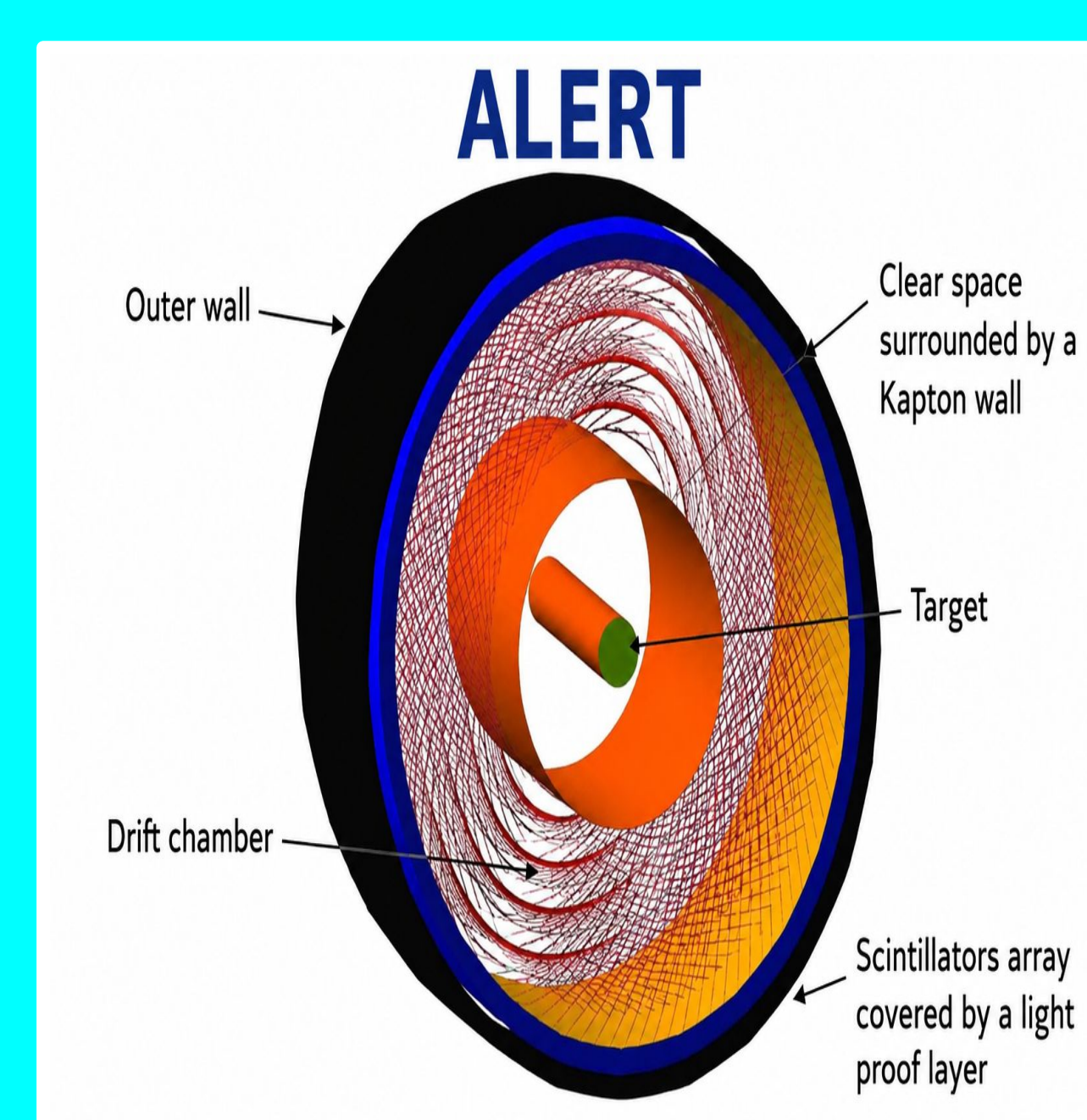
