Photonuclear excitation of 26Mg and particle emission on PANDORA project.

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PANDORA
Photo-Absorption of Nuclei and Decay Observation for Reactions in Astrophysics

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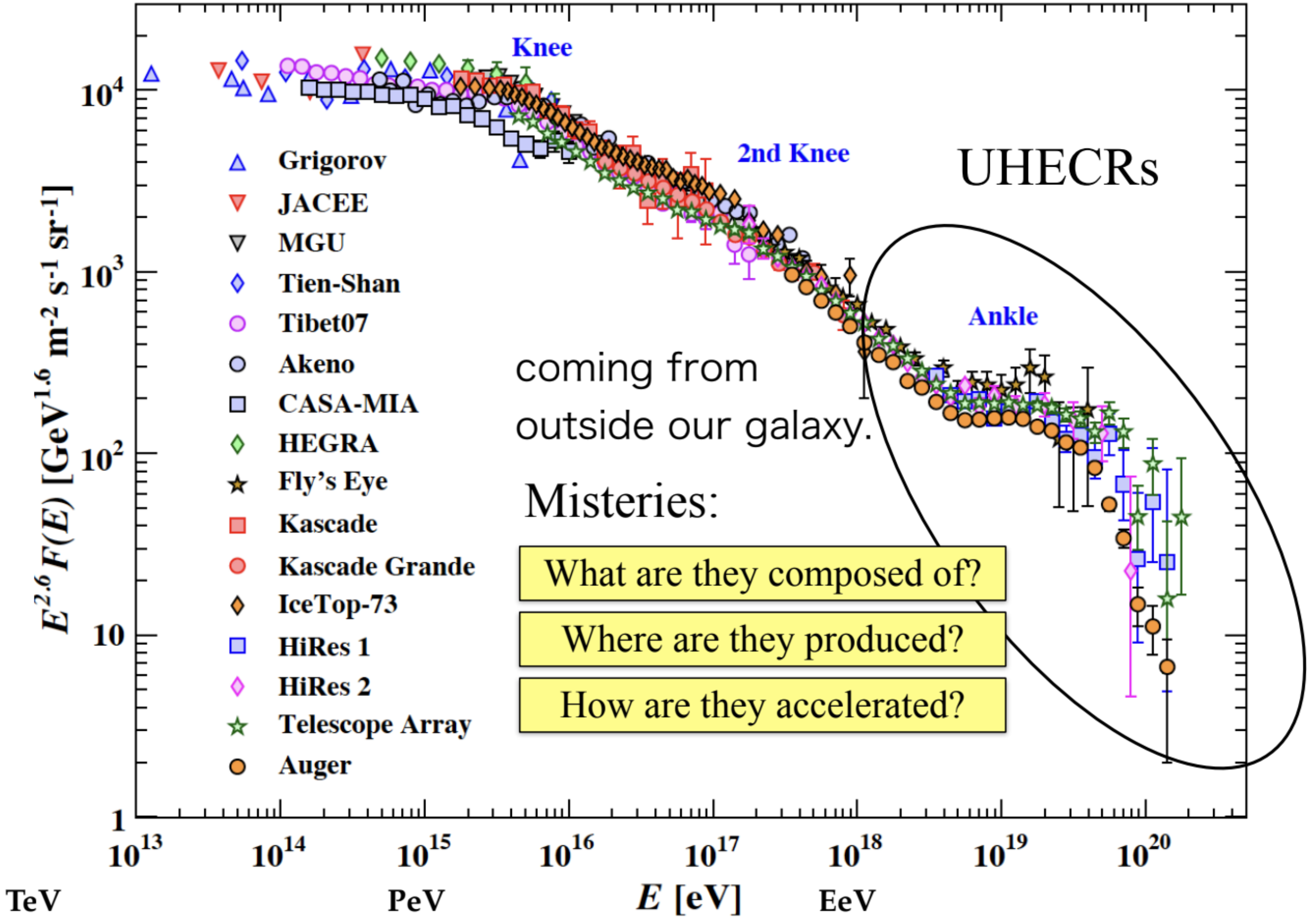
大阪大学
THE UNIVERSITY OF OSAKA

Motivation

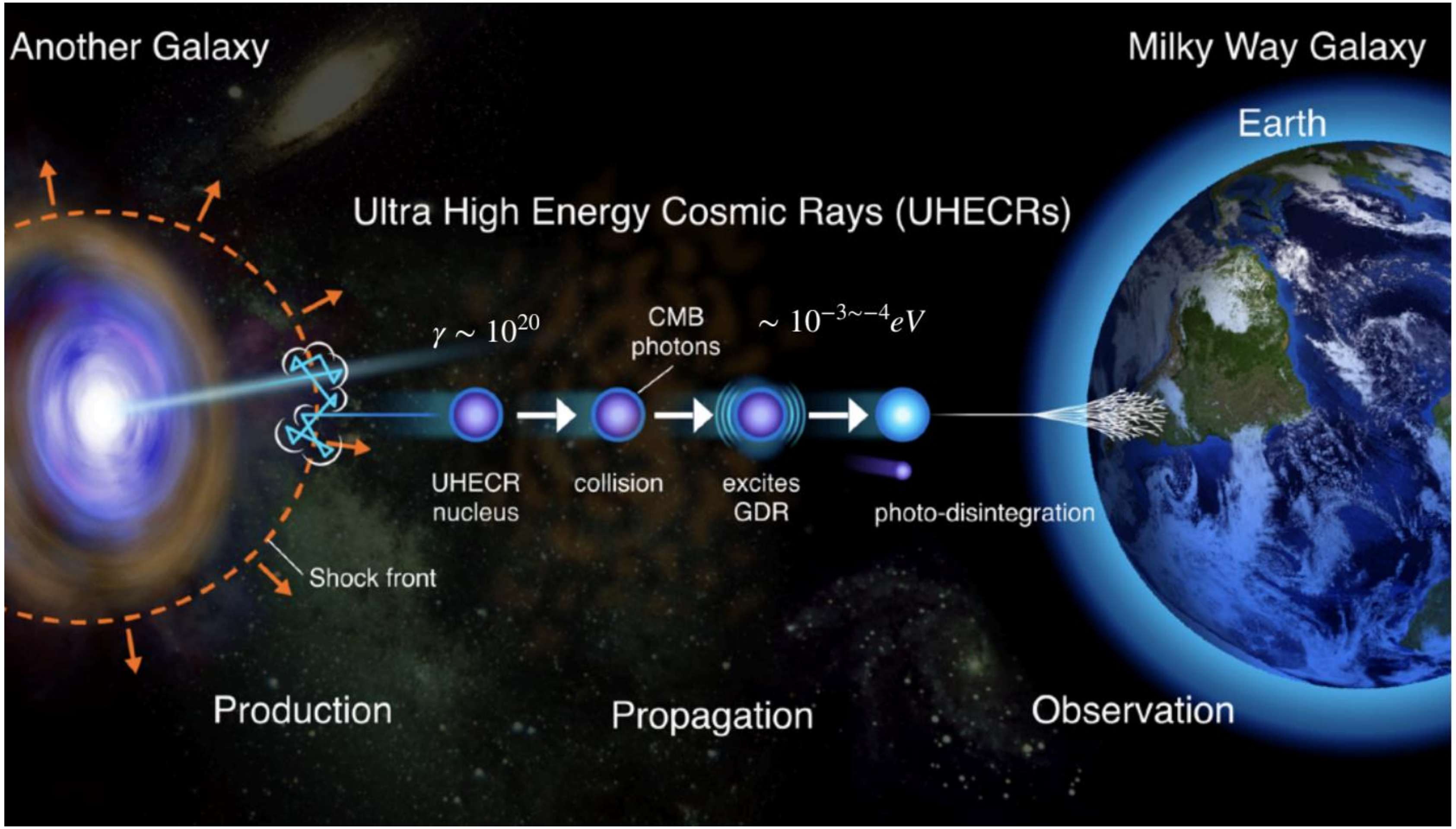
Ultra **H**igh **E**nergy **C**osmic **R**ays (**UHECRs**)



P. D. Group,, P. Zyla, R. Barnett, J. Beringer, O. Dahl, D. Dwyer, D. Groom, C.-J. Lin, K. Lu- govsky, E. Pianori, et al., "Review of particle physics," Progress of Theoretical and Experimental Physics, vol. 2020, no. 8, p. 083C01, 2020.

Motivation

PANDORA: **P**hoto-**A**bsorption of **N**uclei and **D**ecay **O**bservation for **R**eaction in **A**strophysics

