# Direct measurement of the in-medium $\eta'$ mass spectrum via the $\eta' \to \gamma\gamma$ decay at the LEPS2/BGOegg experiment

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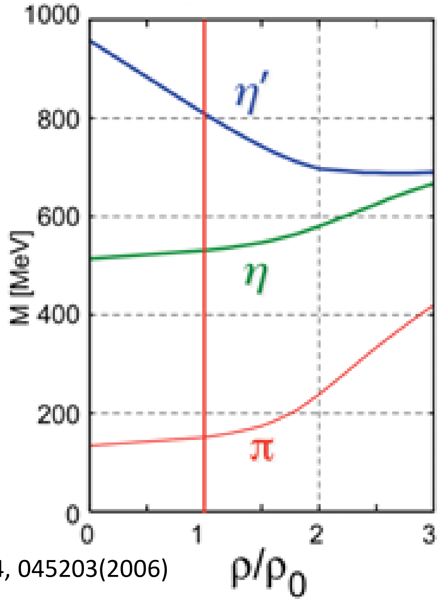
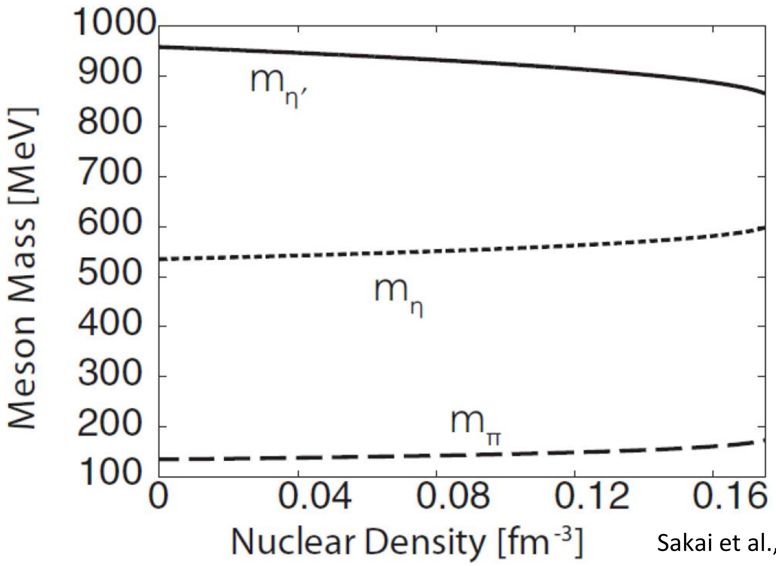
# Introduction

- $\eta'(958)$ meson & axial U(1) anomaly
  - $\eta'$ meson has larger mass than other pseudo scalar mesons in the low-lying nonet of flavor SU(3).
  - $\eta'$ gets large mass through the anomaly effect when chiral symmetry is dynamically broken.
- $\eta'$ mass in nuclear medium
  - Chiral symmetry is expect to be partially restored in high-density environment such as nuclear medium.
    ➡ $\eta'$ mass possibly decreases in a nucleus.




Nagahiro et al., PRC74, 045203(2006)




Sakai et al., PRC88, 064906(2013)

Several effective models predict in-medium mass reduction of $\eta'$.

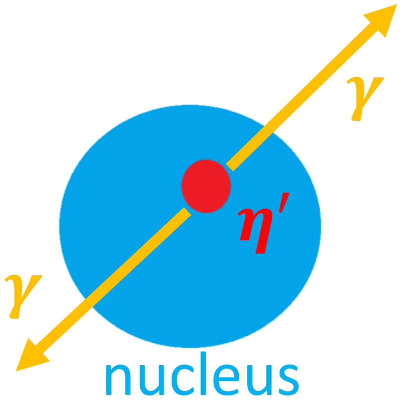
# Direct measurement of in-medium $\eta'$ mass spectrum

- Line shape analysis
  - A direct measurement of mass spectra with invariant mass distribution.

    cf. indirect methods : search for $\eta'$ mesic nuclei , measurement of $\eta' N$ potential

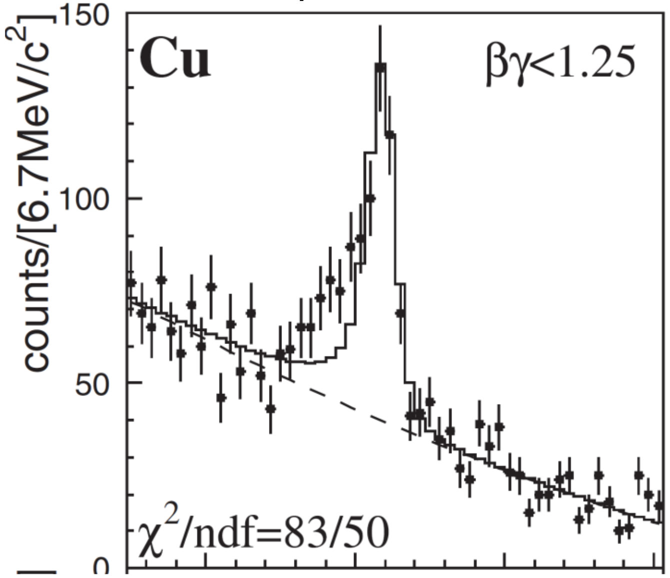
- $\eta' \rightarrow \gamma\gamma$ mode
  - No final state interaction
  - No radiative tail in the spectrum

- High mass resolution is required for such analysis.