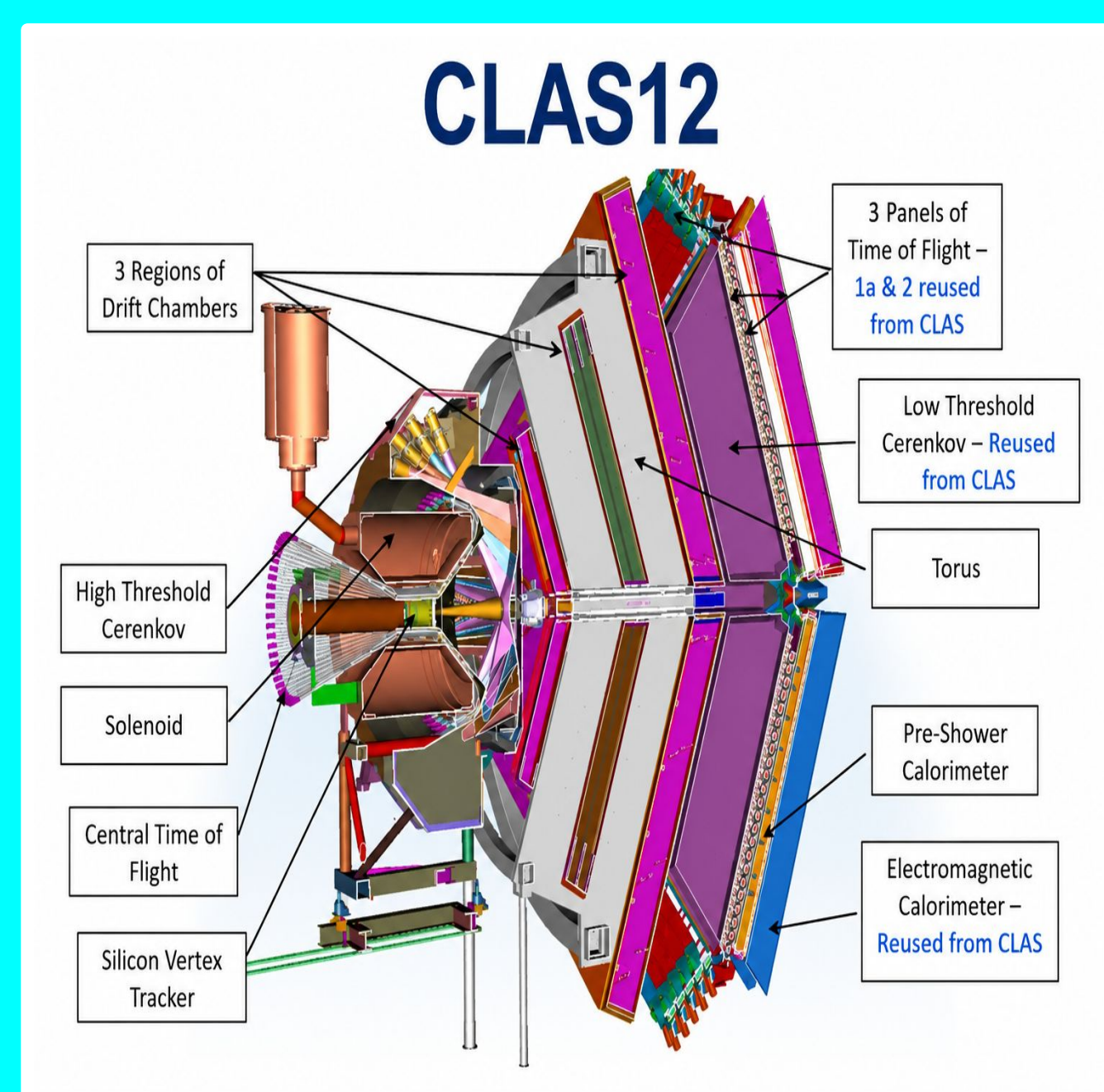
