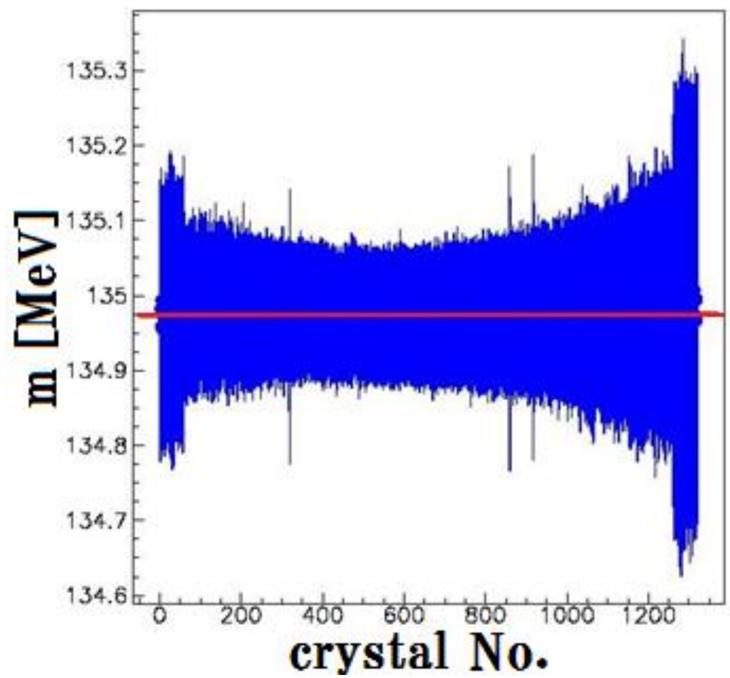
m_π ： π^0 mass

δm_i ： error of m_i

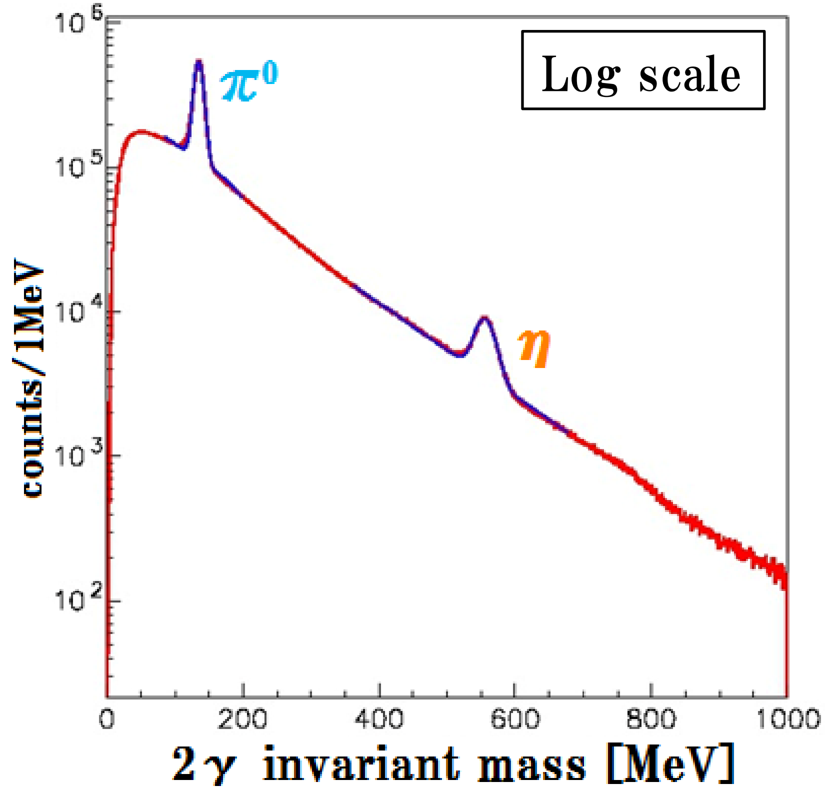
for crystal i

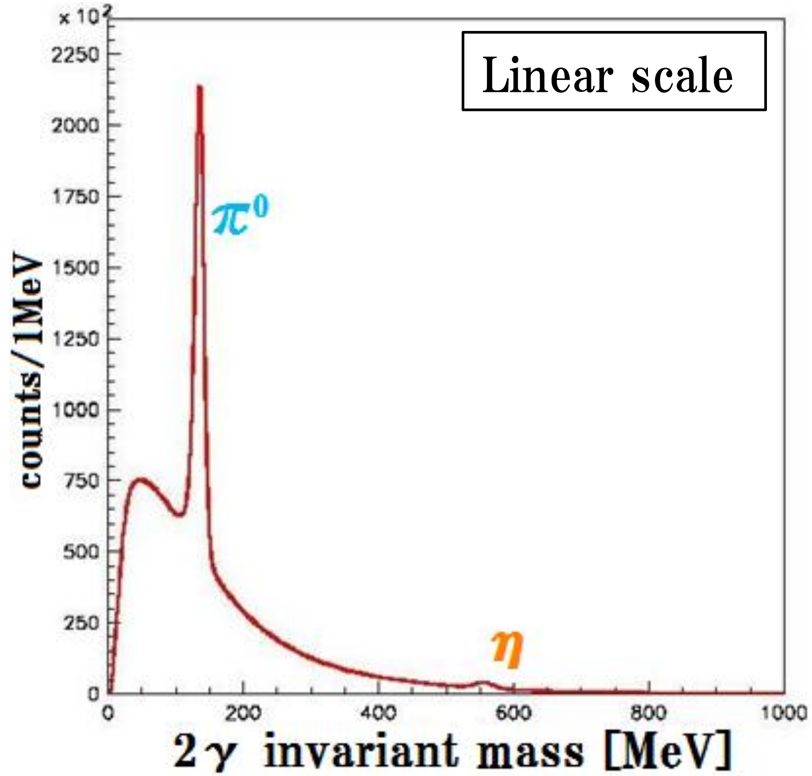
- After convergence , the mean values of π^0 peaks are within $m_\pi \pm 0.05\,\text{MeV}$ for all crystals