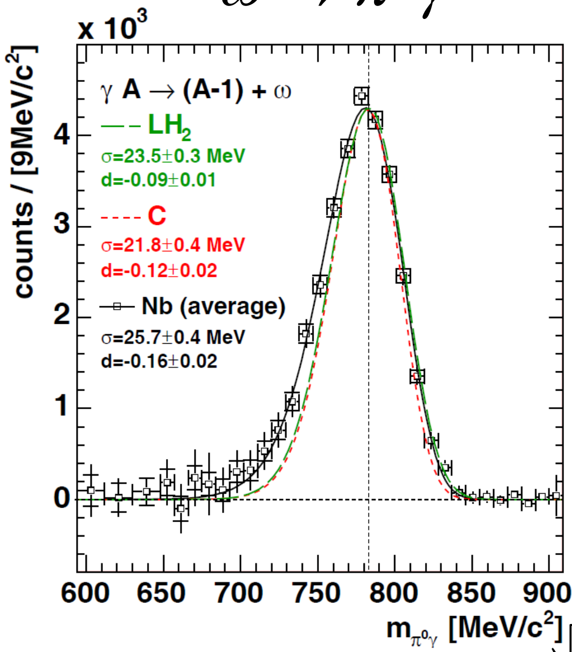

cf. vector mesons

$\phi \rightarrow e^+e^-$



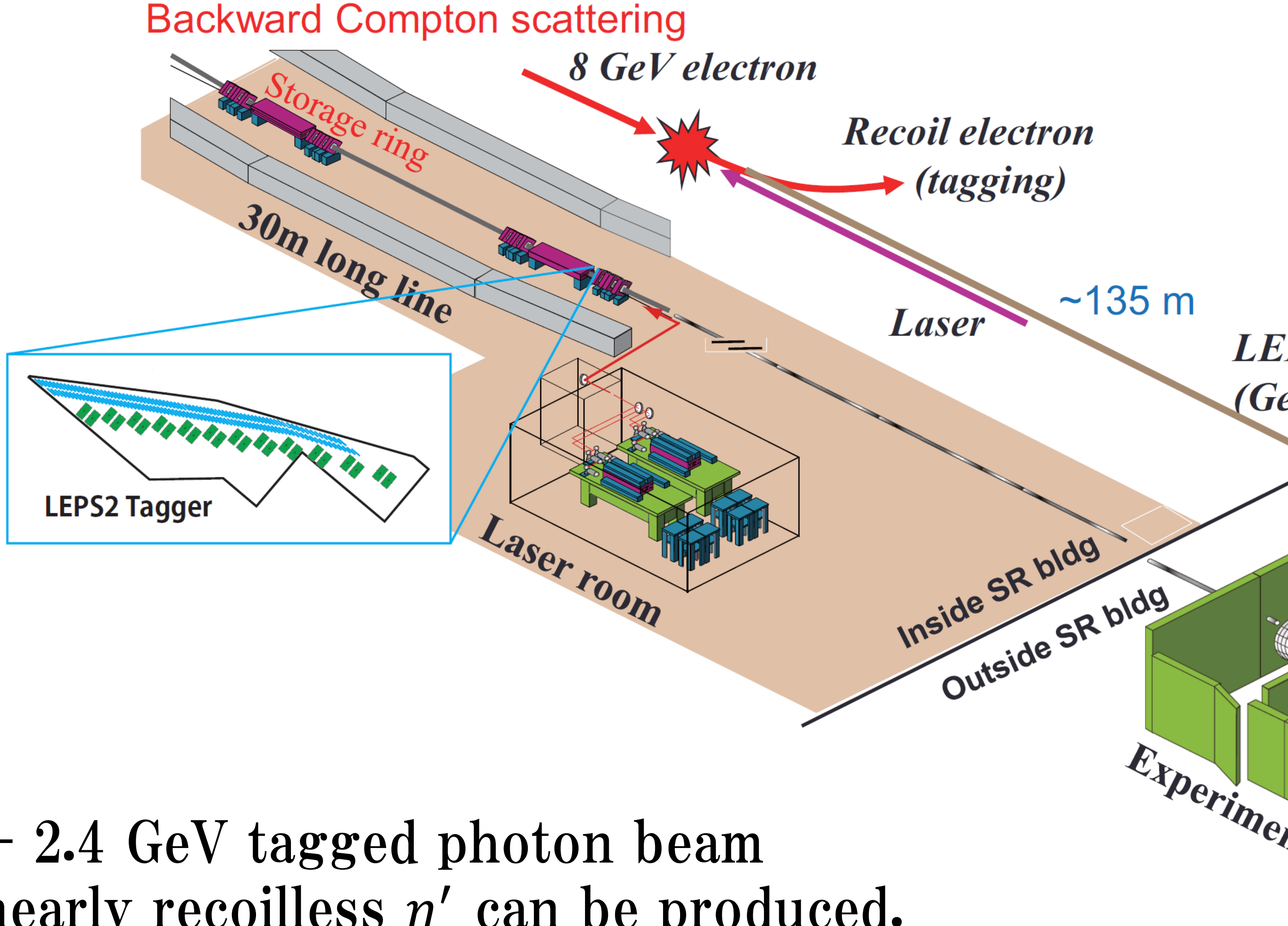

R.Muto et al. PRL98, 042501(2007)

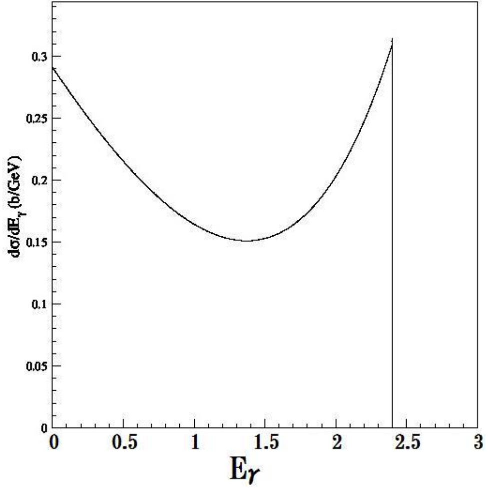
$\omega \rightarrow \pi^0\gamma$




M.Thiel et al. Eur.Phys.J.A49, 132(2013)