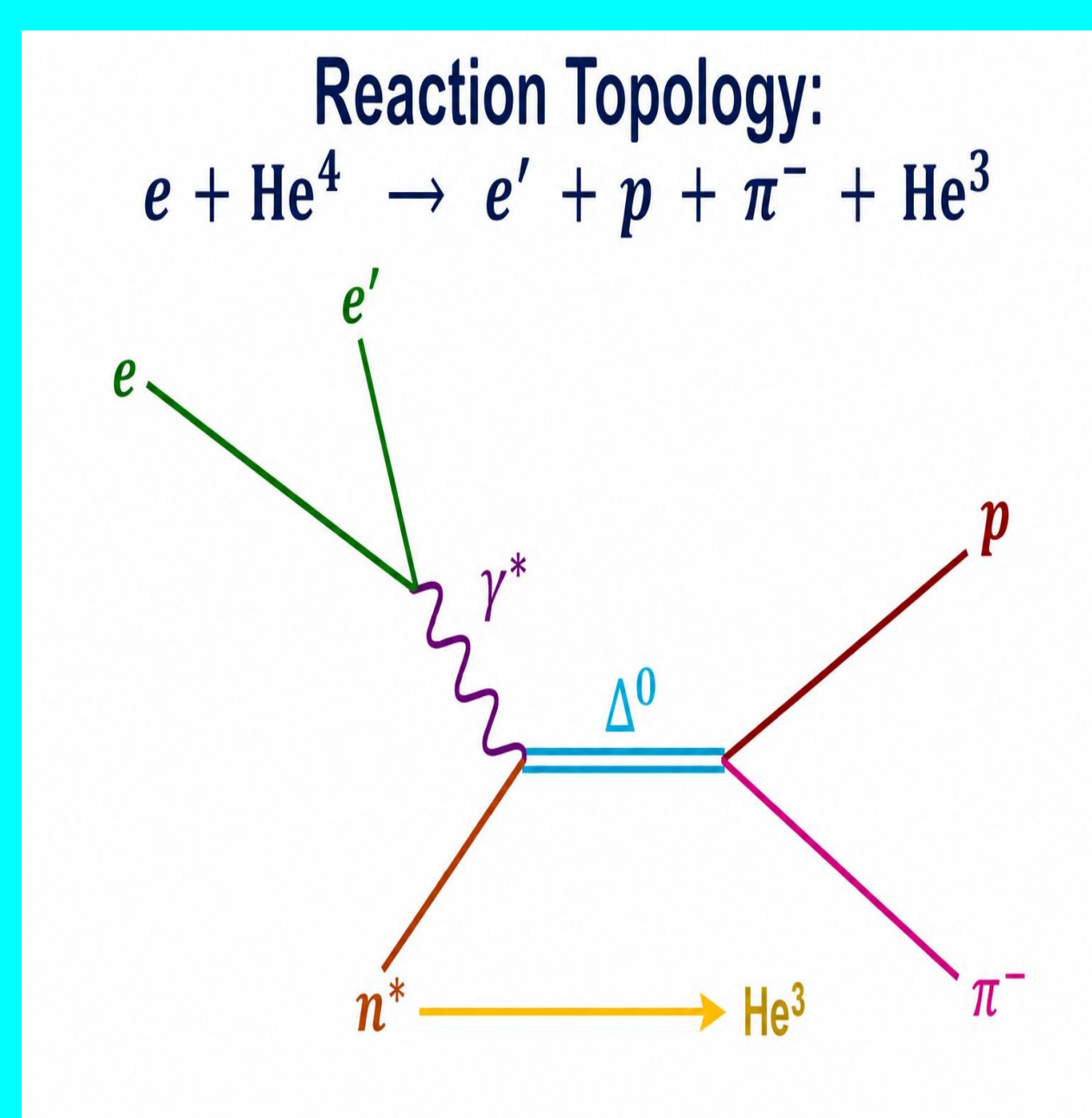