2γ invariant mass distribution





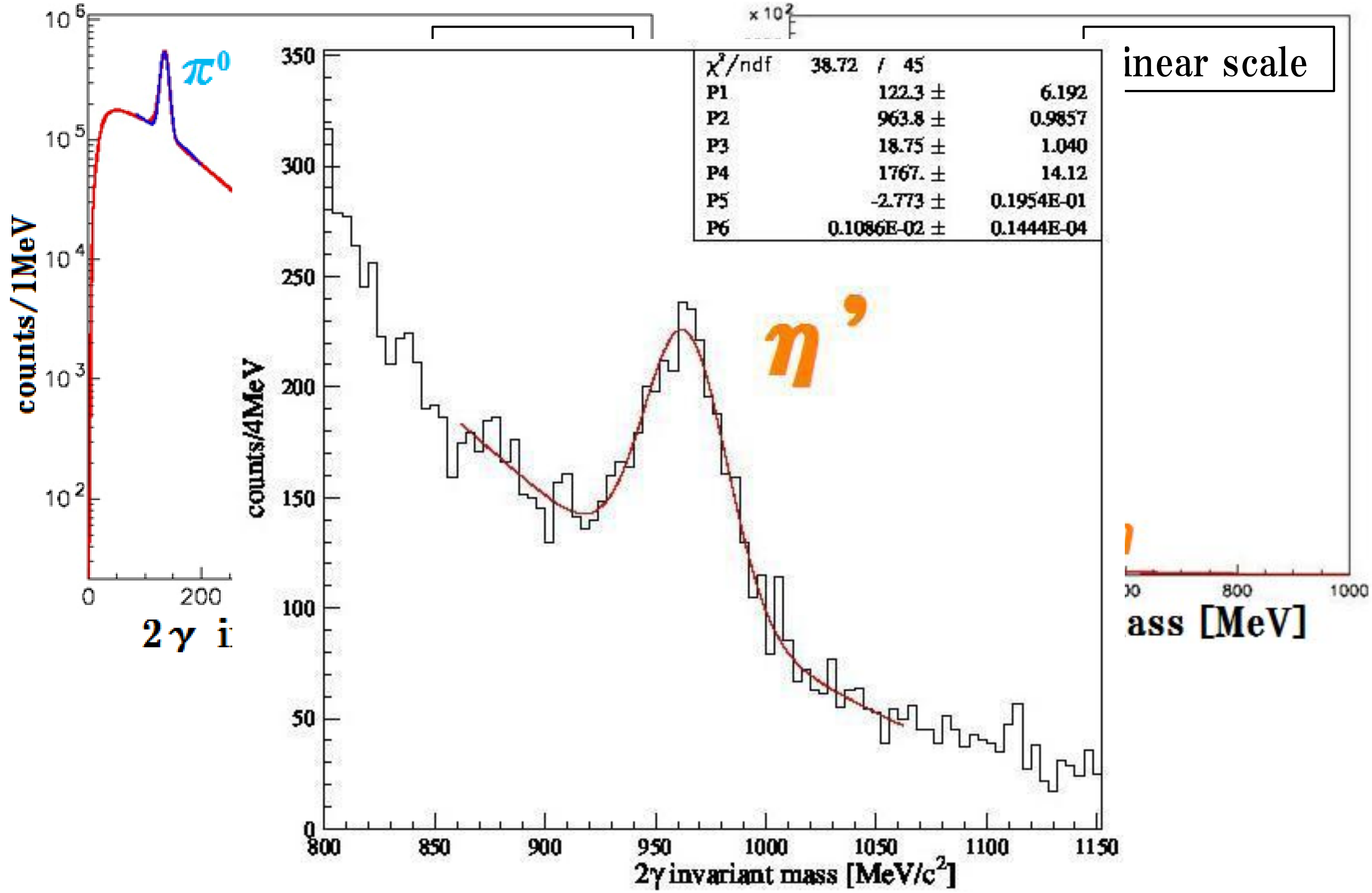
- π^0 peak : mean : 134.98 MeV
  σ : 6.70 MeV
- η peak : mean : 555.98 MeV
  σ : 14.40 MeV

$$\begin{cases} m_\pi = 134.98\,\mathrm{MeV} \\ m_\eta = 547.86\,\mathrm{MeV} \end{cases}$$

(PDG mass)

→ In search for an η' mesic nucleus , ~99% of background events of multi-pi production can be eliminated by tagging η.