# SPring-8/LEPS2 beamline

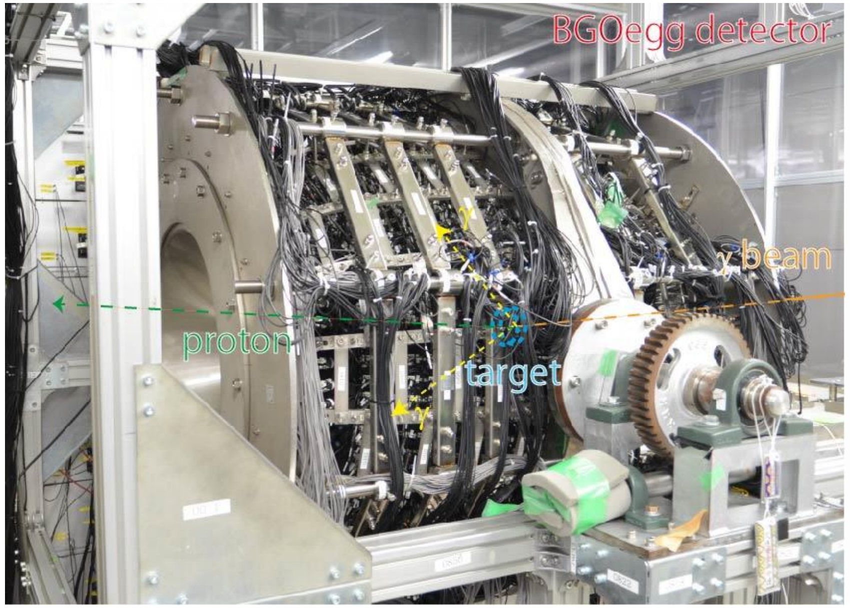


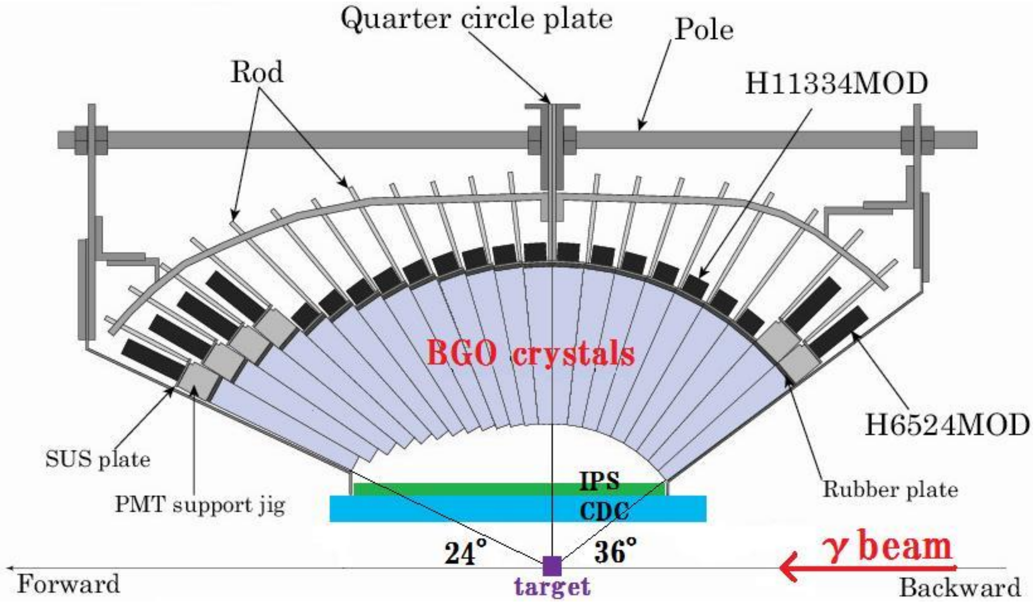




Energy spectrum of BCS

- 1.3 – 2.4 GeV tagged photon beam
  → nearly recoilless $\eta'$ can be produced.

