Updates on the ω Hadronization Analysis

Andrés Bórquez[a]

Advisors: Hayk Hakobyan[a], Michael H. Wood[b], Taisiya Mineeva[a]

[a] *Universidad Técnica Federico Santa María, Valparaíso, Chile*

[b] *Canisius College, Buffalo, NY, United States*

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Jefferson Lab

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Outline

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   - Multiplicity Ratio
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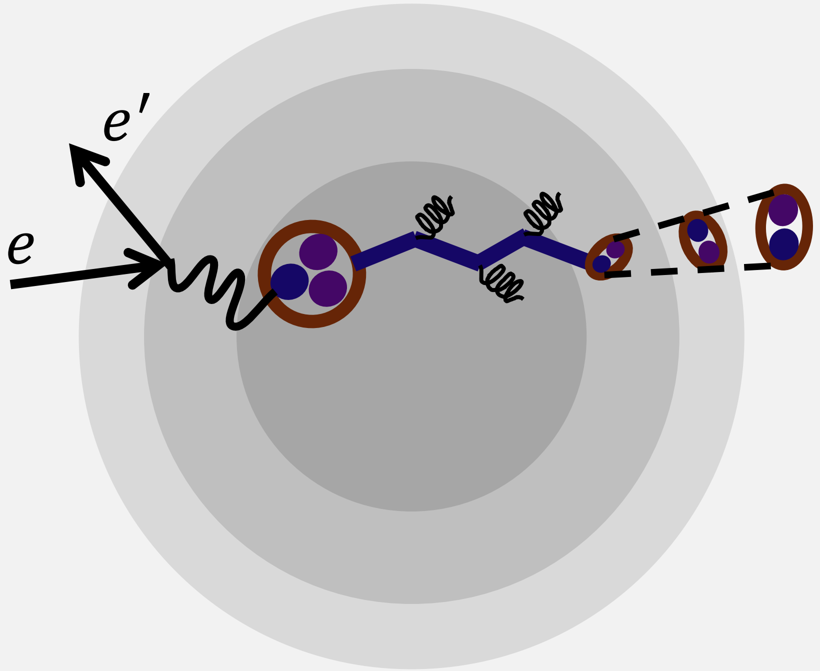
Hadronization is the formation of quarks and gluons into hadrons. **But how do nuclei of different sizes impact on this process?**



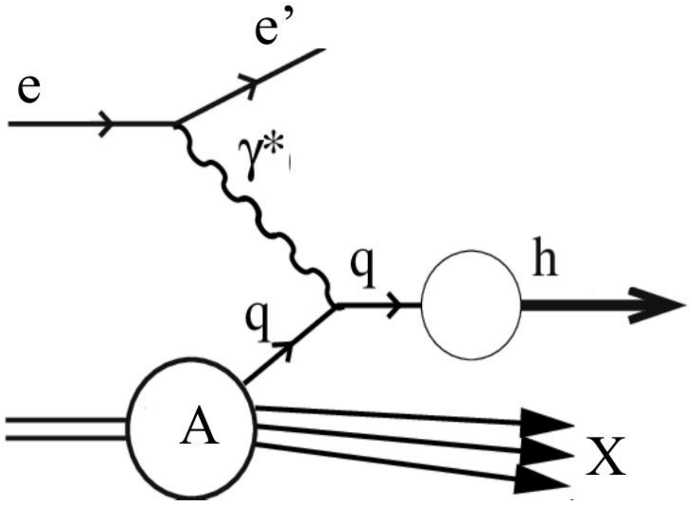
Semi-**I**nclusive **D**eep **I**nelastic **S**cattering

The study of hadron formation can be done through the process of **D**eep **I**nelastic **S**cattering (**DIS**), which allows us to probe the **internal structure of the nuclear medium**.

$$\boldsymbol{eA \to e'X}$$

The **Semi-Inclusive Deep Inelastic Scattering** (**SIDIS**) is an experimental technique where we can detect an extra hadron h at the final state.