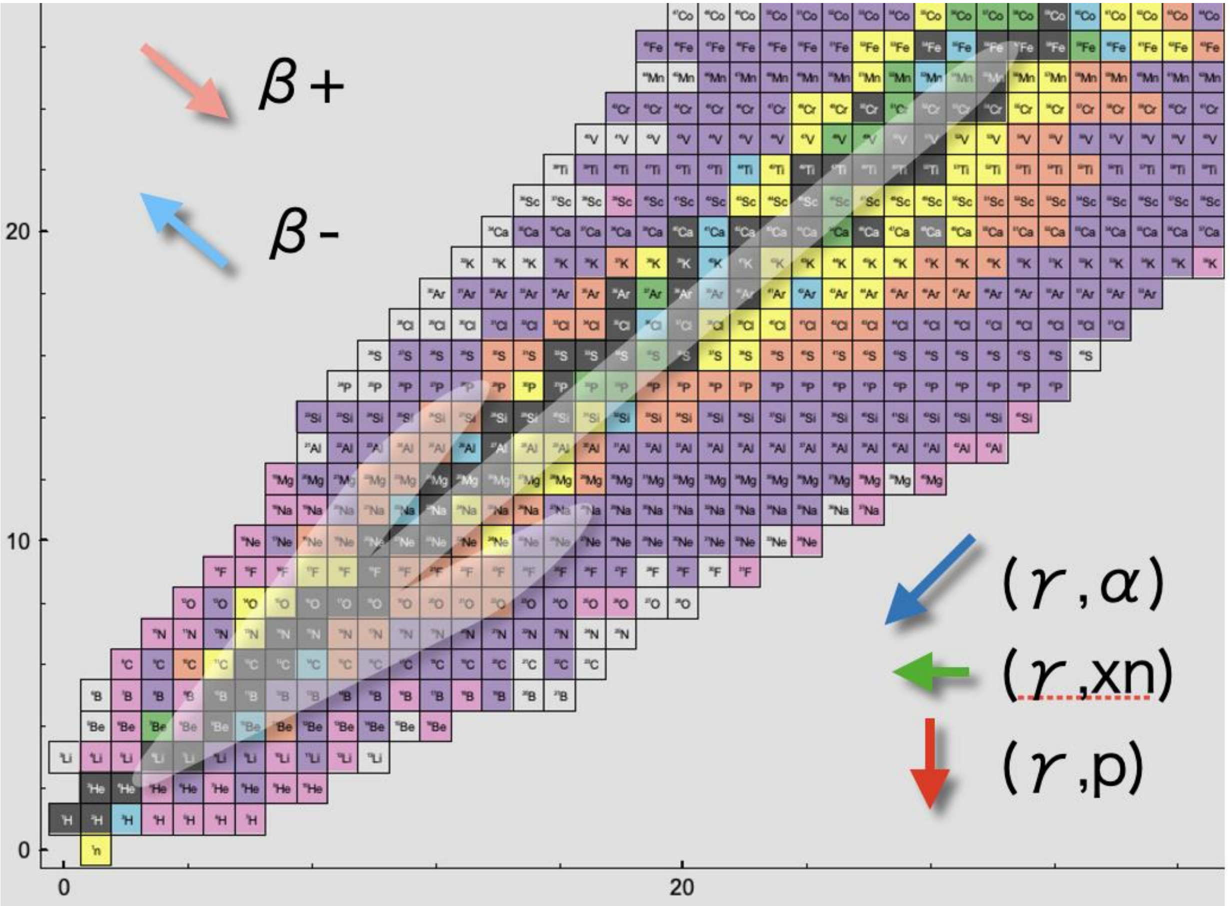


Energy loss process during intergalactic propagation

Motivation

- **Photo absorption cross section**
- **Decay branching ratio**

are important to understand energy loss process of UHECRs

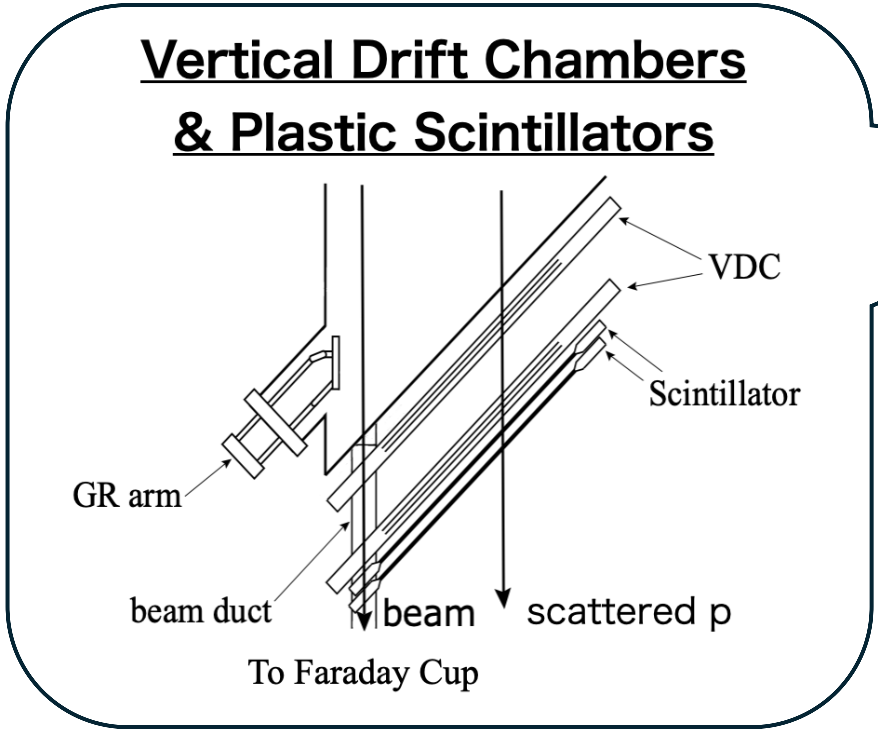


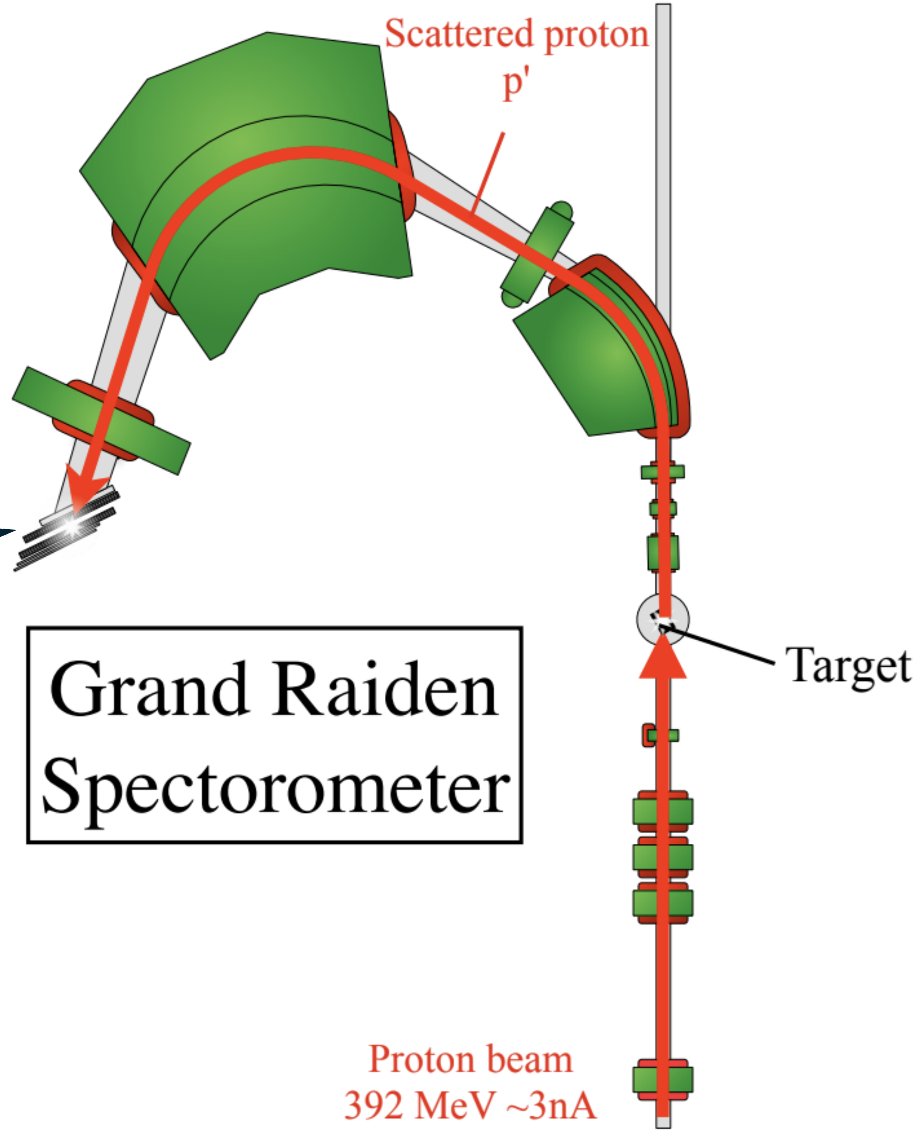
Z

N

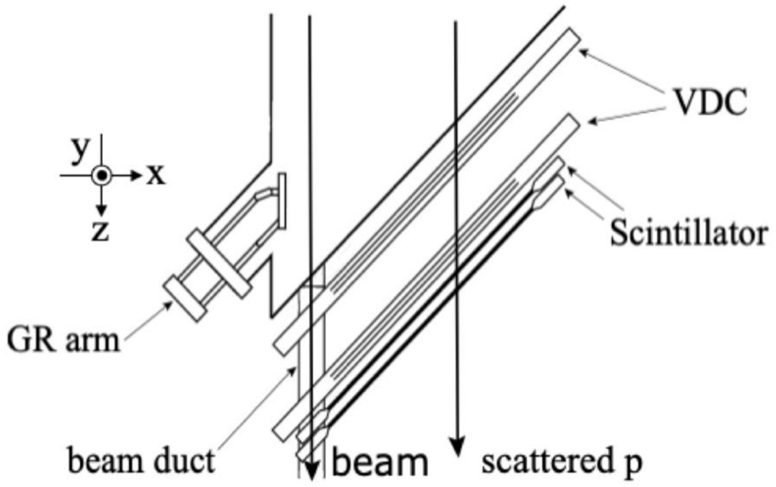
Experimental set-up

- Conducted at RCNP in Oct. 2025
- Beam: 392 MeV proton
- GR angle: 0, 4.5, 6.6 degrees
- Targets: ^{16}O, ^{26}Mg, ^{40}Ca, ^{56}Fe