2γ invariant mass distribution



- η' peak : mean : 963.8 MeV

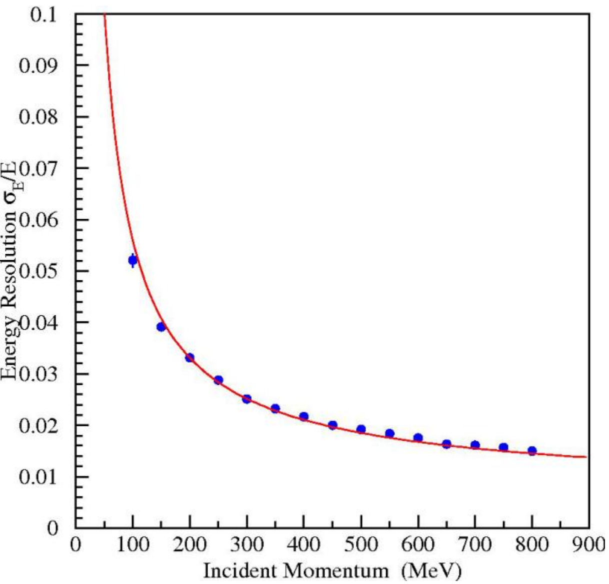
  σ : 18.8 MeV

Comparison of resolution

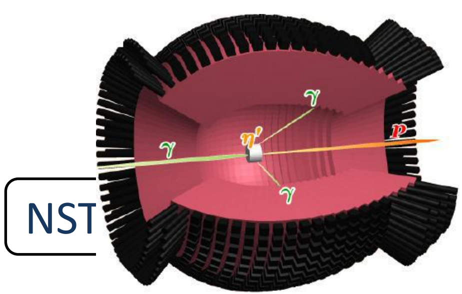
• γ energy resolution

BGOegg

- 1320 BGO crystals
- 24°～ 144°

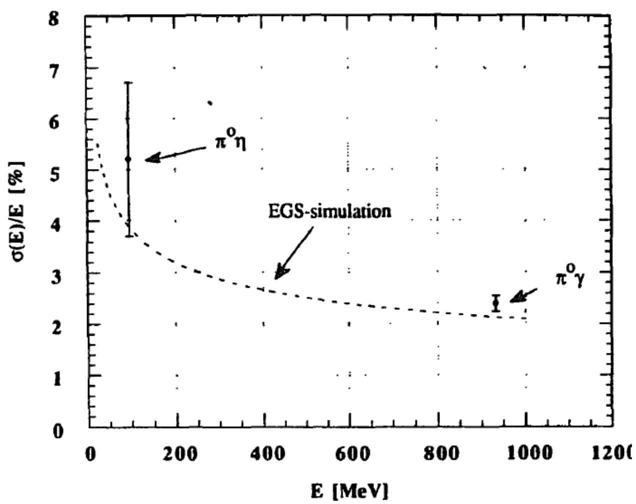


1.3 % @ 1 GeV



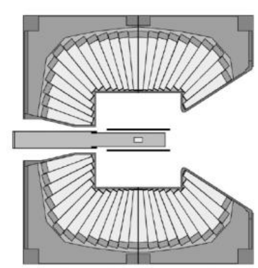
Crystal Barrel

- 1230 CsI(Tl) crystals
- 30°～168°



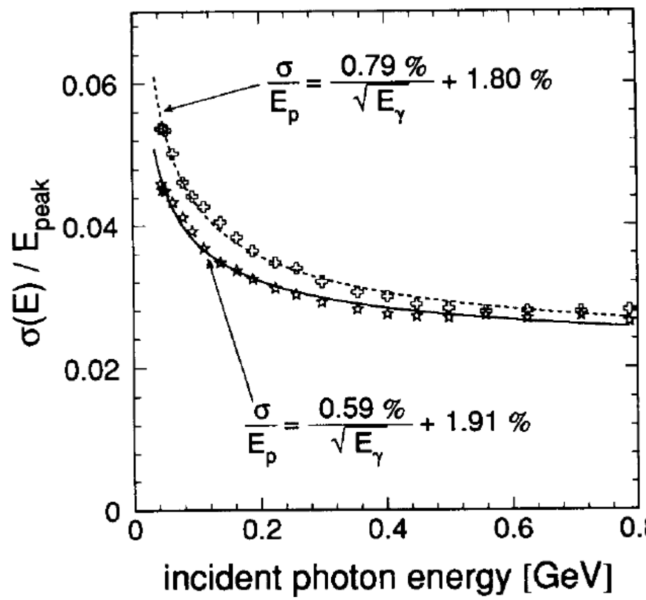
(E.Aker et al., NIMA , 321(1992), 69)

2.5 % @ 1 GeV



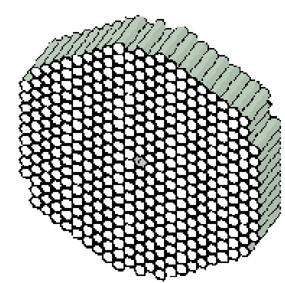
TAPS

- 528 BaF crystals
- 4.5°～30°



(A.R. Gabler et al., NIMA , 346(1994), 168)

2.5 % @ 1 GeV



Comparison of resolution

- π^0 mass resolution
  ($\gamma\gamma$ invariant mass , overall)