$$\boldsymbol{eA \to e'hX}$$



Experimental variables

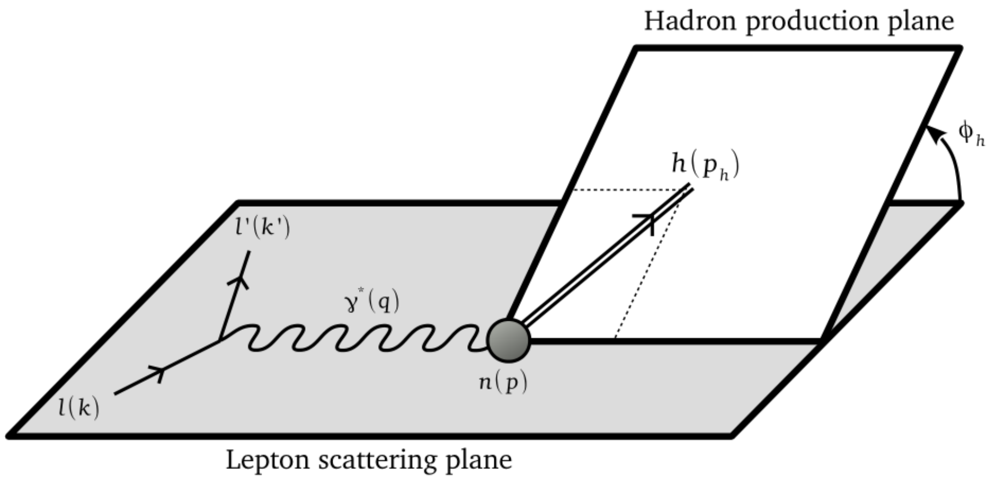
In the **laboratory frame of reference.**

<u>Electron variables</u>:

- $Q^2 = 4\, E_b E' \sin^2(\theta/2)$: virtuality of the probe electron.
- $\nu = E_b - E'$: energy transferred from the electron to the target.

<u>Hadron variables</u>:

- $z = E_h/\nu$: fraction of the virtual photon energy carried by the produced hadron.
- $p_T^2 = p_h^2\left(1 - \cos(\theta_{PQ})\right)$: transversal momentum of the hadron w.r.t. virtual photon direction.

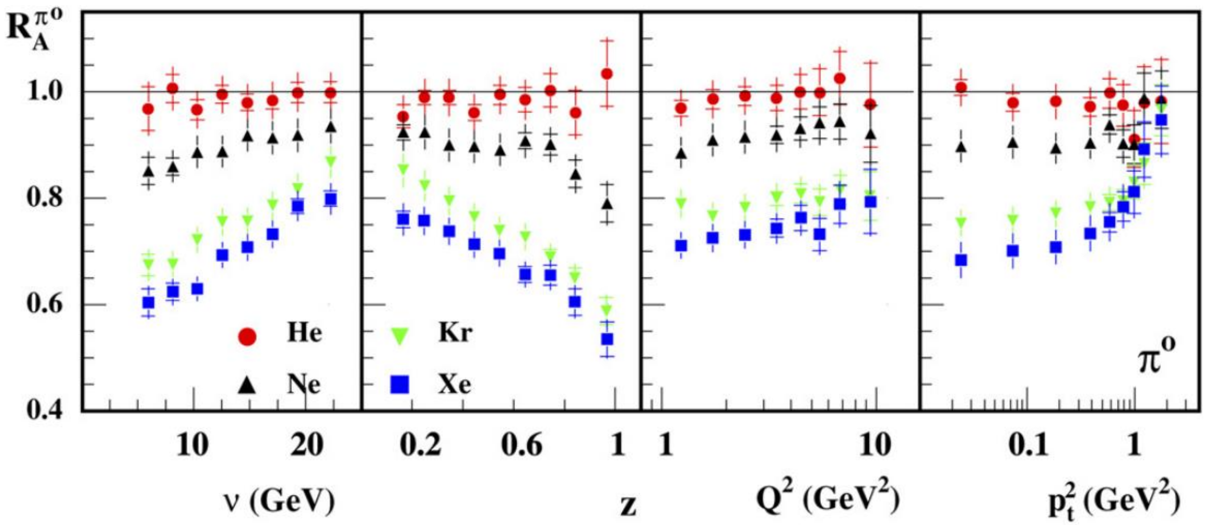


Multiplicity Ratio

The experimental **observable** to measure is the **ratio of hadron multiplicities** R_A^h observed in the scattering of a nucleus (A) to those on the deuteron (D):