Analysis – focal plane calibration

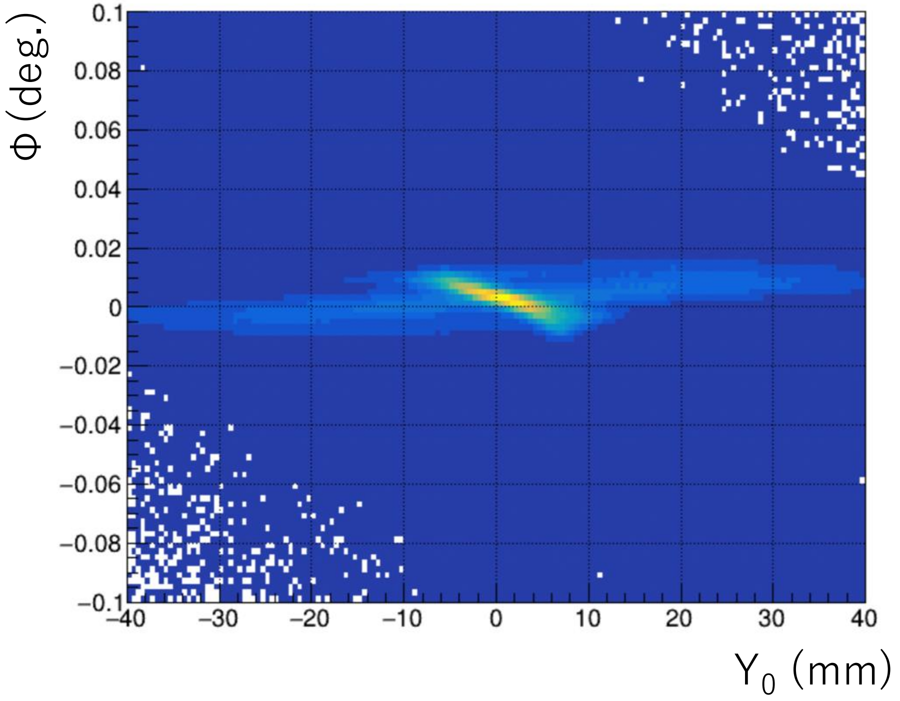


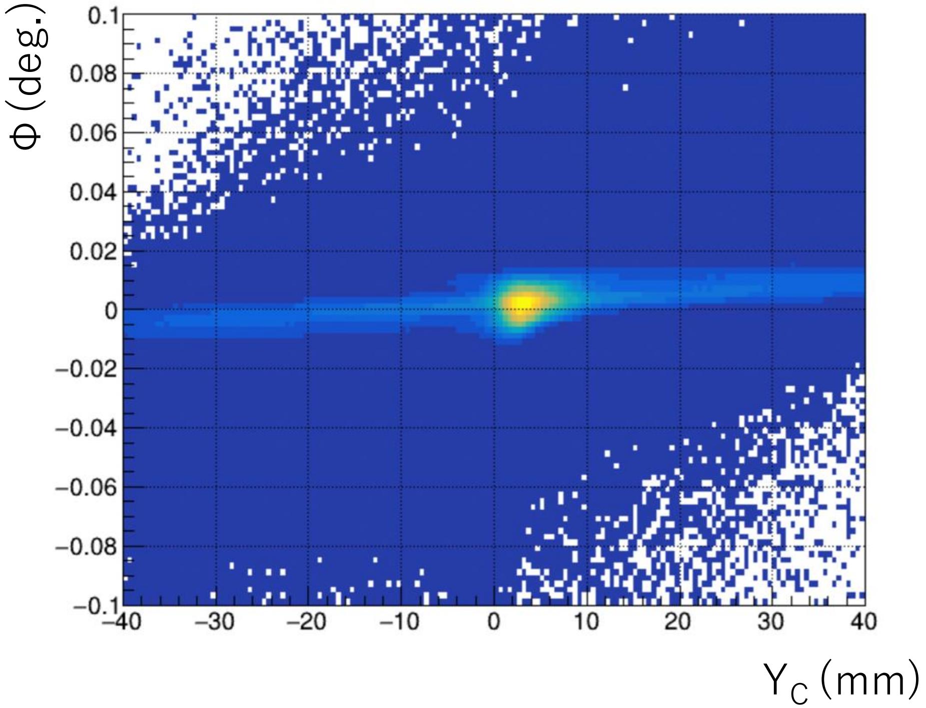
Analysis – focal plane calibration

Method of Y calibration

- Segment the data at 60 mm intervals along the X-axis and define gates accordingly.
- Determine the slope (m = ΔY/ΔB) for each corresponding peak.
- Apply the method of least squares to the (x, m) dataset to derive the functional form f(X).

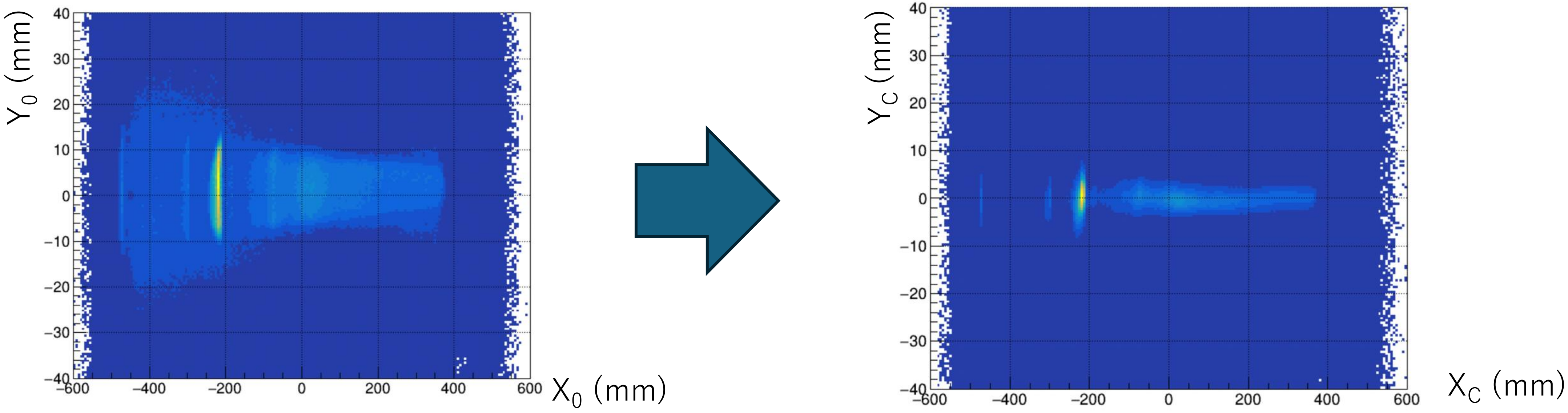
$$Y_c = Y_0 + f(\mathrm{X}) \cdot \varphi \qquad f(\mathrm{X}) = \frac{\Delta Y}{\Delta \varphi} = c_2 X^2 + c_1 X + c_0$$