# BGOegg calorimeter



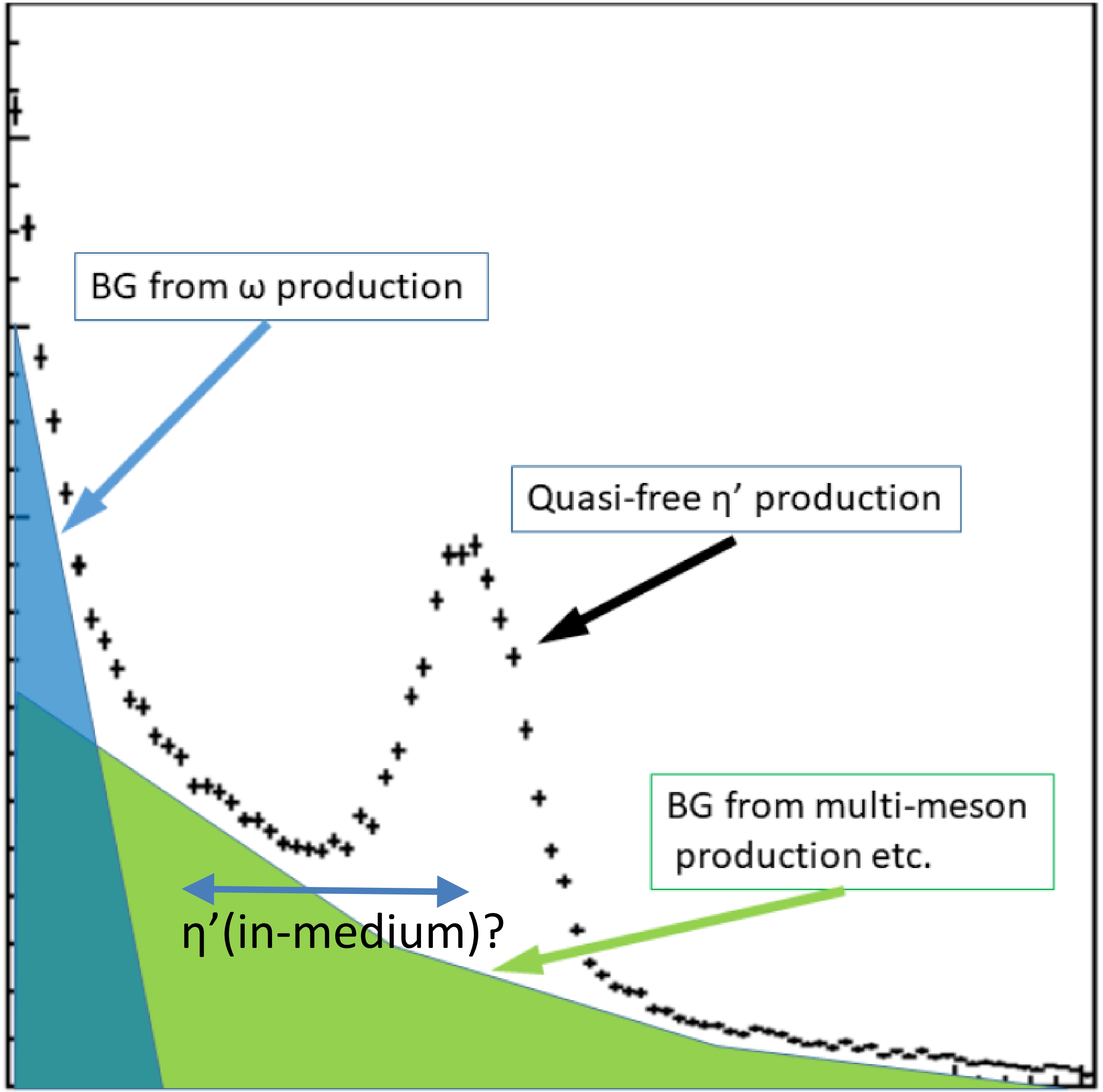




20 mm thick C target

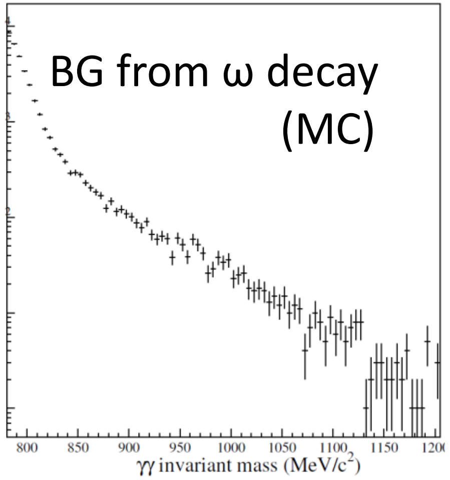
- 1320 BGO crystals
- polar angle：24° ～144°
  azimuthal angle：360°
- homogeneous
- no housing material
- energy resolution：1.38% @ 1GeV
- position resolution：3.1mm @ 1GeV

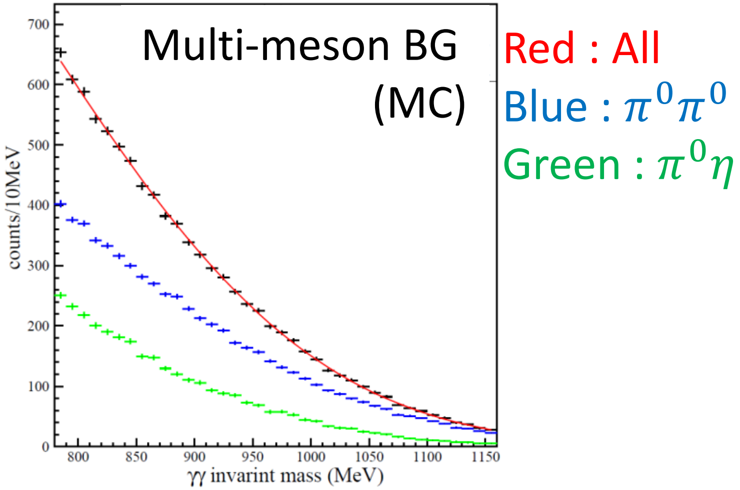
# Line shape analysis

Realistic functions that describe $\gamma\gamma$ distribution of known processes were fitted to obtained $\gamma\gamma$ spectra.