BGOegg

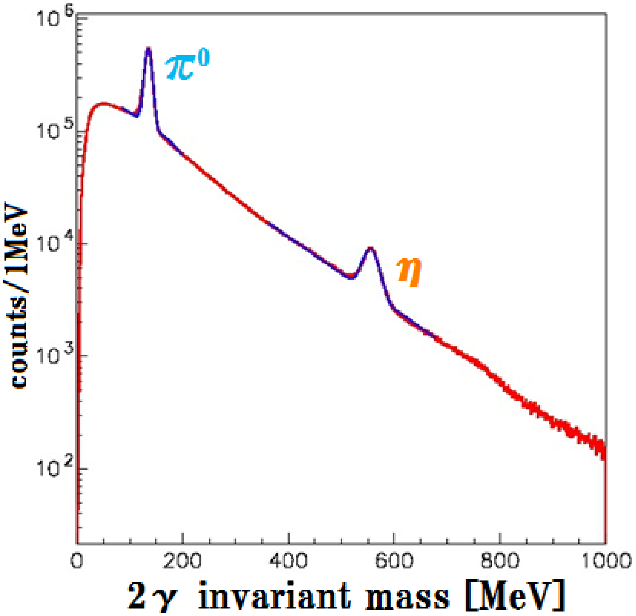
- 1320 BGO crystals
- 24° ～ 144°

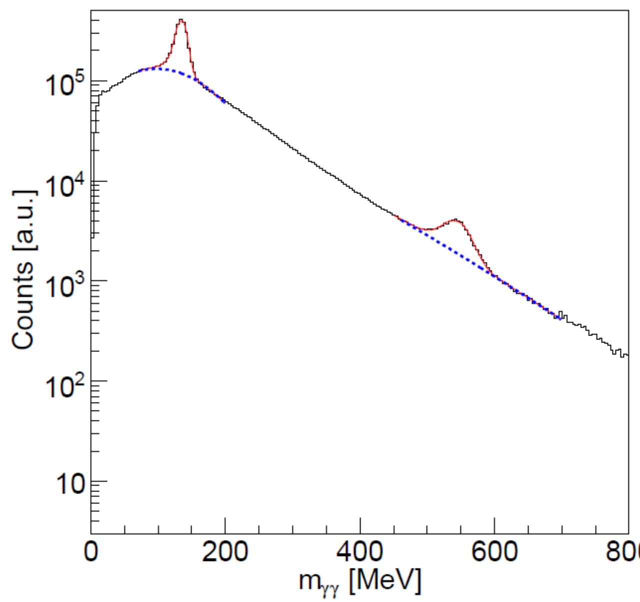
Crystal Barrel

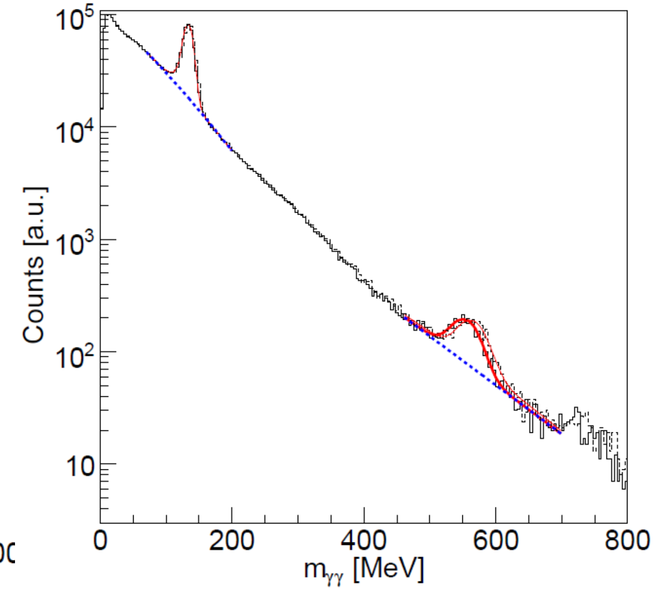
- 1230 CsI(Tl) crystals
- 30° ～ 168°

TAPS

- 528 BaF crystals
- 4.5° ～ 30°





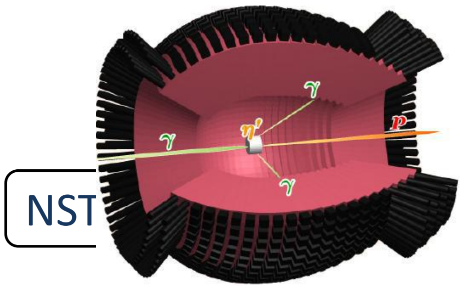


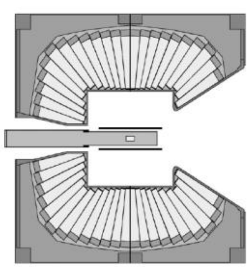
(I.Jaegle, Ph.D.thesis, Basel Univ.(2009))