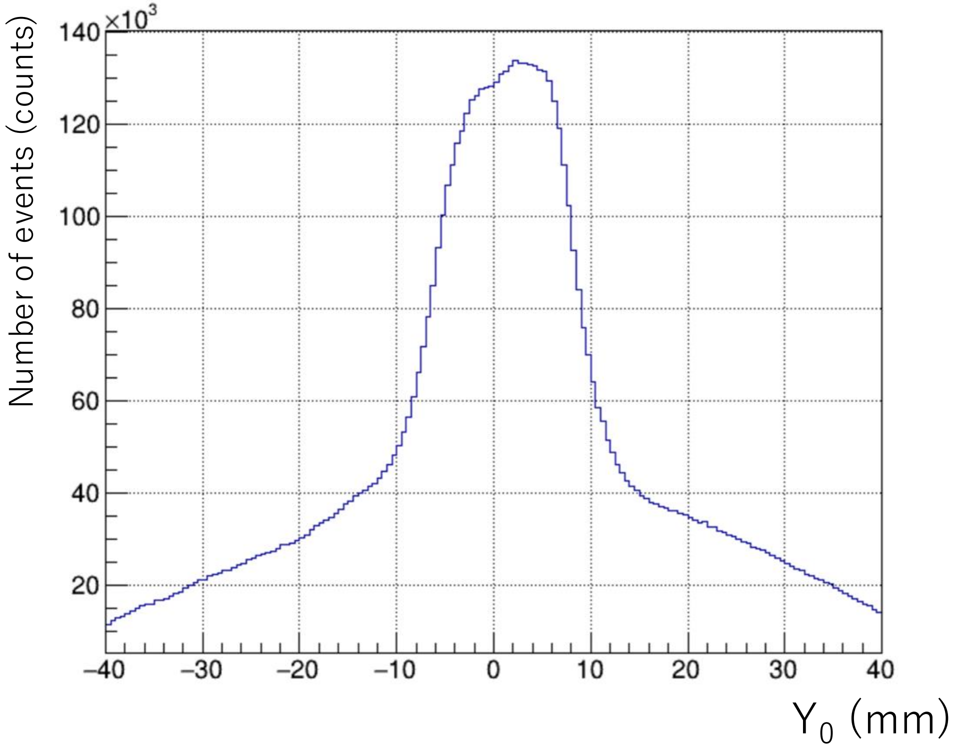
Analysis – focal plane calibration

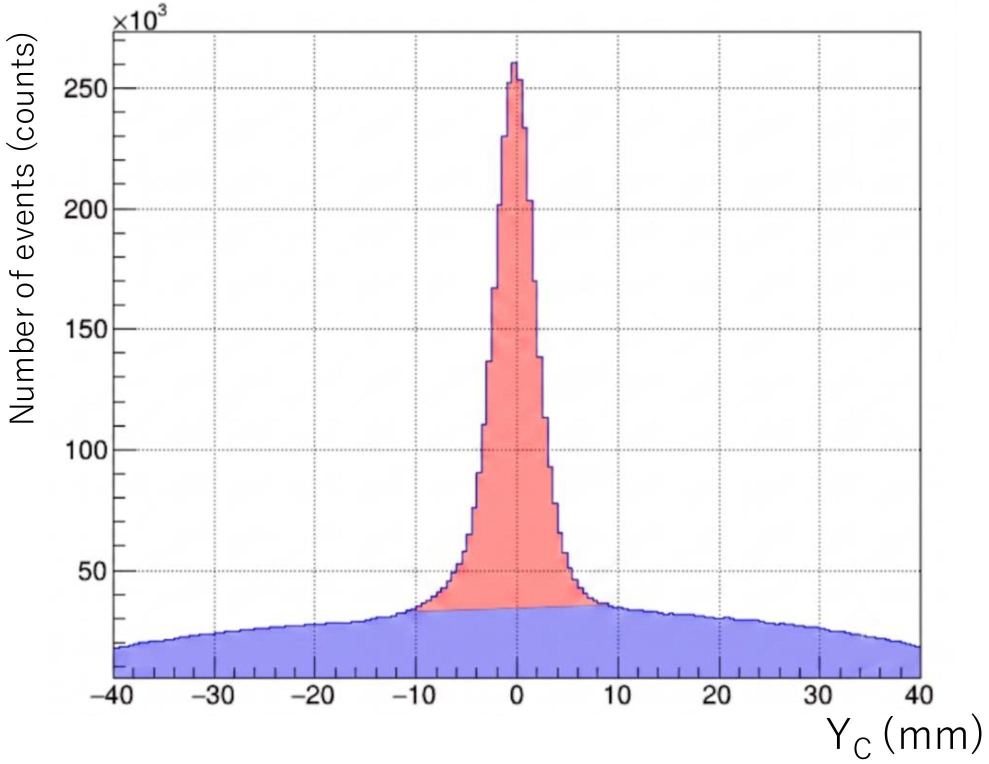
Comparison of Y vs X



Analysis – focal plane calibration

Comparison of Y - histgram





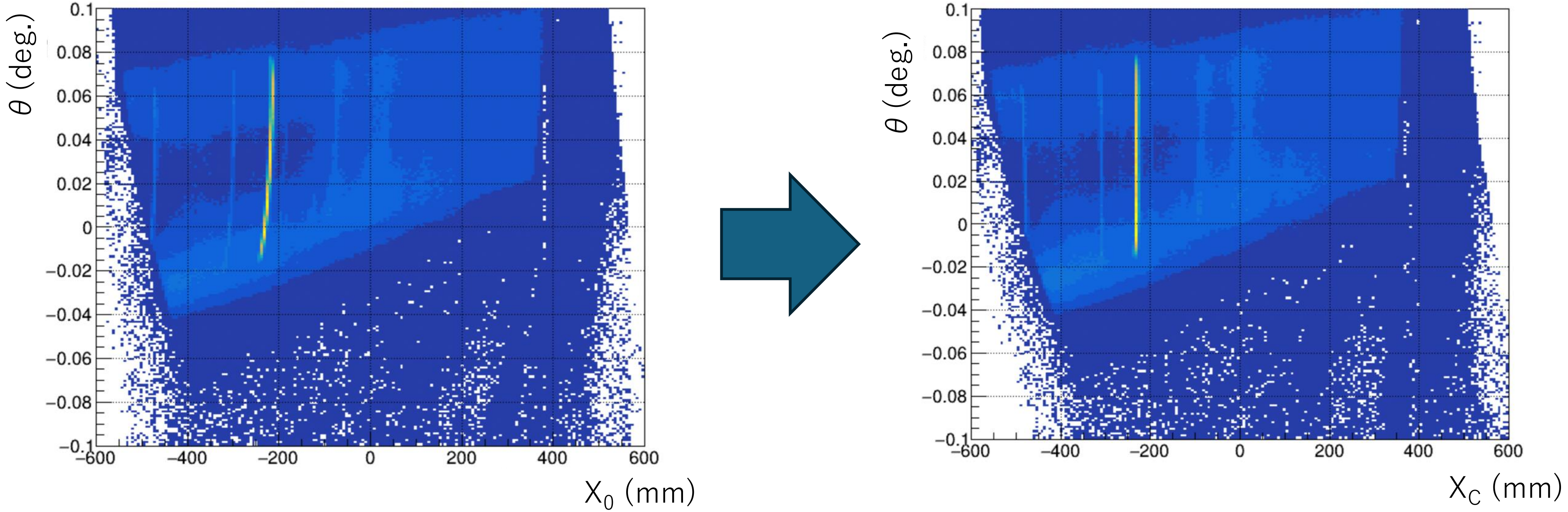
→Separate the true peak from the background more accurately.

Analysis – focal plane calibration

Method of X calibration

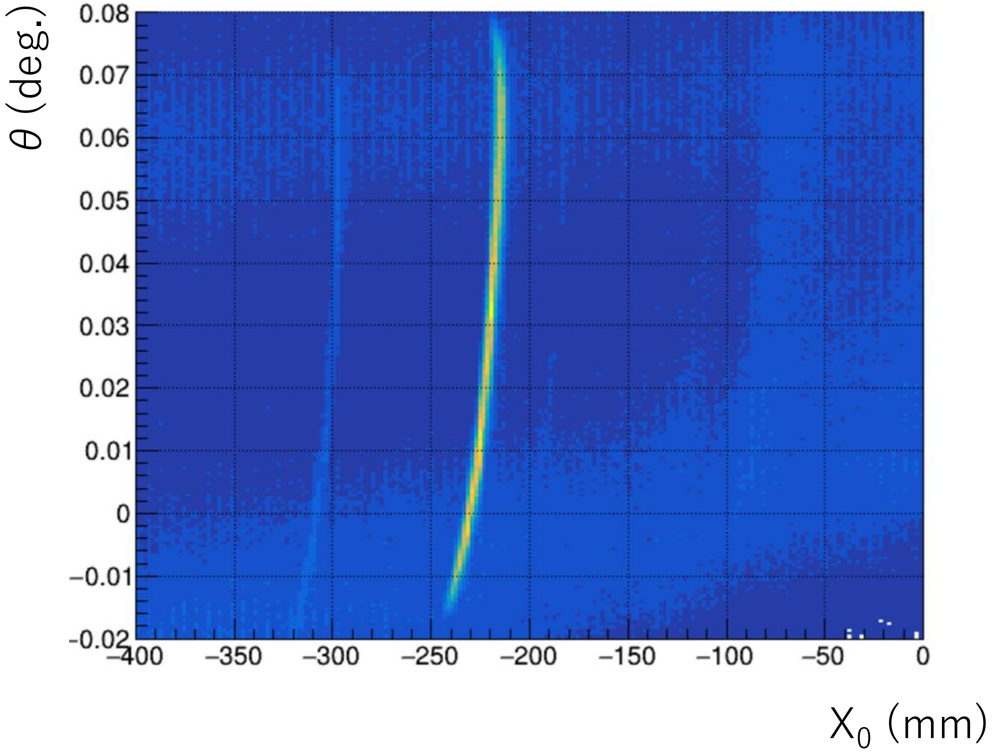
- Gate the 15.1 MeV peak region ($\theta \in [-0.02, 0.08]$) in 0.02 deg. increments and analyze the X histograms.
- Extract the 15.1 MeV peak position for each increment.
- Fit the (x, θ) dataset using the method of least squares to obtain the function f(θ).

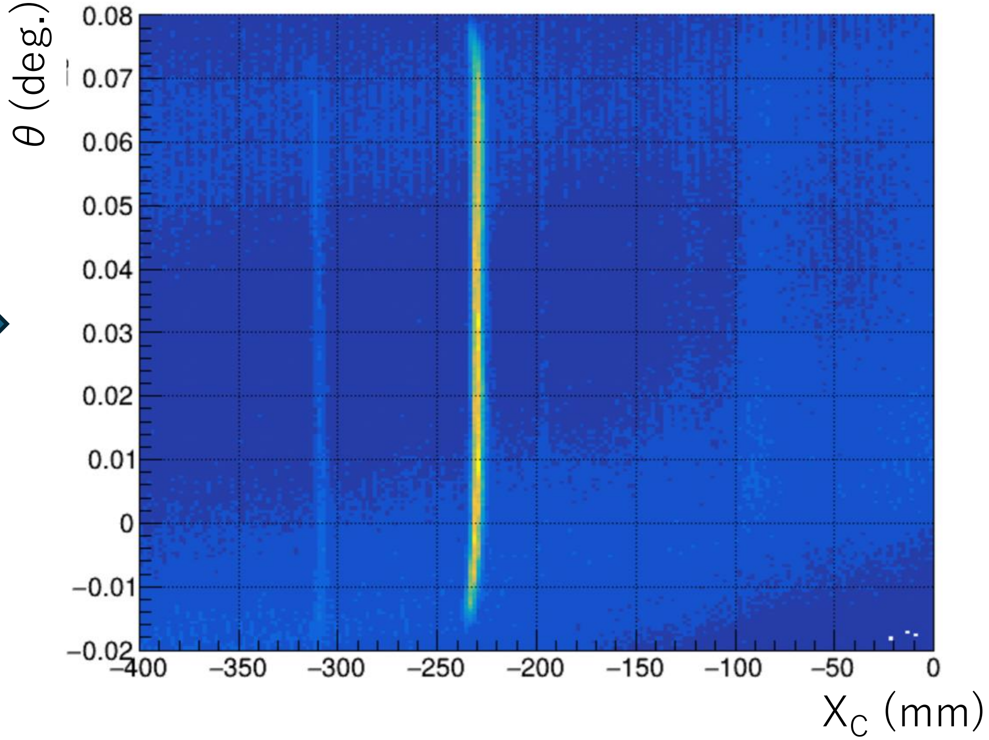
$$X_c = X_0 + f(\theta) \qquad f(\theta) = d_2\theta^2 + d_1\theta$$