## Abstract

The Low Energy Recoil Tracker (ALERT) program at Jefferson Lab studies the structure of nucleons bound in nuclei through electron scattering. This work investigates the N→Δ(1232) transition of strongly bound neutrons in He<sup>4</sup> by measuring the scattered electron, Δ decay products, and recoiling He<sup>3</sup> nucleus. The extracted transition form factors will be compared with quasi-free measurements to probe differences between bound and free nucleons. These measurements provide sensitivity to the influence of the nuclear environment on nucleon structure and dynamics. Presented here is progress on the Monte Carlo simulations and reconstruction studies that support future analysis of experimental ALERT data.

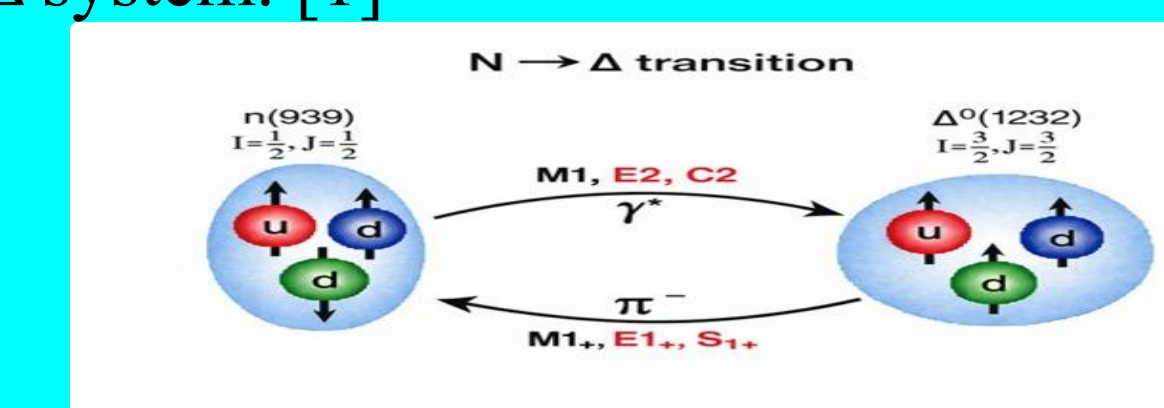
## CLAS12 and ALERT (HALL B)

- CLAS12 detects scattered electrons and other charged and neutral particles produced in electron–target interactions. e<sup>+</sup>, p, π<sup>-</sup> are detected in CLAS12.
- ALERT detects and identifies low-energy recoil nuclei and nucleons emitted from the target. p, He<sup>3</sup> are detected in ALERT.



## Electromagnetic Form Factors

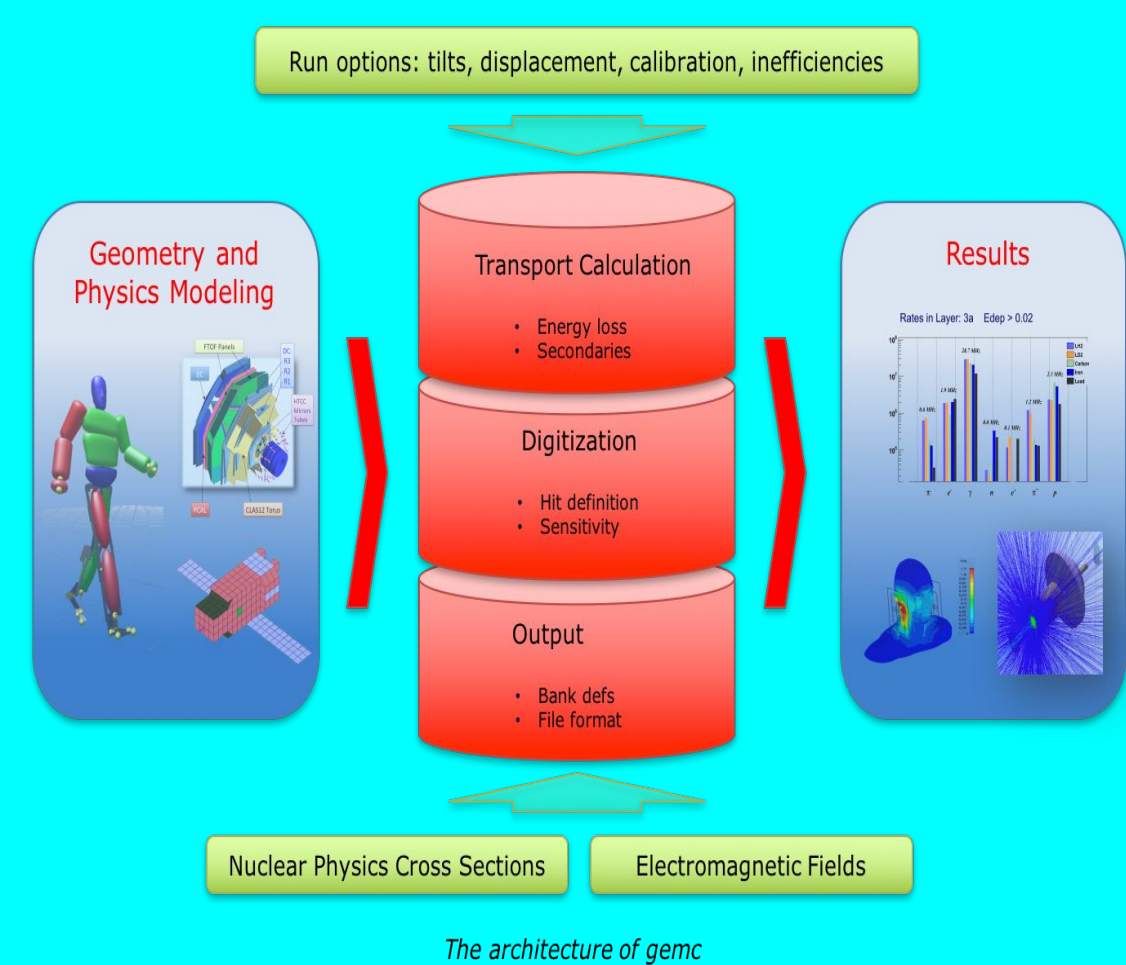
- N → Δ(1232) transition form factors describe how a nucleon is electromagnetically excited into its first excited state, the Δ(1232) [1].
- The ratios EMR = E2/M1 and CMR = C2/M1 quantify the electric and Coulomb quadrupole contributions relative to the dominant magnetic dipole (M1) transition. [1]
- Non-zero EMR and CMR are sensitive probes of non-spherical structure in the nucleon–Δ system. [1]