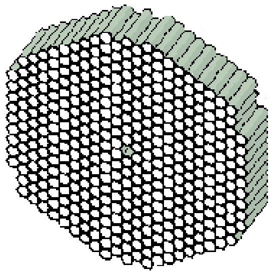
σ_π = 6.7 MeV

σ_π = 10 MeV

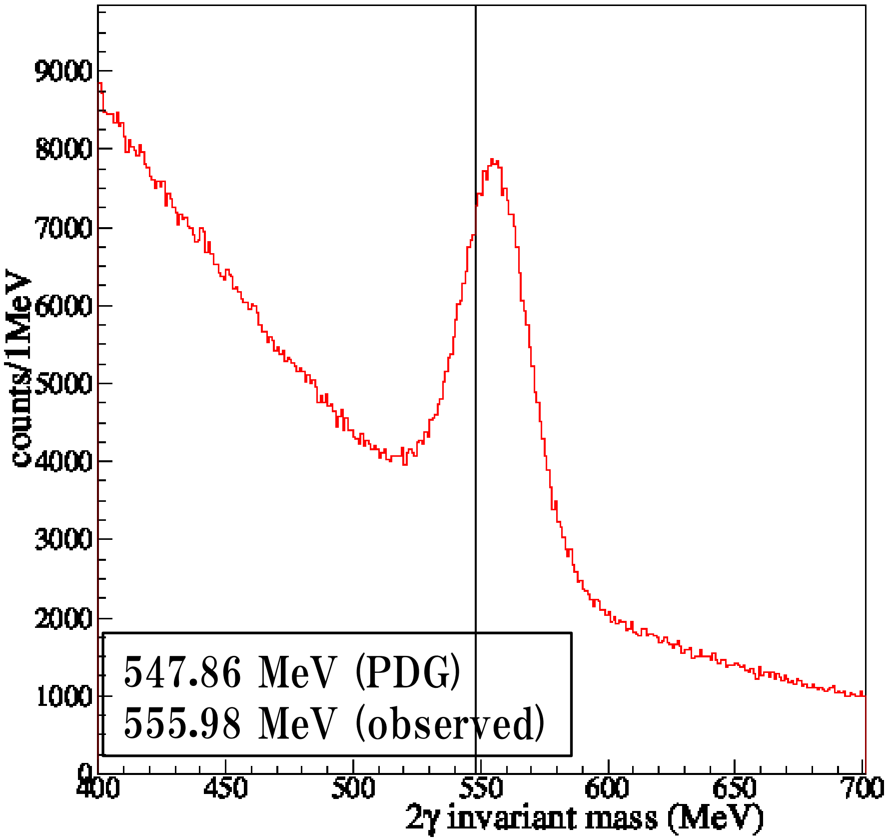
σ_π = 8 MeV

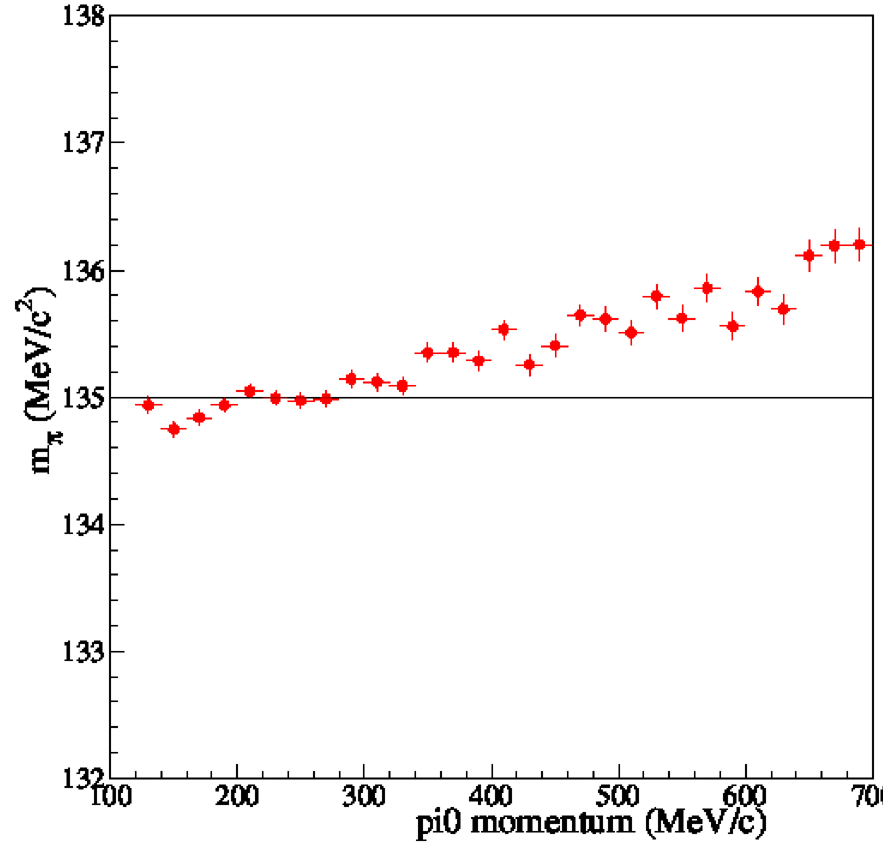






π^0, η peak position



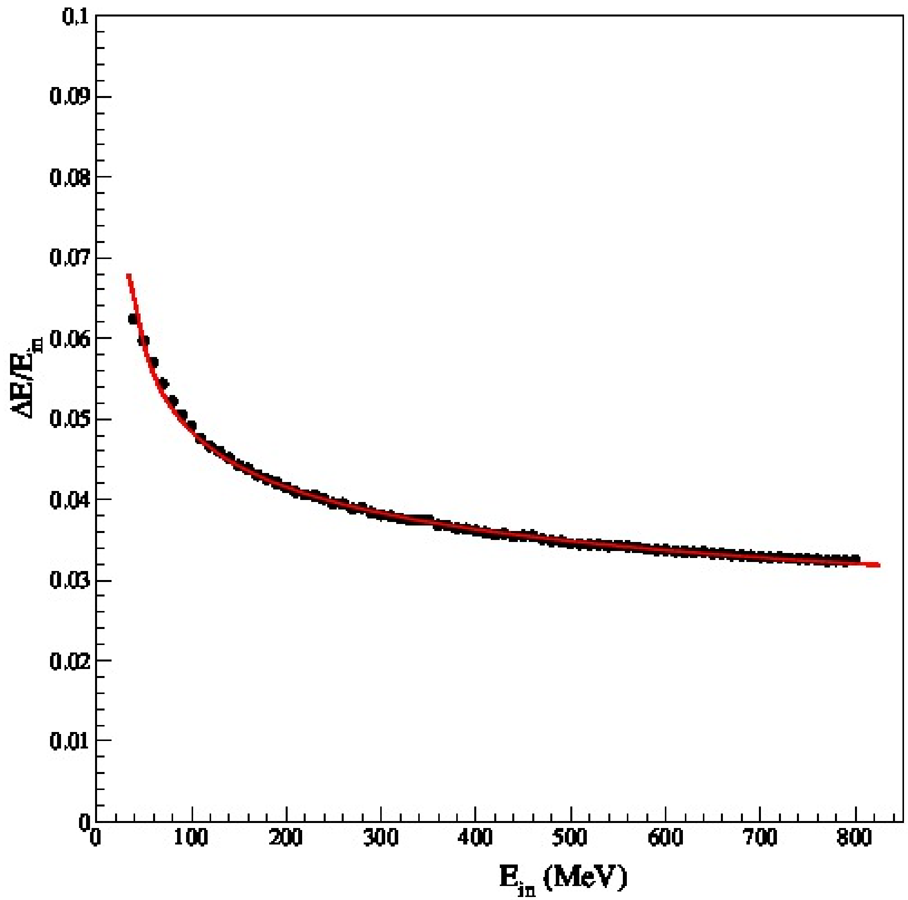


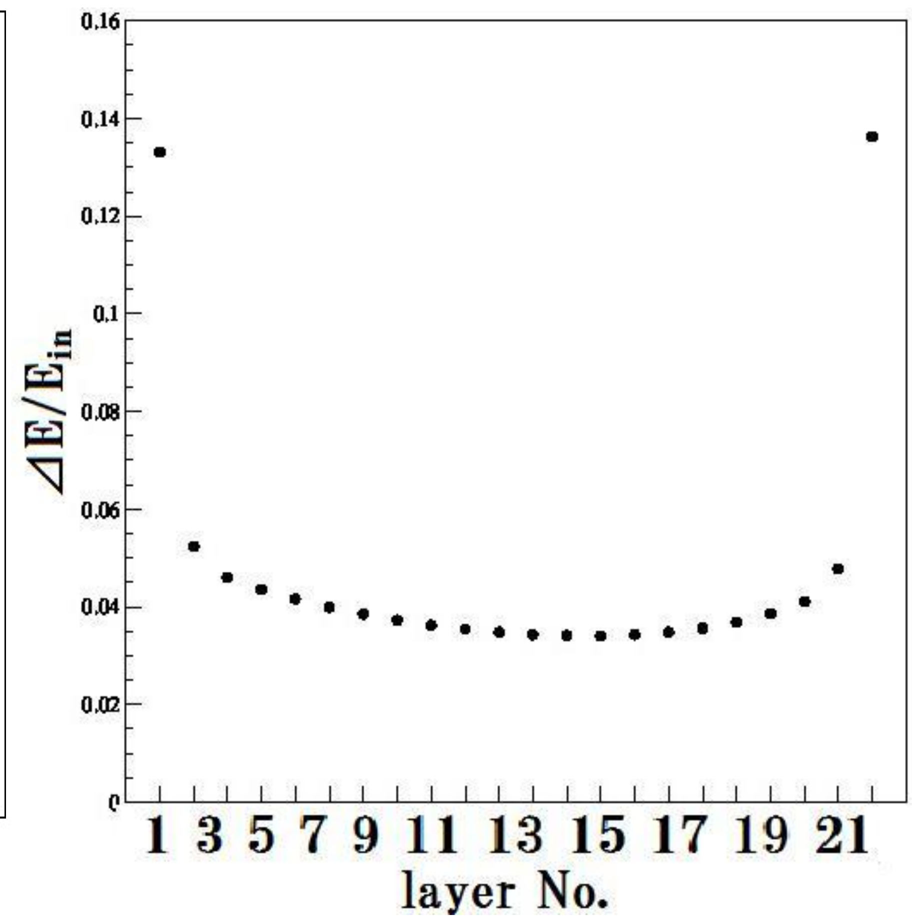
- η peak position is high.
- π^0 peak position is dependent on π^0 momentum.

: The inconsistency of π^0, η peak position is caused by energy leakage.
→ Check of the leakage effect by MC simulation.

Energy leakage

- When reconstructing a cluster of a gamma hit , a few % of energy leaks out of the cluster.
- Leaked energy ratio $\Delta E / E$ was estimated by MC simulation.