Analysis – focal plane calibration

Close-up view

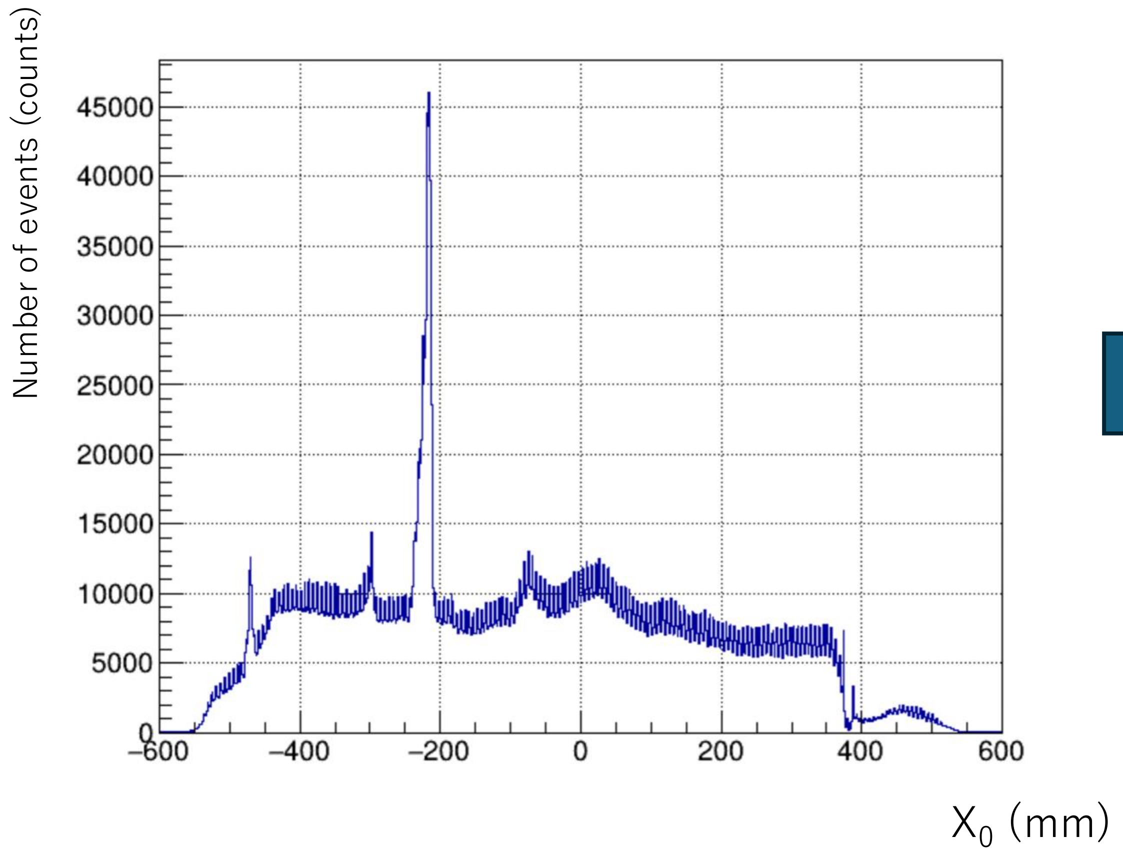


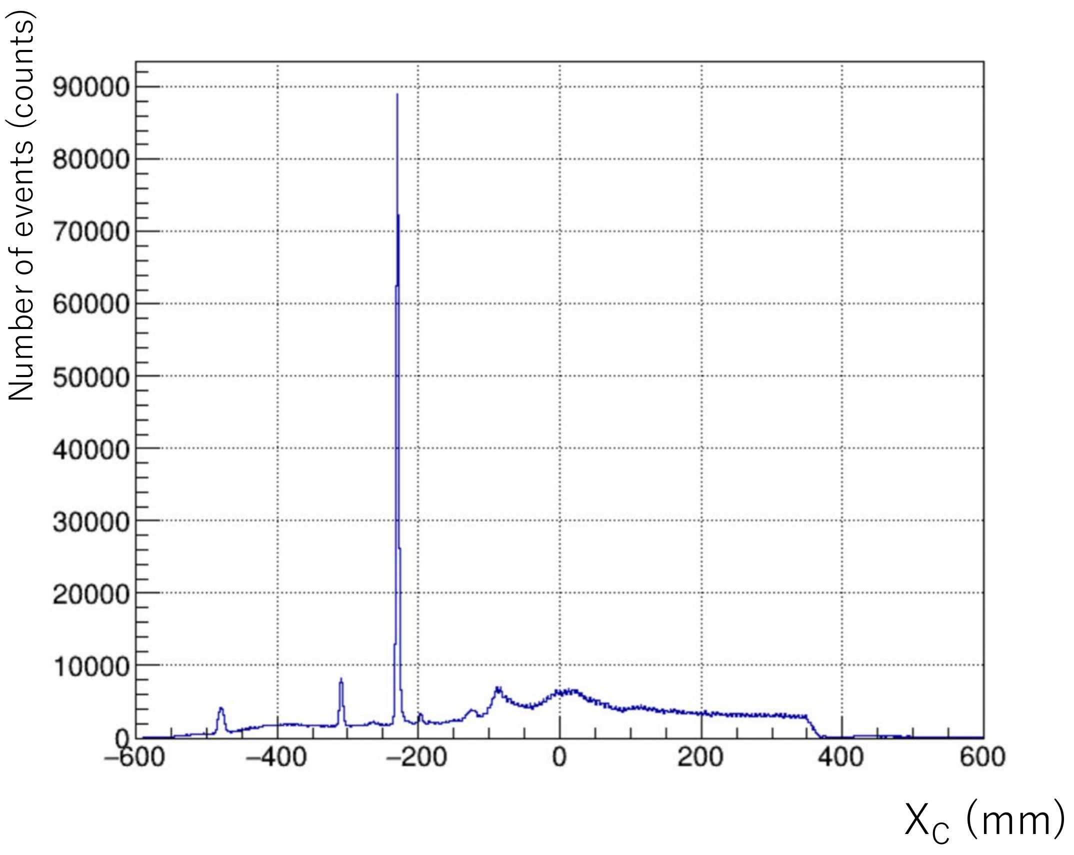


→Improve the peak resolution of the X histogram.