- **Background processes**



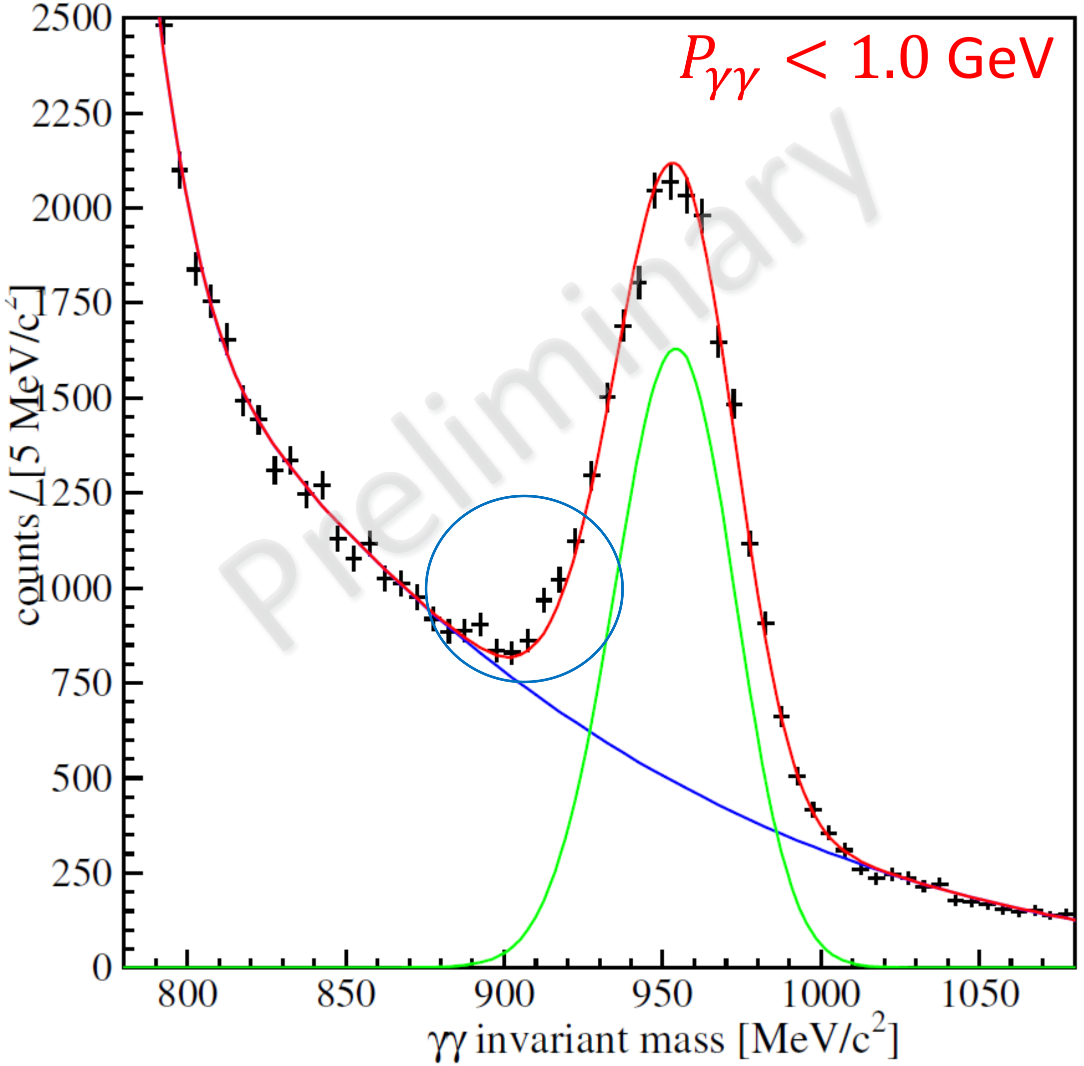




- **Spectral functions for the quasi-free $\eta'$ peak**
  - prepared as template histograms using a MC simulation

- The resolution and the detector geometry in the MC simulations were precisely adjusted to reproduce the experimental data.