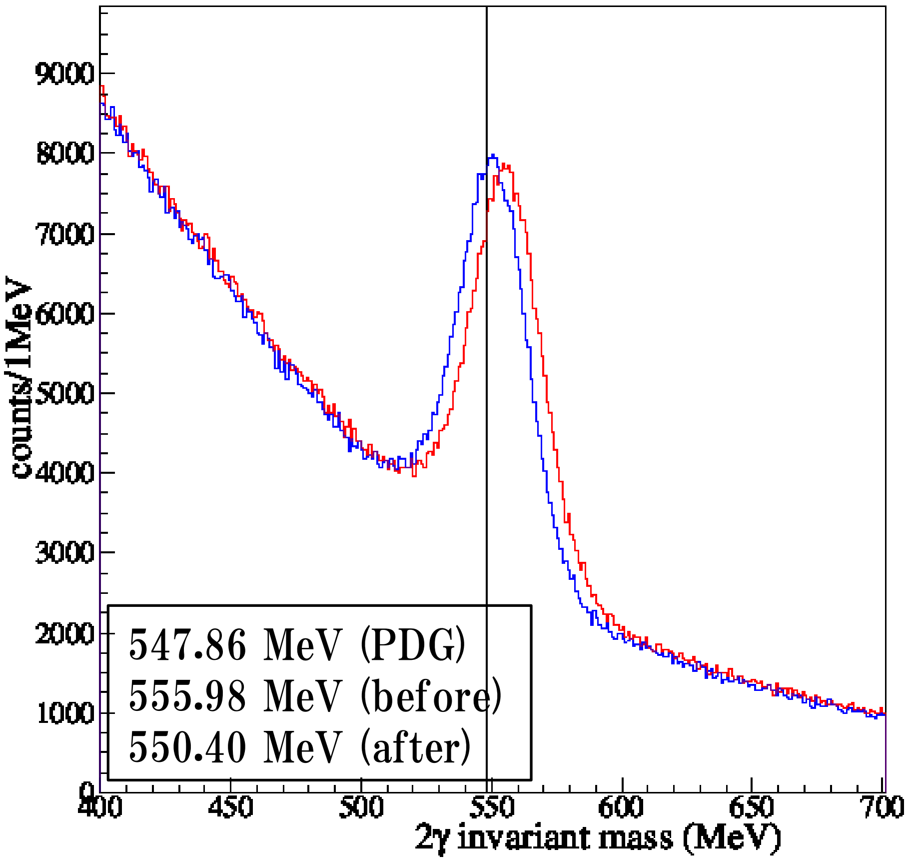


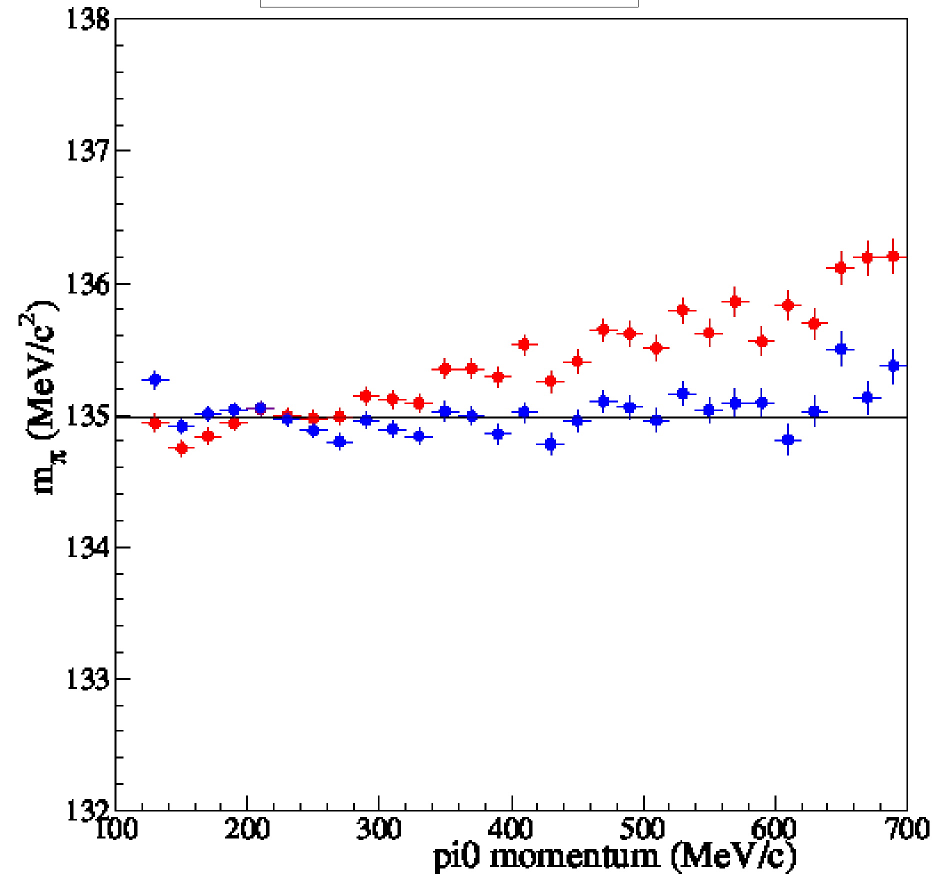
- γ energy dependence
- layer(polar angle) dependence

Energy correction

- re-calibrated taking energy leakage into account

Red : before
Blue : After





- η peak position : improved.
  (8 MeV high → 2.5 MeV high)

- momentum dependence of π^0 peak position
  → improved !

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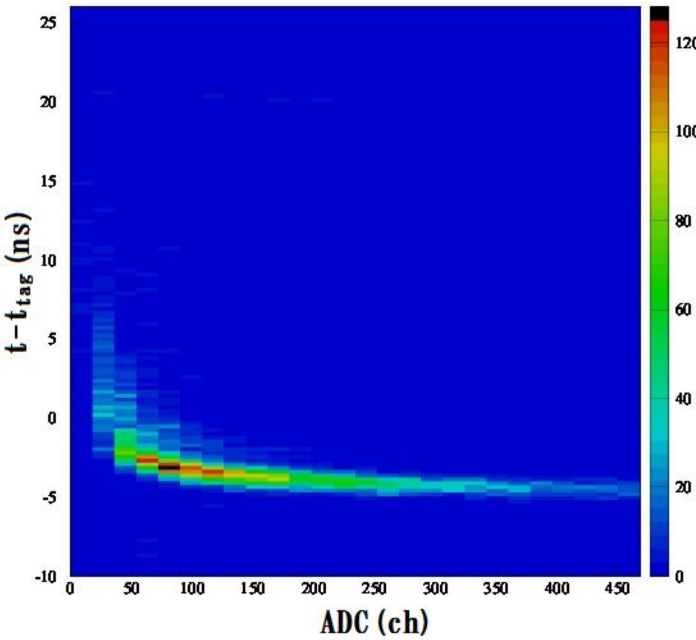
Timing calibration

- **Timing information**
  - event selection
  - RF separation (2ns)

  - Timing information independent of crystal and energy is required.
    → Timing calibration was performed
    so that gamma timing became 0.