- ❑ **M1 (Magnetic Dipole)** — the dominant electromagnetic transition that excites the nucleon to the Δ(1232).
- ❑ **E2 (Electric Quadrupole)** — a smaller transition sensitive to non-spherical (deformed) quark distributions.
- ❑ **C2 (Coulomb Quadrupole)** — another smaller quadrupole transition, associated with the longitudinal (charge) component of the virtual photon and also sensitive to non-spherical structure.

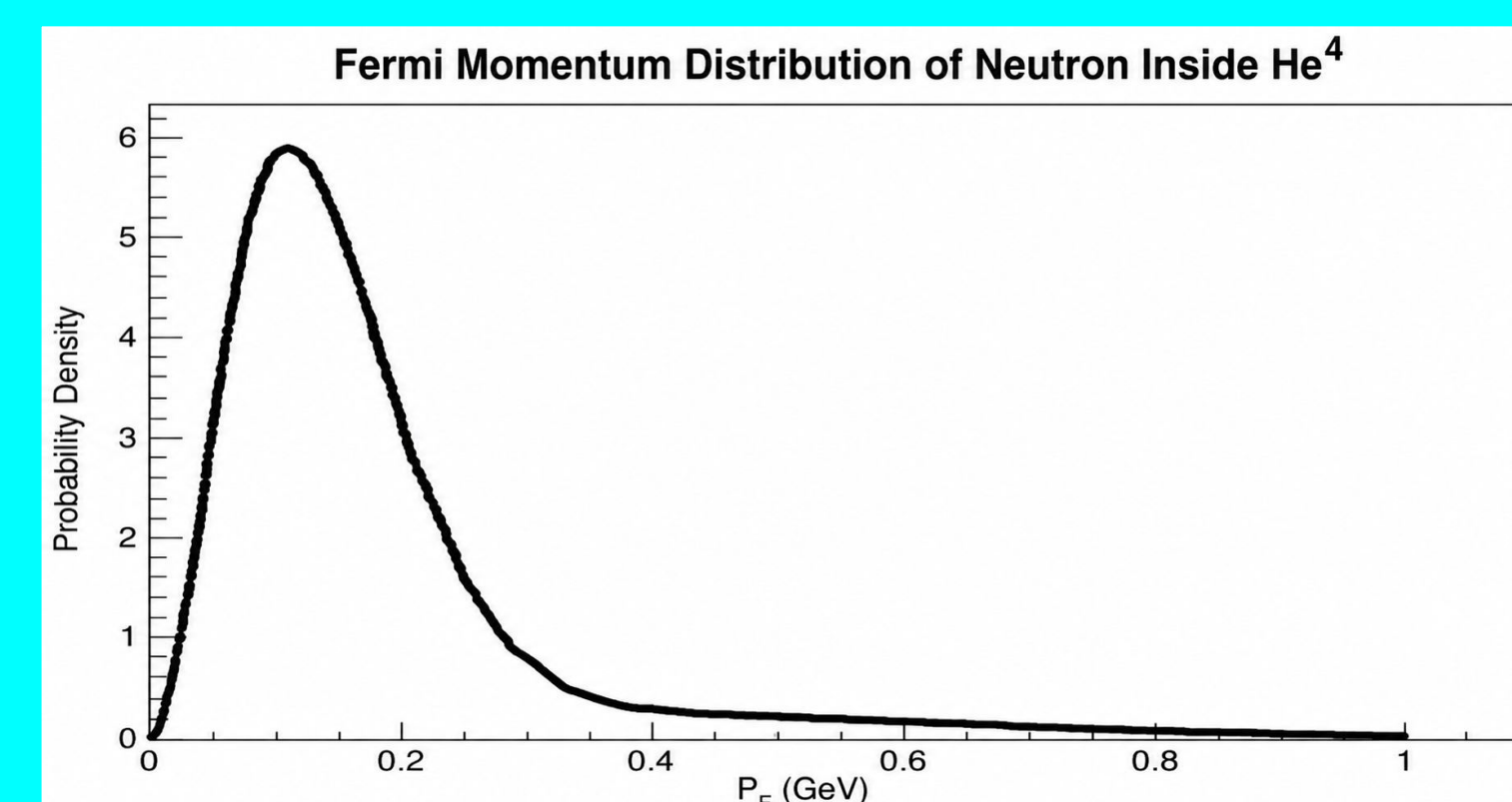
## GEMC

GEMC is the Geant4-based detector simulation package used by CLAS12. It models detector response, acceptance, and resolution, allowing realistic reconstruction studies before comparison with experimental data. [2, 3]