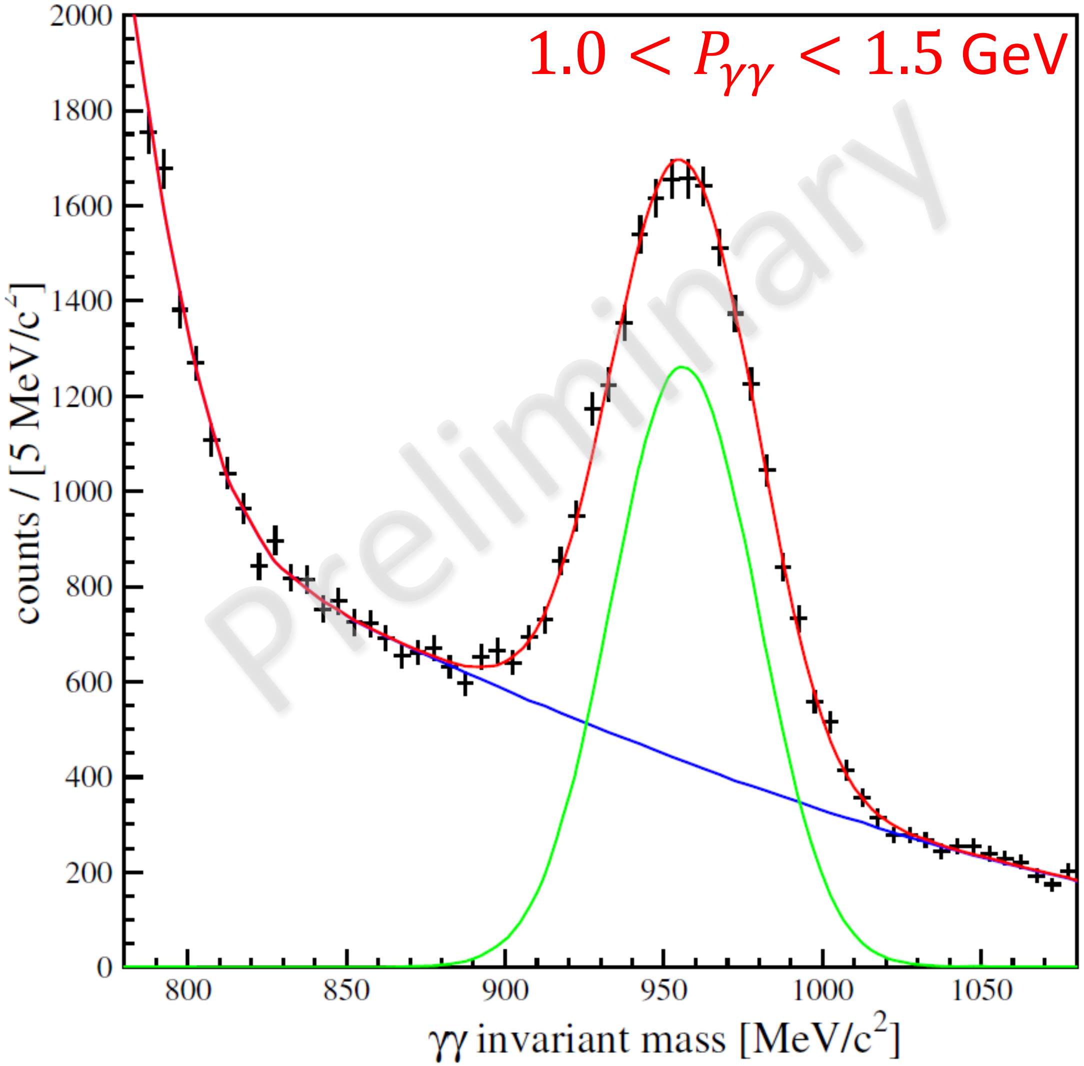
# Spectral fit

$\chi^2$/ndf = 69.2/54




Worse $\chi^2$ comes from some enhancement in the lower tail of the $\eta'$ mass peak.

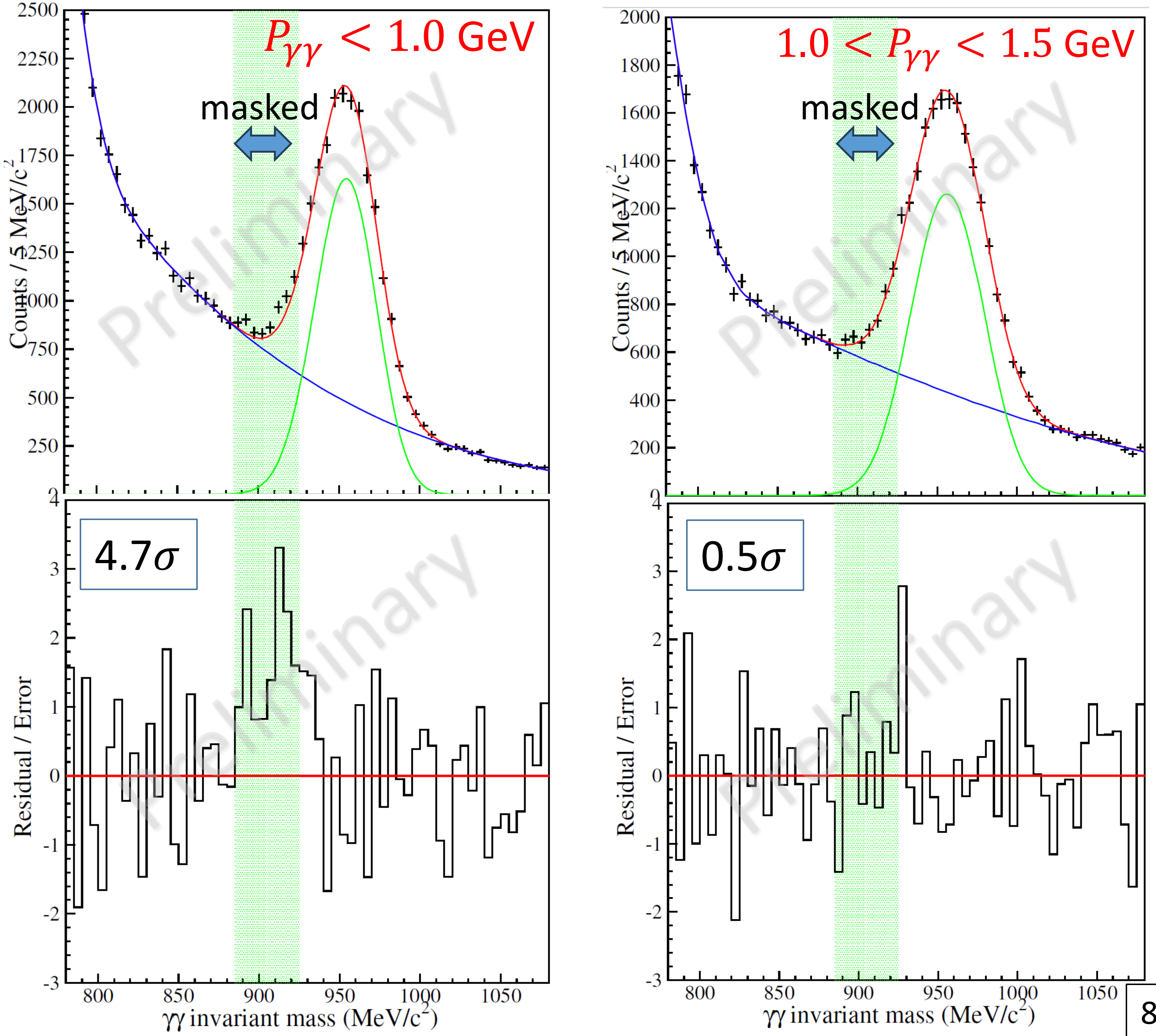
$\chi^2$/ndf = 48.7/54




High-momentum events
(no in-medium signal is expected)
➡ well described by known processes