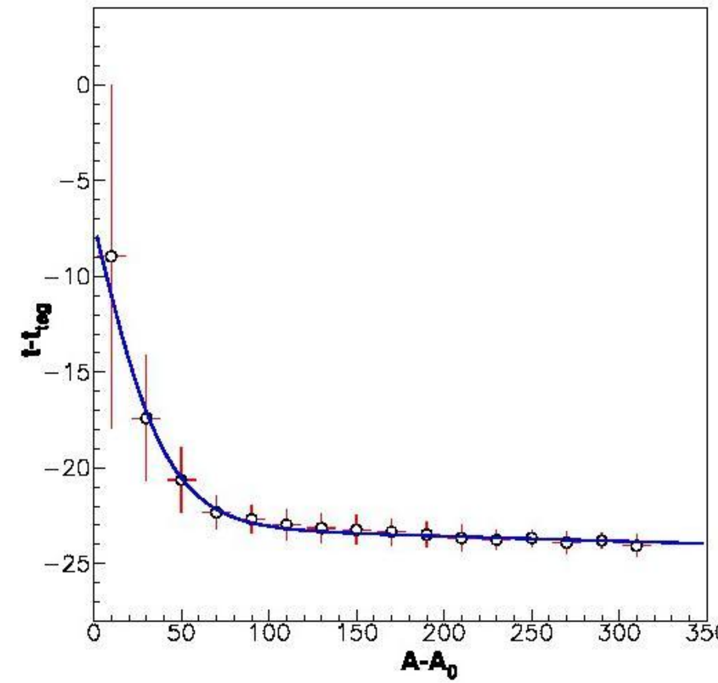
- **Pulse height – time walk correlation**
  - Correlation between ADC and timing
    : timewalk effect



Timing calibration

- **slewing correction**
  - fitting function

$$t = t_0 - \alpha \tanh(\beta(A - A_0)) - \gamma(A - A_0)$$



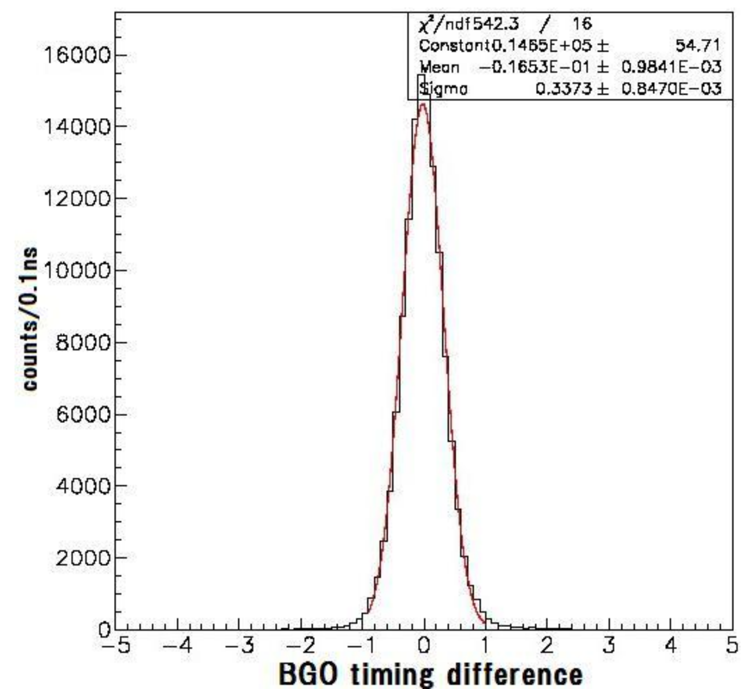
- **timing resolution**
  - timing difference distribution between 2γs from the same π^0

  : σ = 0.32 ns ($E_\gamma > 200$ MeV)

  - timing resolution for a single crystal

  : $\sigma/\sqrt{2}$ = 0.23 ns

→ • RF bunches can be separated.
 • accidental hits (ex. cosmic ray) can almost be eliminated.