Analysis – focal plane calibration

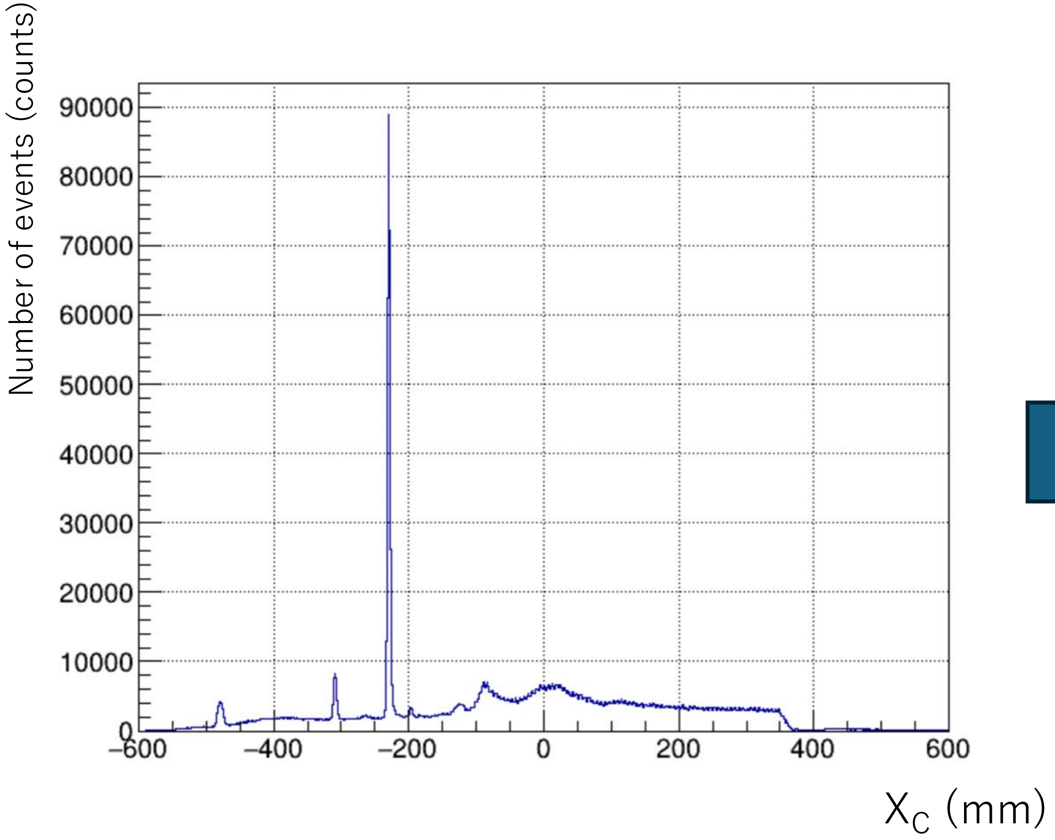
Comparison of X - histgram

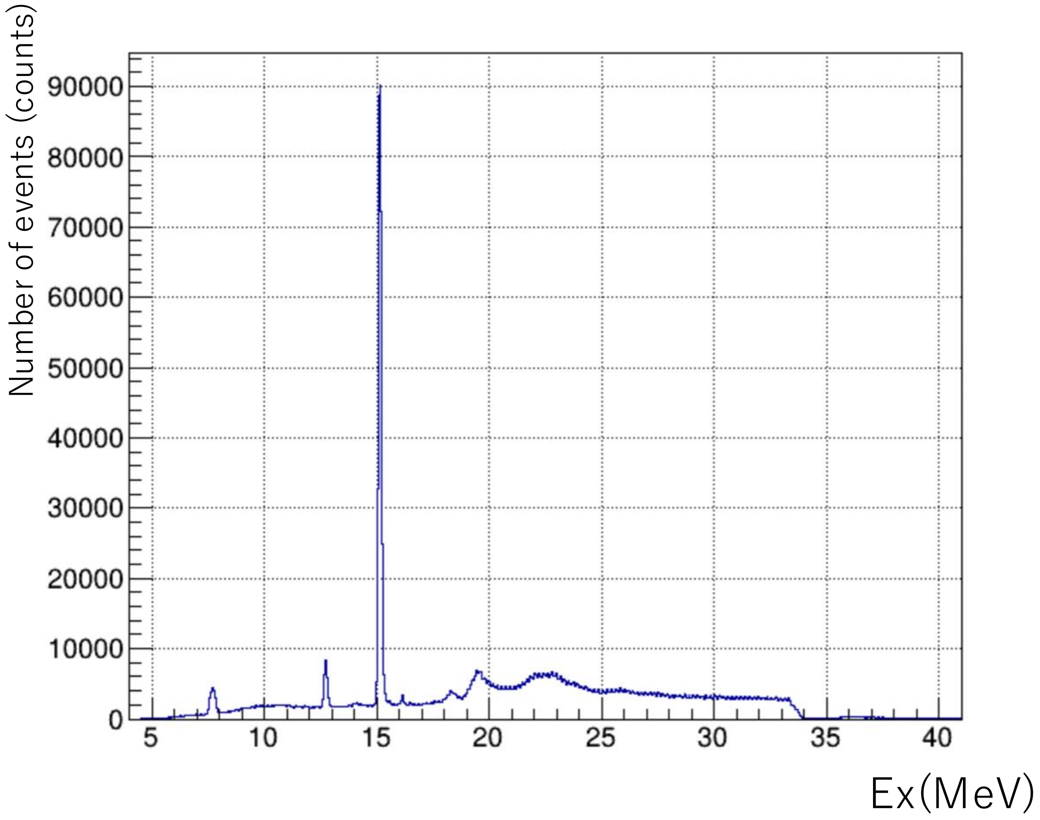




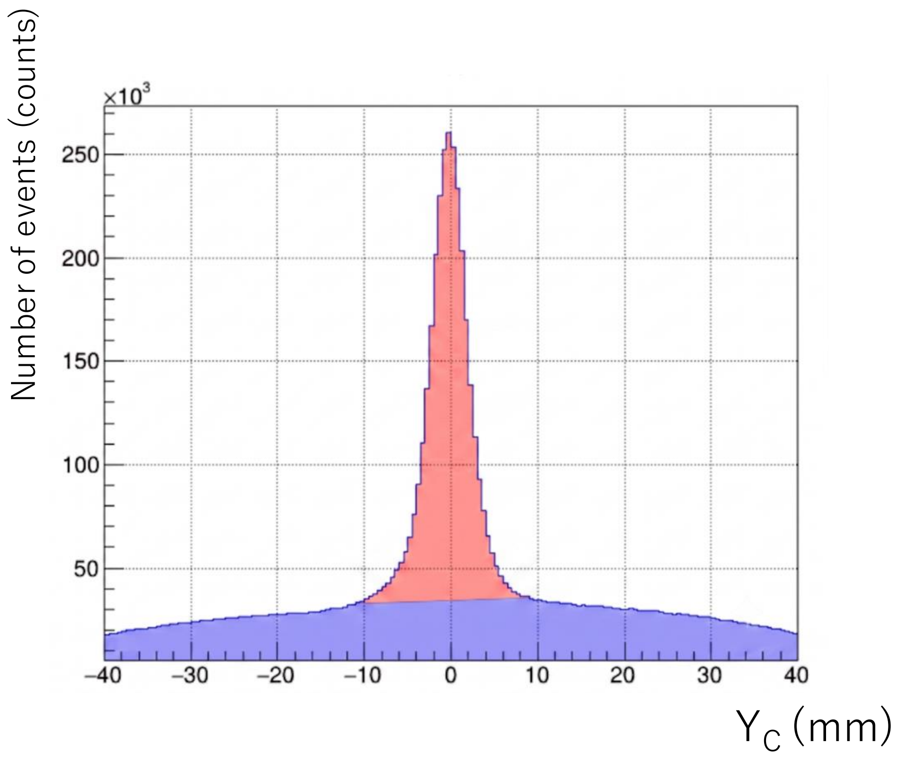
Analysis – Energy Calibration

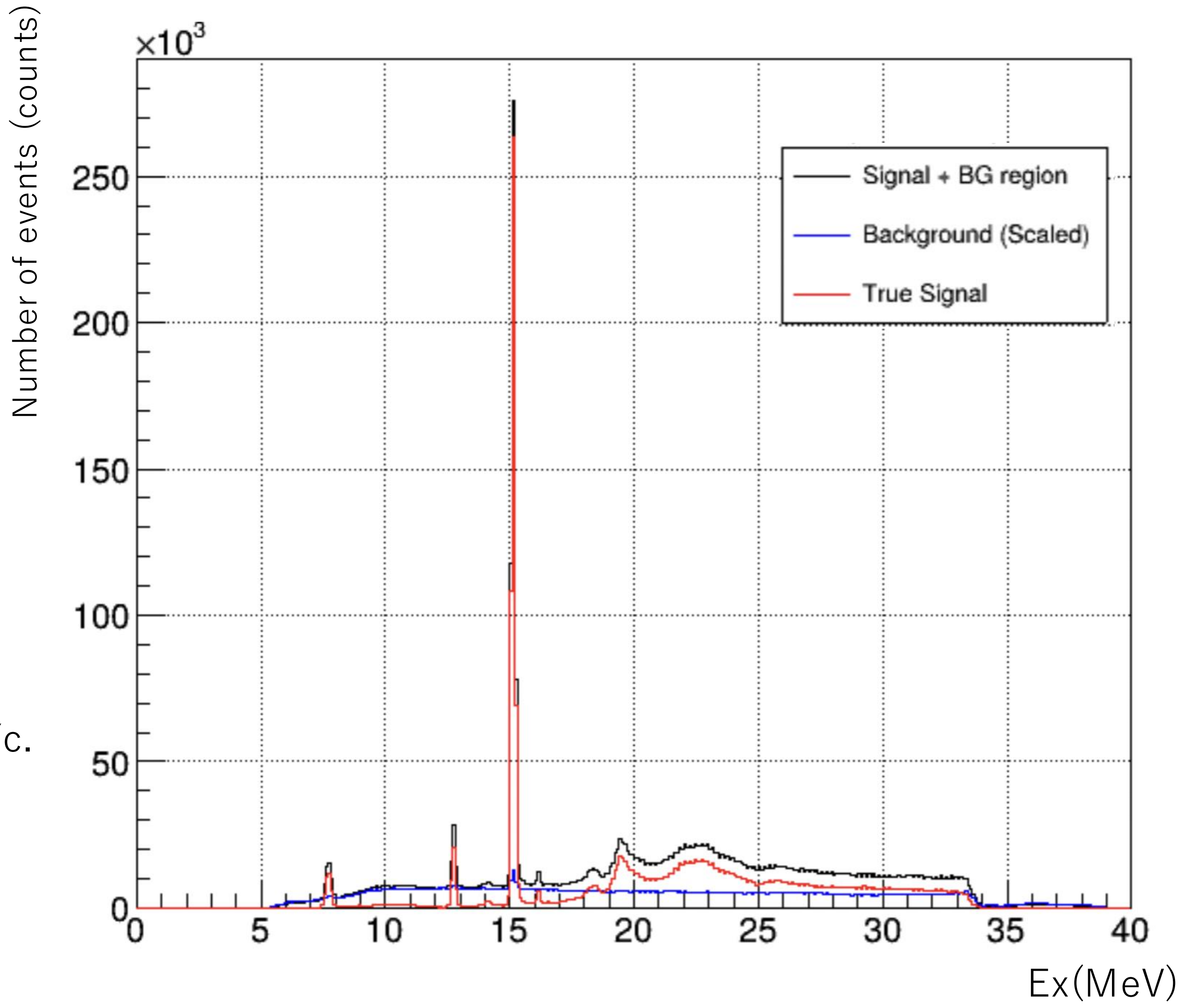
- Extract Xc coordinates for the three known excitation energies (7.65MeV, 12.7MeV, 15.1MeV) using Gaussian peak fitting.
- Fit the (Ex, Xc) dataset using the method of least squares to obtain the function Ex = f(Xc).





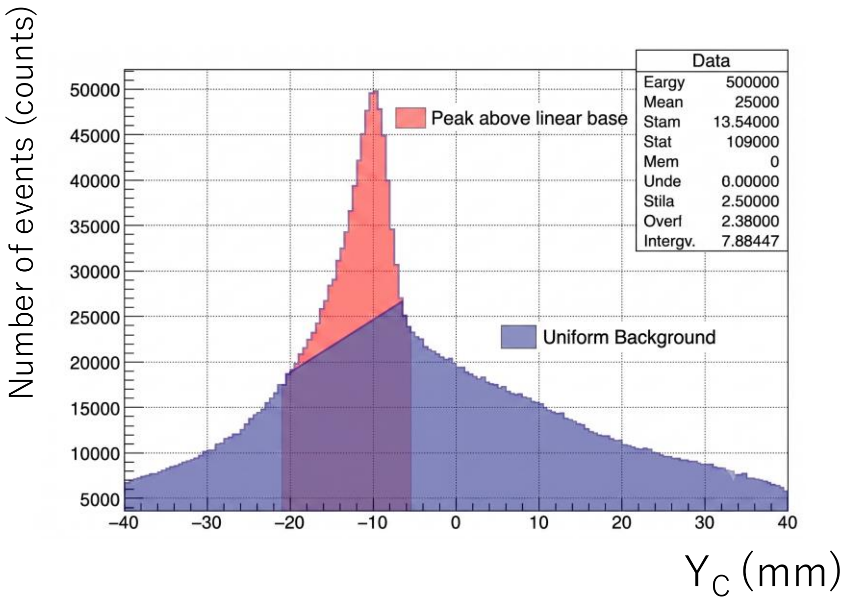
Analysis – ^{12}C Background Subtraction

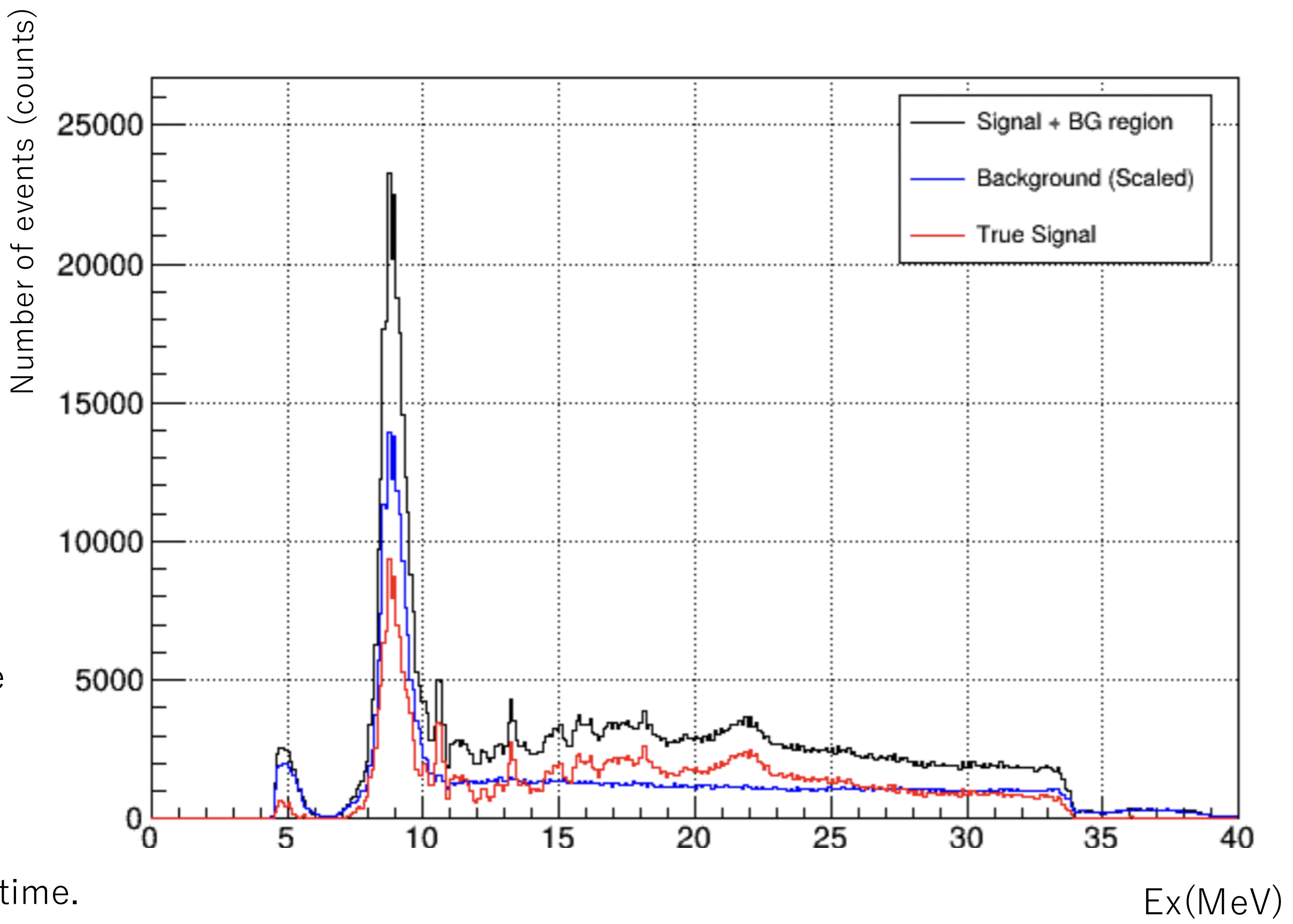




- Background subtraction was performed by gating on Yc.
- The gated ranges were set to [-7, 7] for the true peak, and [-17, -7] & [7, 17] for the background.