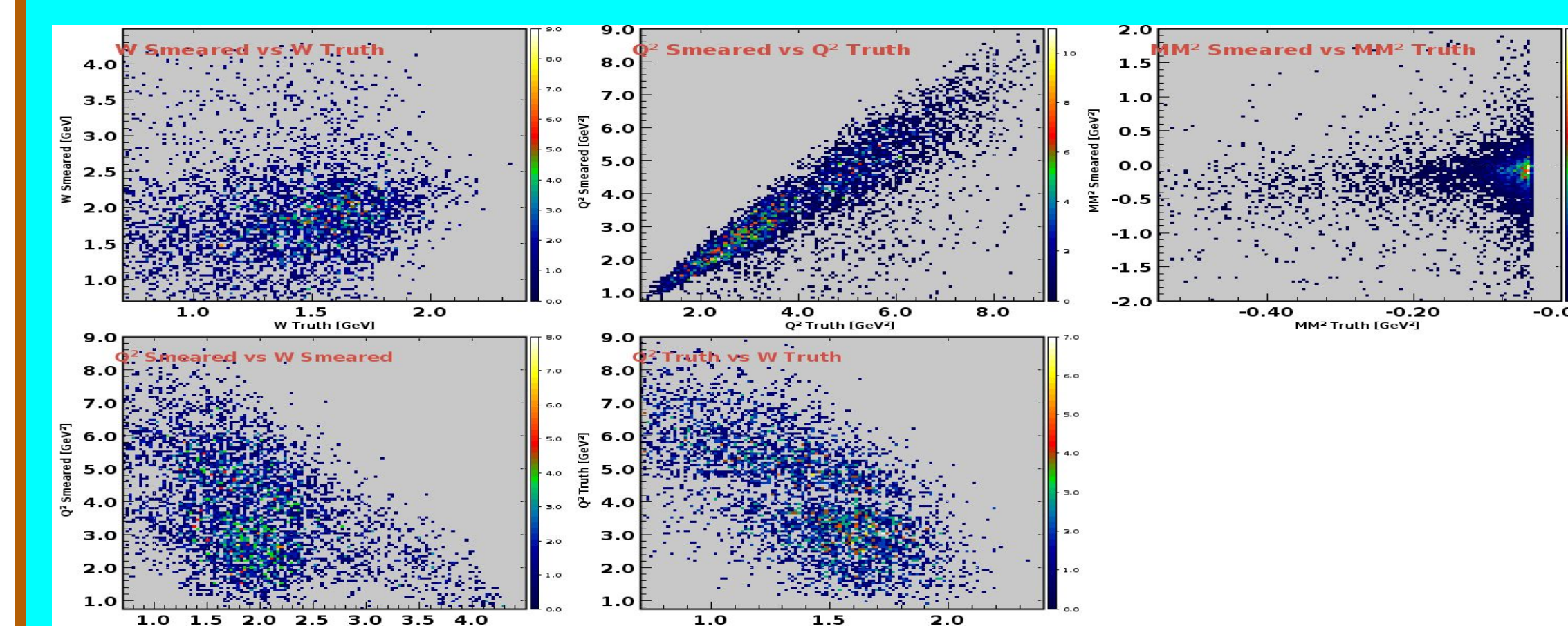


## Neutron Fermi Momentum

The Fermi motion of neutrons bound in He<sup>4</sup> modifies the reaction kinematics. Measuring the recoil He<sup>3</sup> nucleus helps reconstruct the neutron's initial momentum [4].