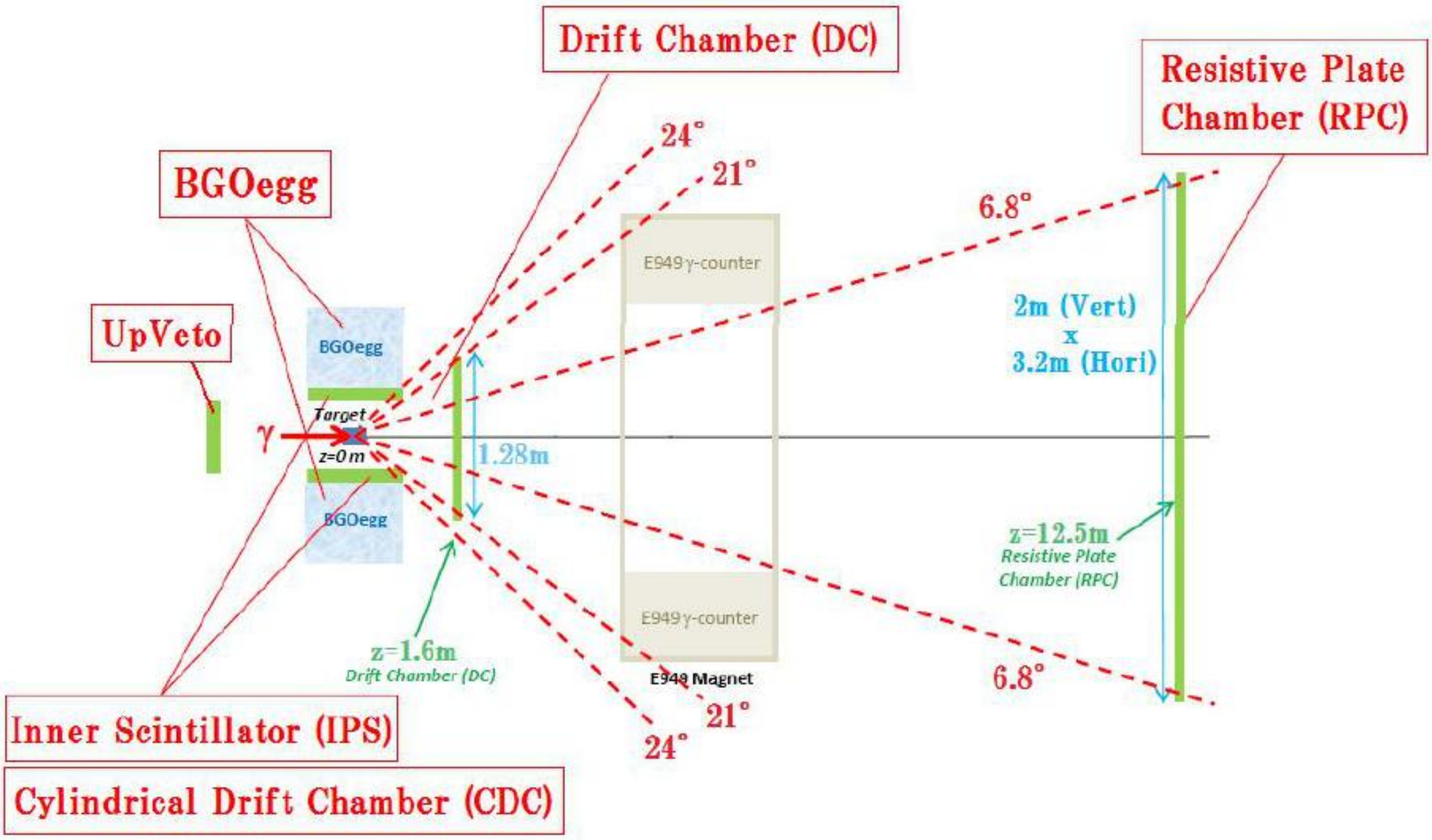


Summary

- We are aiming to search for an η' mesic nucleus in the LEPS2/BGOegg experiment.
- The electro-magnetic calorimeter BGOegg is used to detect γs and identify mesons in final states.
- Energy calibration of BGOegg was performed and high mass resolution of 6.7 MeV(π^0), 14.4 MeV(η) was achieved.
- Timing calibration of BGOegg was performed and timing resolution of 0.23 ns for $E_\gamma > 200$ MeV was achieved. This is enough for RF separation and elimination of accidental hits.

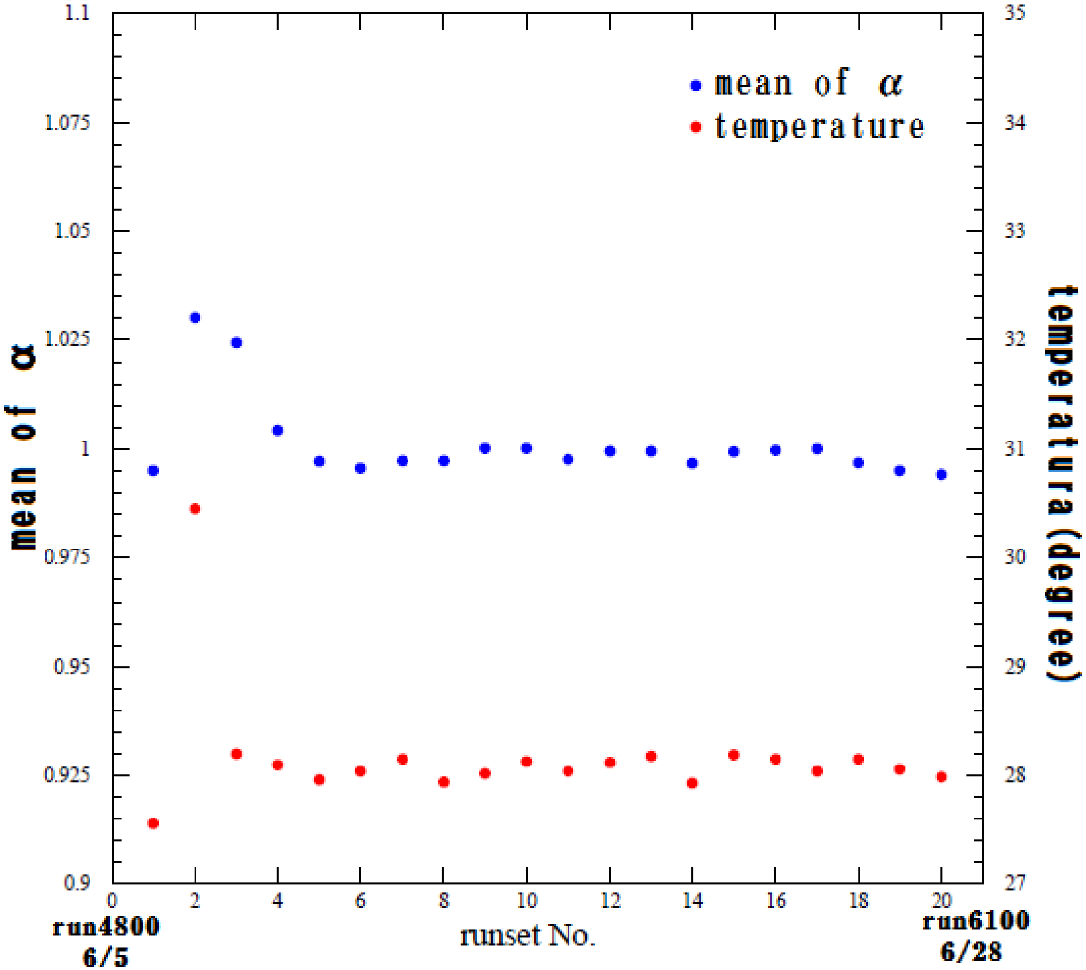
backup

Experimental setup



Gain factor and temperature

- run dependence of α and temperature



- There is a few % fluctuation
- There is a correlation between temperature and gain factor α.
- ~2K high temperature
  →~3% high gain factor
  → consistent with BGO light output correlation with temperature (dL/dT ~ −1.5%/K)