Analysis – ^{26}Mg Background Subtraction





- Applied the same method and parameters as the previous analysis for ^{26}Mg calibration and background subtraction.
- The gated ranges were set to [-20, -6] for the true peak, and [-30, -20] & [-6, 4] for the background.
- Note that the Yc peak parameters need adjustment, but were left unchanged for this time.

Result

Formula of Double-differential Cross Section

$$\frac{d^2\sigma}{d\Omega dE_x} = \frac{A}{\rho N_A N_{in}} \frac{1}{\varepsilon_{DAQ}\varepsilon_{VDC}} \frac{J}{\Delta\Omega} \frac{1}{\Delta E} Y \qquad [\mathrm{mb/sr/MeV}]$$

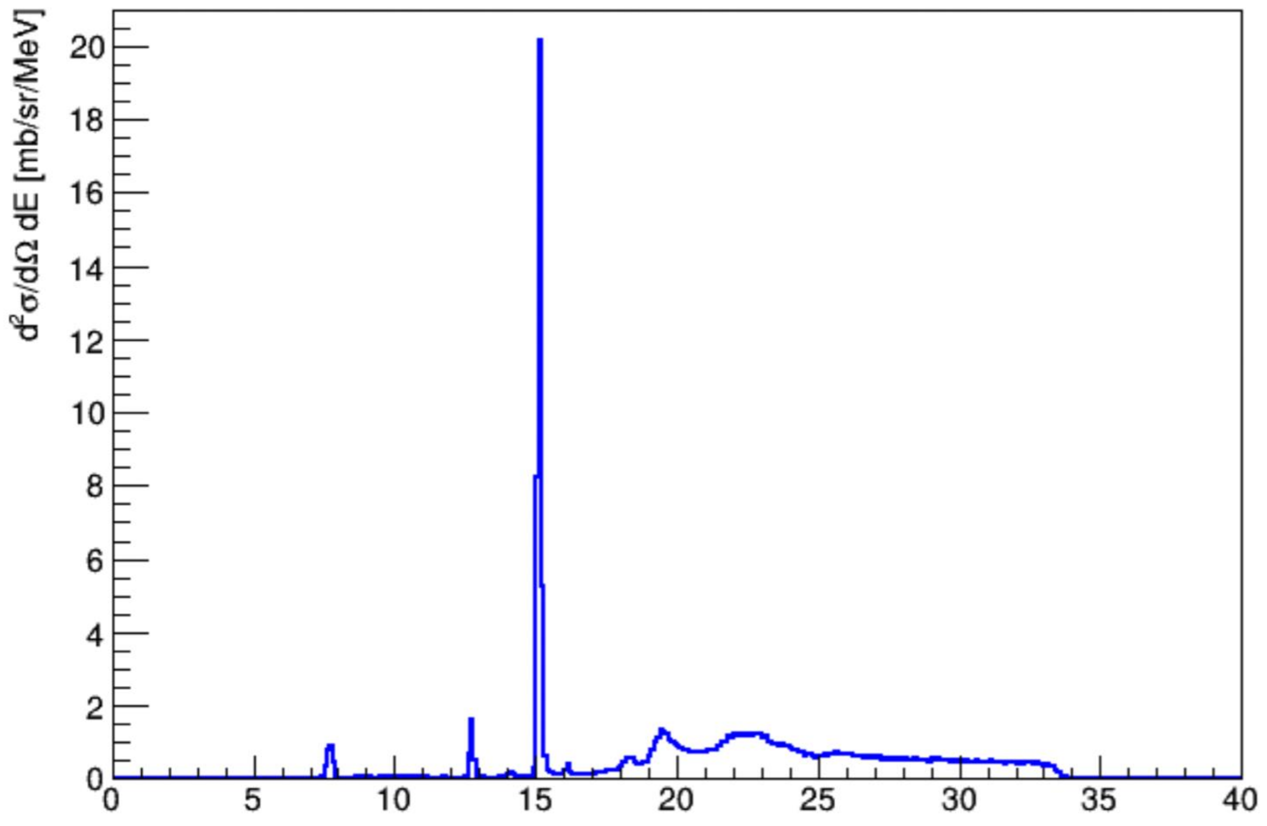
N_A : Avogadro's number
J : Jacobian for the laboratory-to-center-of-mass transformation
A : Mass per mol
ρ : Target density
N_{in} : Number of incident particles
$\Delta\Omega$: Scattering solid angle used in this analysis
ΔE : Energy bin width
ε_{DAQ}: DAQ efficiency
ε_{VDC}: VDC tracking efficiency
Y : Yield

	12C	26Mg
J	0.81	0.81
A (g/mol)	12	26
ρ (g/cm^2)	29.0	0.872
Nin	2.3E+13	1.0E+14
Δ Ω (msr)	4.0	4.0
Δ E (MeV)	0.1	0.1
ε DAQ (%)	100	100
ε VDC (%)	70	70

Result Double-differential Cross Section

The DDCS of ^{12}C

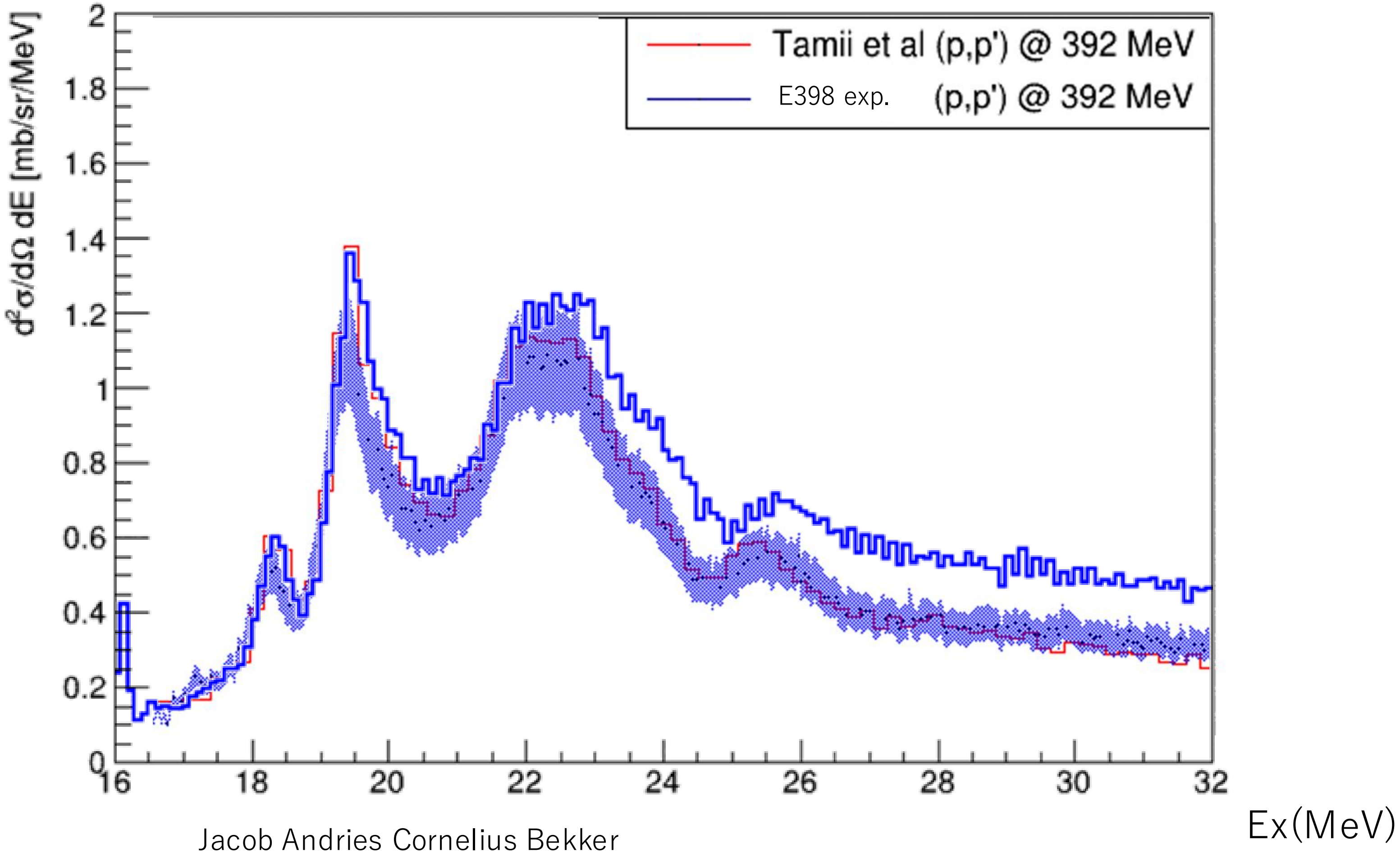
- Plot over the full excitation energy region.



Ex(MeV)

Result

The plot focused on the Giant Dipole Resonance (GDR) region above 16 MeV was compared with previous experimental data.