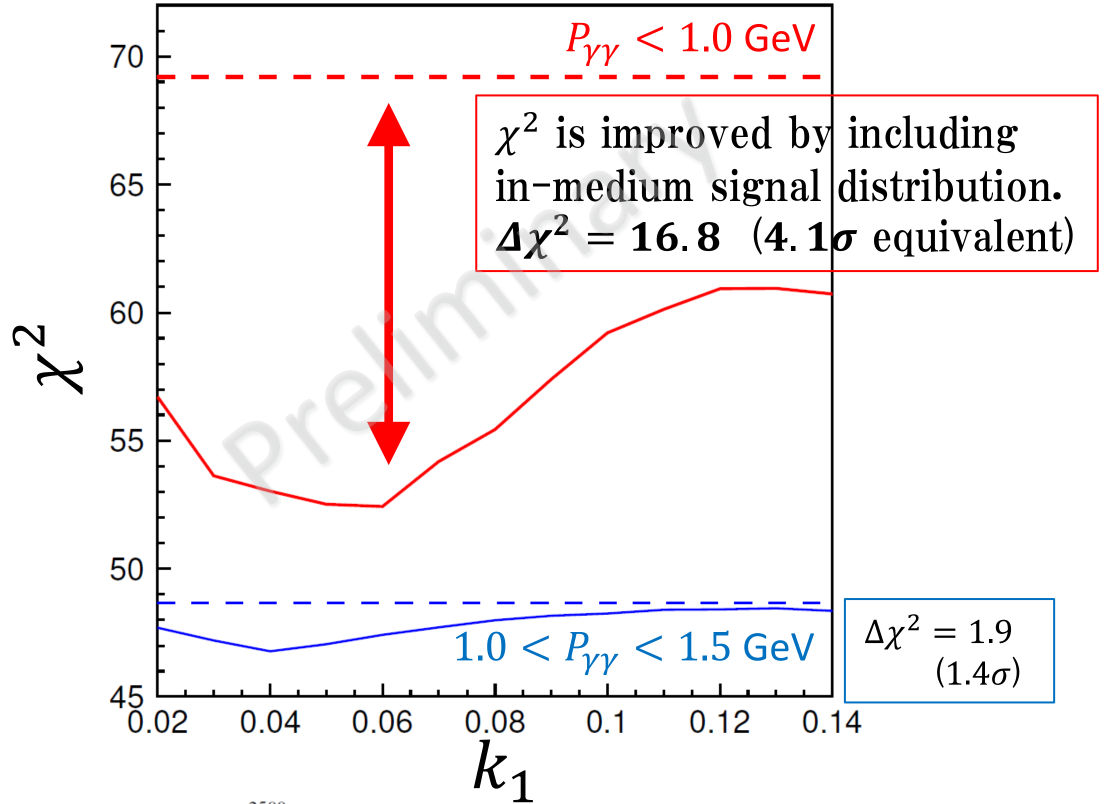
# Spectral fit

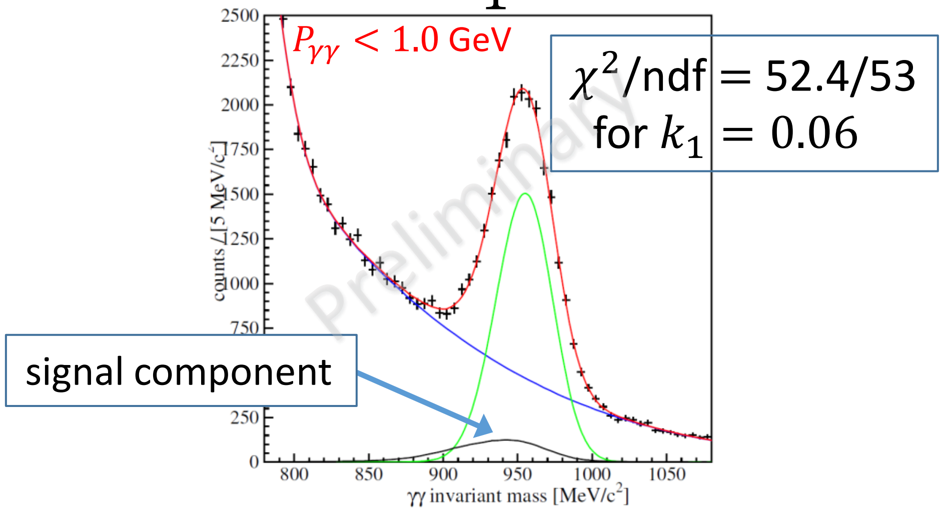
The spectral fits were performed with the signal region masked to evaluate the significance of the enhancement.




A clear enhancement was seen with significance of **4.7$\sigma$** in the low-momentum events.

# Discussion for in-medium modification




- To discuss the in-medium $\eta'$ mass spectra, $\eta'$ decay signals in nuclei were simulated with a simple model, and included into the spectral fit.

: $\eta'$ mass in nuclei $\boxed{m_{\eta'}(\rho) = m_0(1 - k_1 \frac{\rho}{\rho_0})}$

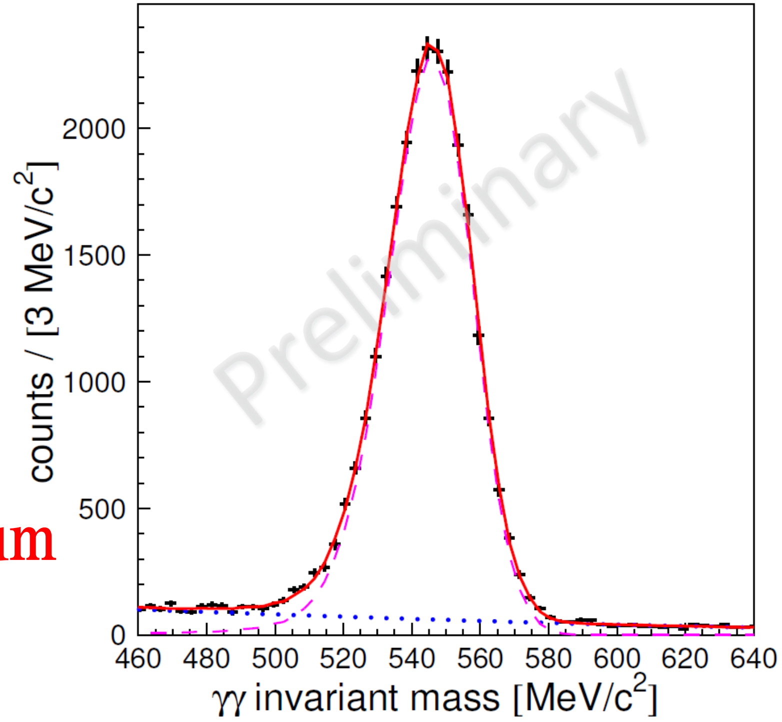
($m_0$ = 958.78 MeV / $\rho_0$ : normal nuclear density)

- $\chi^2$ difference between the fits including and omitting the signal component reaches $\Delta\chi^2 = 16.8$, corresponding to significance of $\mathbf{4.1}\boldsymbol{\sigma}$.