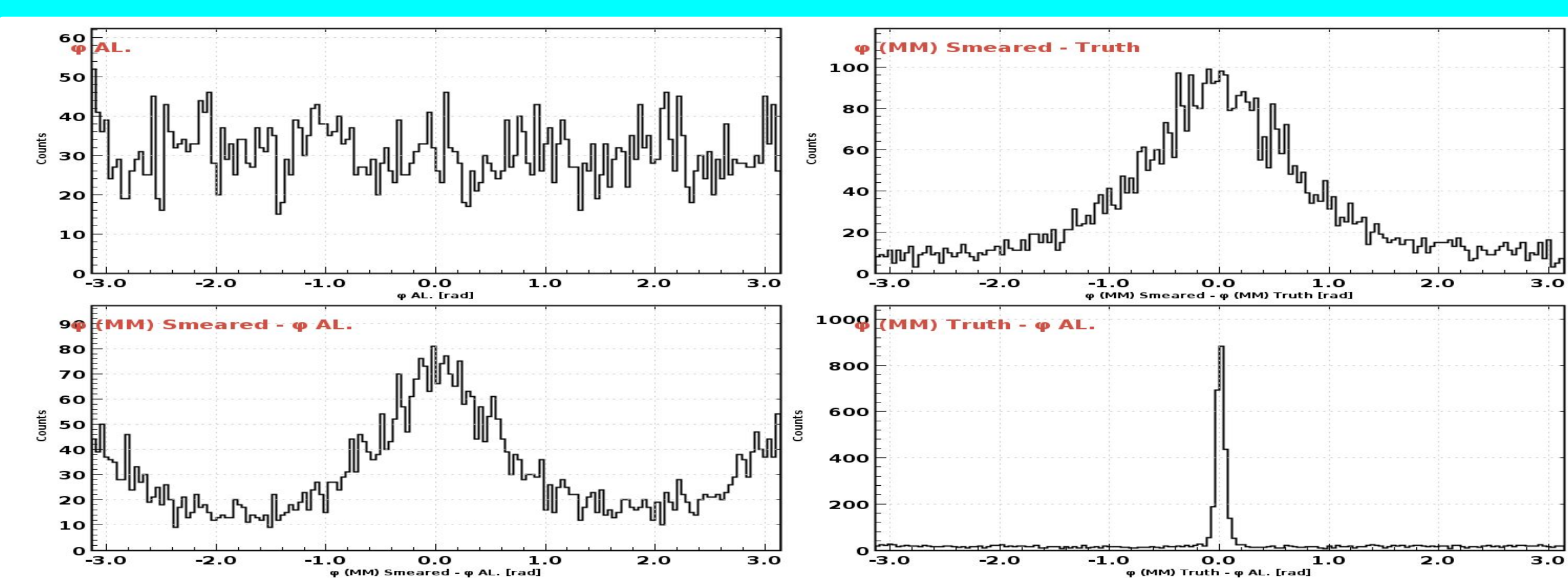


## CLAS12 Validation



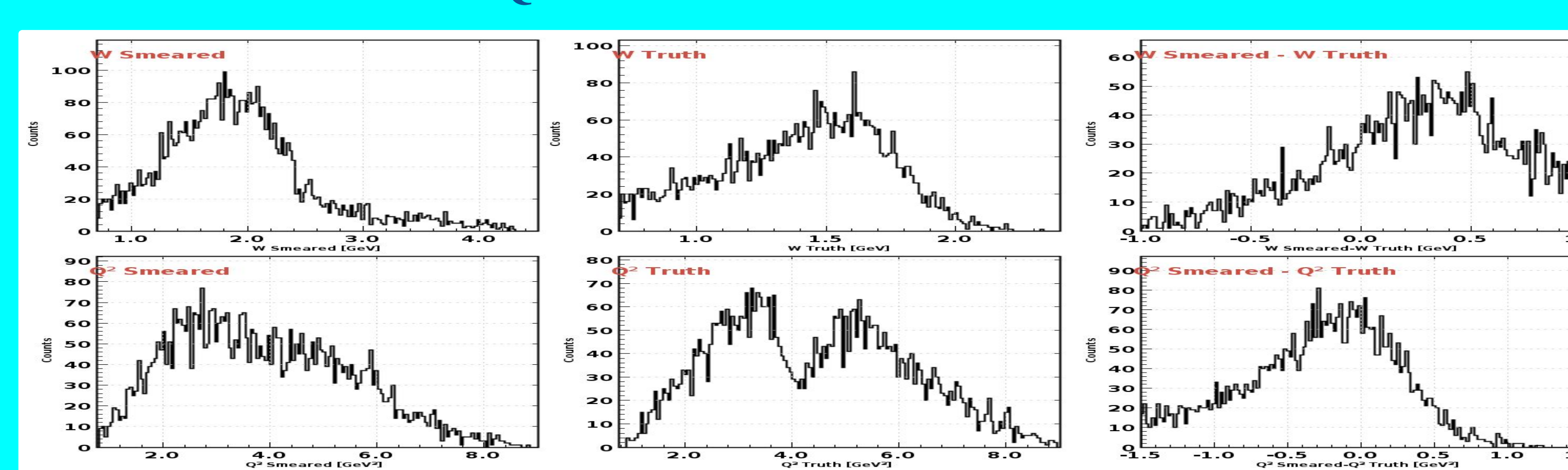
- ➔ Reconstructed Q<sup>2</sup> closely reproduces the generated distribution.
- ➔ Reconstructed W remains strongly correlated with the generated value.
- ➔ The missing-mass distribution is consistent with the simulated event topology.
- ➔ Accepted events populate the Q<sup>2</sup>–W phase space relevant for N→Δ(1232) studies.

## ALERT φ Validation



- ➔ φ (AL.) provides broad angular coverage across the detector acceptance.
- ➔ φ (MM) and φ (AL.) show good overall agreement.
- ➔ φ (MM) Truth – φ (AL.) peaks strongly at zero.
- ➔ ALERT tracking is consistent with the generated event topology.

## W and Q<sup>2</sup> Reconstruction Performance



- ➔ Reconstructed W and Q<sup>2</sup> distributions closely follow the generated kinematics.
- ➔ Q<sup>2</sup> resolution is centered near zero, while W shows a broader asymmetric response.
- ➔ These results demonstrate stable kinematic reconstruction for future N→Δ studies in He<sup>4</sup>.

## Future Work

- ❖ Apply the validated reconstruction framework to experimental ALERT data.
- ❖ Refine event selection and background suppression for N→Δ(1232) events.
- ❖ Extract N→Δ transition form factors for bound neutrons and compare with quasi-free measurements.

## Acknowledgments

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## References

1. C. Alexandrou, C. N. Papanicolas, and M. Vanderhaeghen, The Shape of Hadrons, Rev. Mod. Phys. 84, 1231 (2012).
2. M. Ungaro et al., GEMC: A Geant4 Monte Carlo for the CLAS12 Detector, Jefferson Lab.
3. <https://gemc.jlab.org/gemc/html/index.html>.
4. <https://koza.if.uj.edu.pl/files/f9a0d7be3bc6d315f04d727fb4b68e98/1509.01385.pdf>.