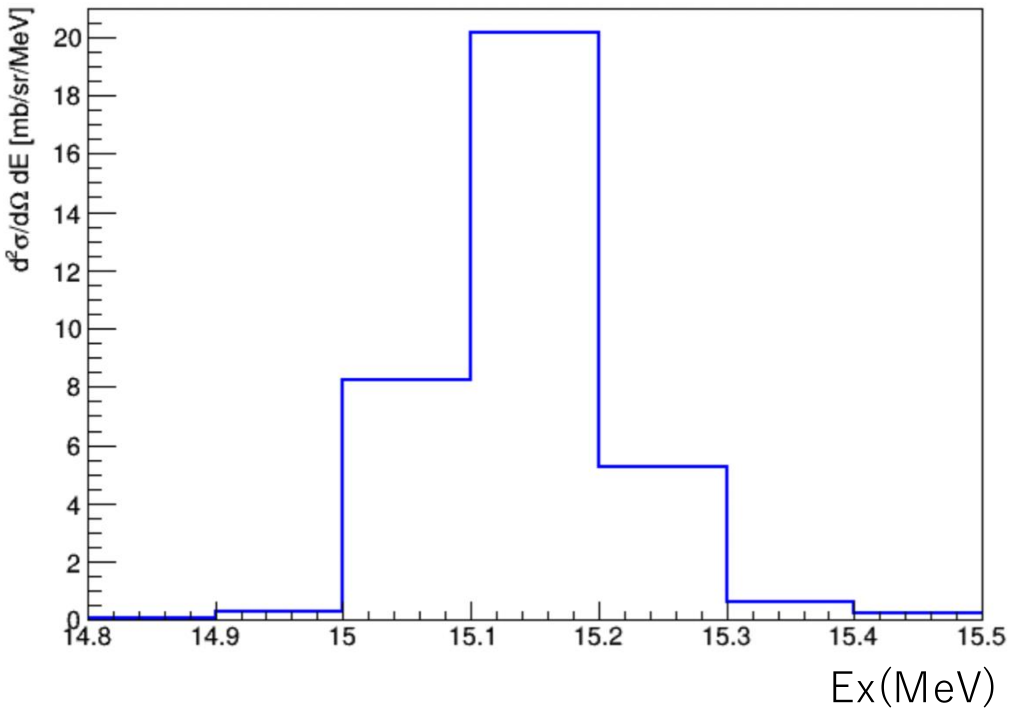


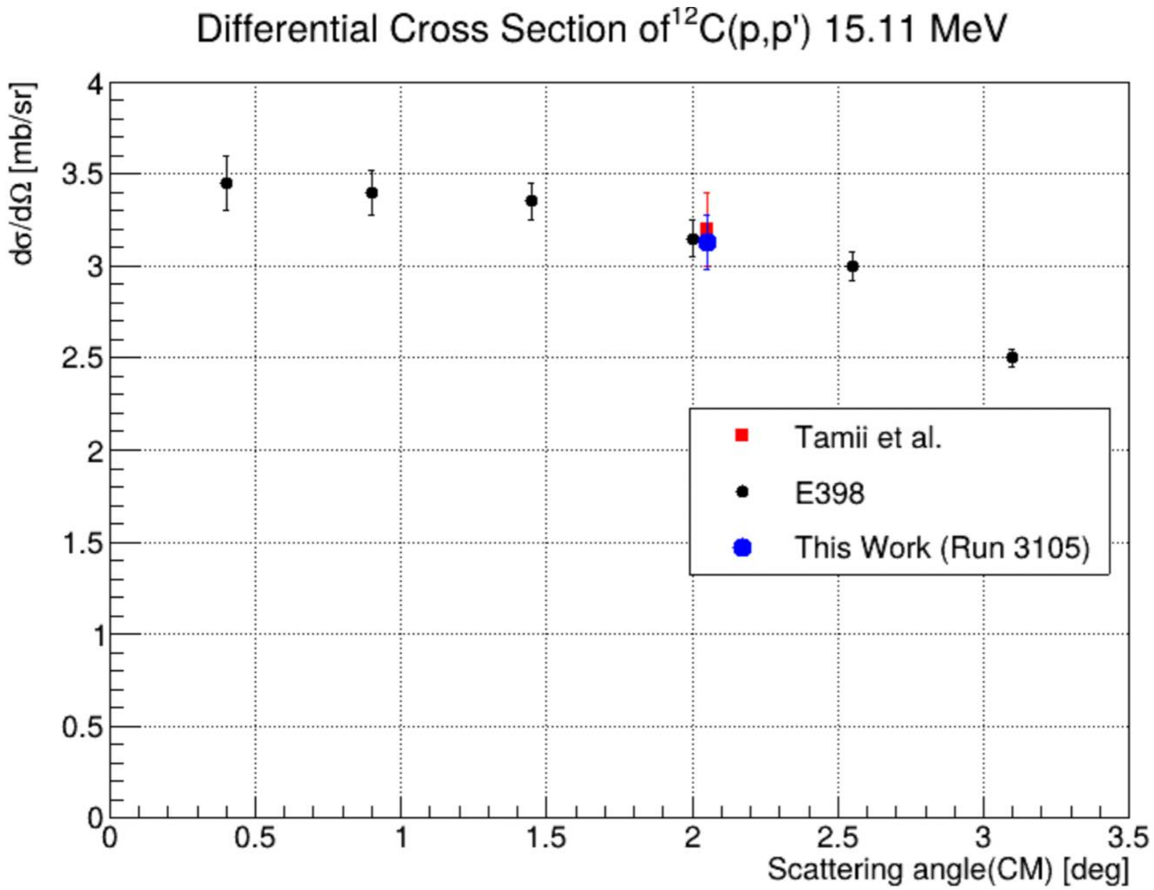
Jacob Andries Cornelius Bekker
PANDORA Project: Study of the photo-absorption response in light nuclei as input for UHECR propagation studies

Result

Differential cross section of 15.1MeV region

- The peak cross section was determined by Gaussian fitting and integration.
- The result shows very good agreement with past experimental data.

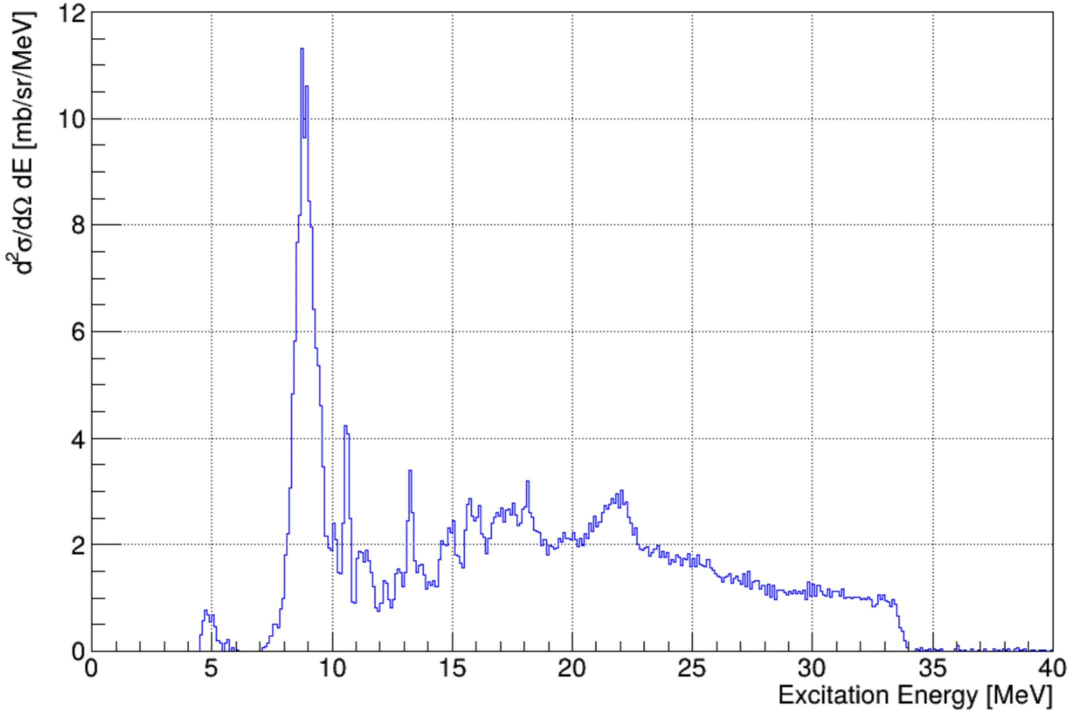


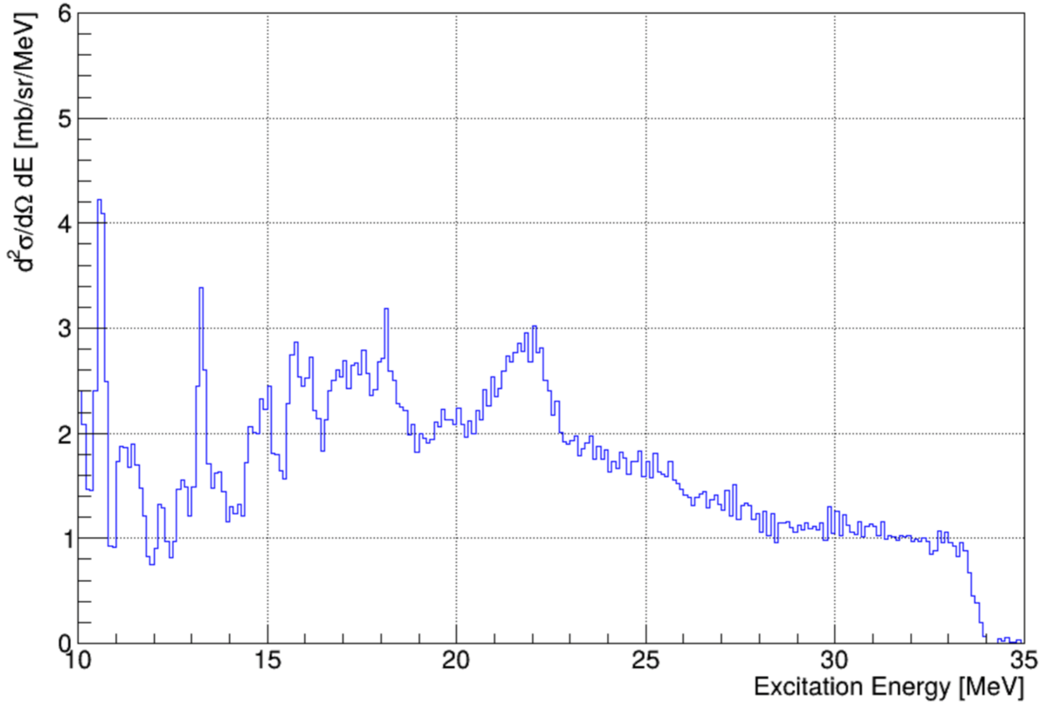


Results

The DDCS of ^{26}Mg

Left: Plot over the full excitation energy region.
Right: Plot focused on the GDR region.





Summary and Attempt

Summary

- The second PANDORA experiment was performed at RCNP in 2025 to figure out the energy loss mechanisms of ultra-high-energy cosmic rays (UHECRs) during intergalactic propagation.
- Data analysis of the ^{12}C nucleus was conducted and its scattering cross section was determined to calibrate the VDC and compare the results with the first experiment.
- The differential scattering cross sections for ^{26}Mg at 0 deg. were successfully obtained.

Attempt

- Deduced provisional values (such as VDC efficiency and scattering solid angle adopted from the previous experiment) will be updated with precise values to achieve higher accuracy for the final cross sections.

- The photoabsorption cross section and the decay branching ratios for proton and α emissions from ^{26}Mg at will 0 deg. be determined.