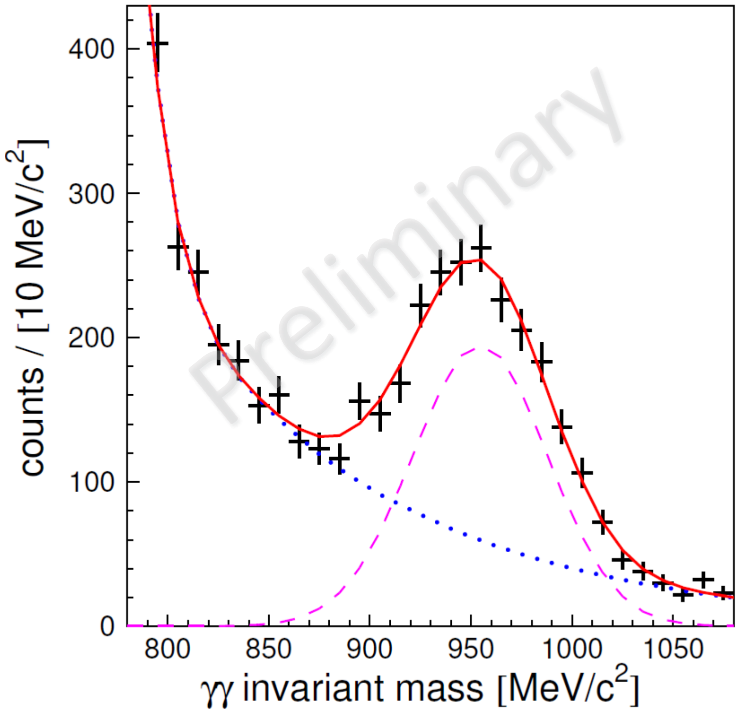
- The best fit was obtained with $k_1$=0.06, corresponding to mass reduction of $\Delta m_{\eta'} = 57.5$ MeV. (uncertainty $^{+5.7}_{-27.8}$ MeV)

# Discussion for in-medium modification

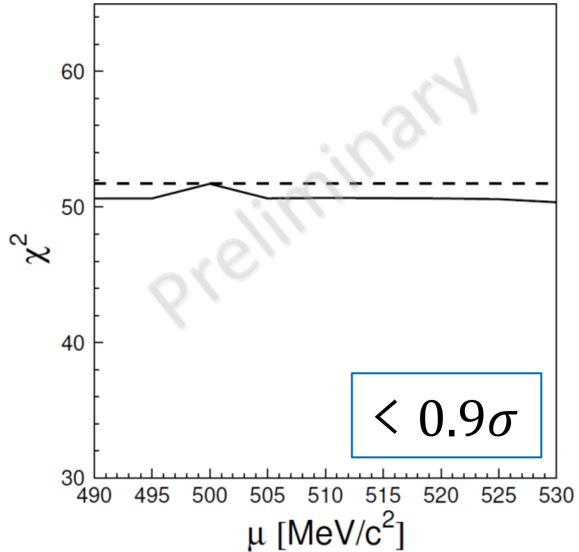
Various systematics checks were also performed to confirm validity of the results.

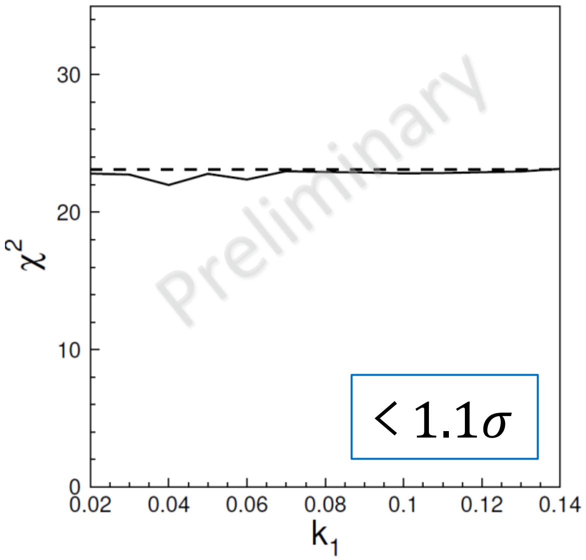



$\eta \to \gamma\gamma$ spectrum for C target
($P_{\gamma\gamma} < 0.6$ GeV)




$\eta' \to \gamma\gamma$ spectrum for proton target
($P_{\gamma\gamma} < 1.0$ GeV)




No deviation was obtained by the spectral fits and $\chi^2$ difference tests for reference samples.

# Summary

- We measured the $\eta'(958)$ mass spectrum through the $\eta' \rightarrow \gamma\gamma$ decay with an electro-magnetic calorimeter BGOegg to investigate the in-medium modification of the $\eta'$ mass. The obtained invariant-mass spectra were analyzed by fitting realistic spectral functions.

- Deviation with significance of above $4\sigma$ was obtained only in the low-momentum ($P_{\eta'} < 1$ GeV/c) sample of the carbon target data.
  This could not be explained by known sources other than the in-medium decay signal.

- $\chi^2$ difference test comparing the fits with and without the in-medium decay signals indicates the $\eta'$ mass reduction of $\Delta m_{\eta'} = 30$–$63$ MeV.