$$R_A^h \equiv \frac{\left(\frac{N_h(Q^2,\nu,z,p_T^2)}{N_e^{DIS}(Q^2,\nu)}\right)_A}{\left(\frac{N_h(Q^2,\nu,z,p_T^2)}{N_e^{DIS}(Q^2,\nu)}\right)_D}$$

Where $\boldsymbol{N_h}$ is the number of semi-inclusive hadrons h in a given (Q^2,ν,z,p_T^2) bin and $\boldsymbol{N_e^{DIS}}$ the number of inclusive DIS electrons in the same (Q^2,ν) bin.



HERMES Collaboration. *Hadronization in semi-inclusive deep-inelastic scattering on nuclei.* Nucl. Phys. B **780,** 1-27 (2007)

The meson sector

- This analysis follows a line of investigation in the hadronization of the meson sector,
  - π^0 analysis from Taisiya Mineeva[a]
  - η meson hadronization from Orlando Soto[b]

Particle	$\boldsymbol{\pi^0}$	$\boldsymbol{\eta}$	$\boldsymbol{\omega}$
Charge	0	0	0
Type of meson	Pseudoscalar	Pseudoscalar	Vector
Mass (GeV)	~ 0.135	~ 0.548	~ 0.782
Mean lifetime (s)	$\sim 10^{-17}$	$\sim 10^{-19}$	$\sim 10^{-23}$
Quark content	$u\bar{u} - d\bar{d}$	$u\bar{u} + d\bar{d} - 2s\bar{s}$	$u\bar{u} + d\bar{d}$
Decay channels (%)	$\pi^0 \rightarrow \gamma\gamma$ (99%)	$\eta \rightarrow \gamma\gamma$ (39%) $\eta \rightarrow \pi^0\pi^0\pi^0$ (33%) $\eta \rightarrow \pi^+\pi^-\pi^0$ (23%)	$\boldsymbol{\omega \rightarrow \pi^+\pi^-\pi^0}$ **(89%)** $\omega \rightarrow \pi^0\gamma$ (8%)

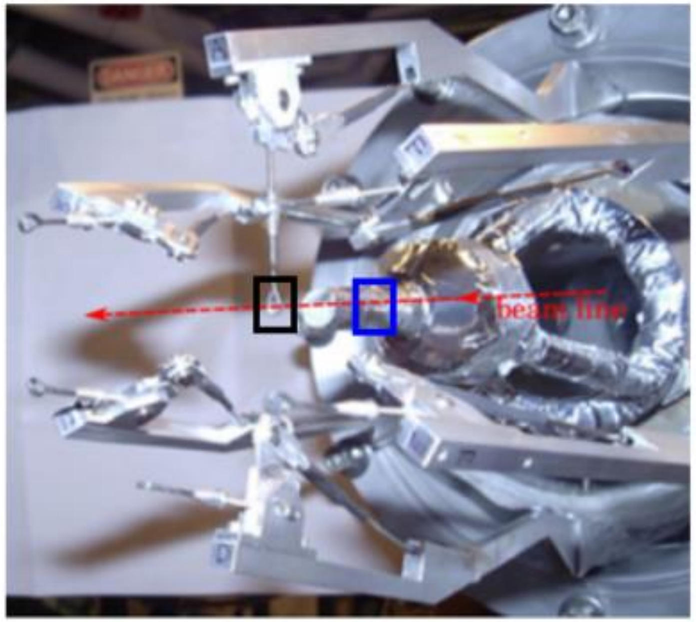
- World's first study on the hadronization of the ω meson.

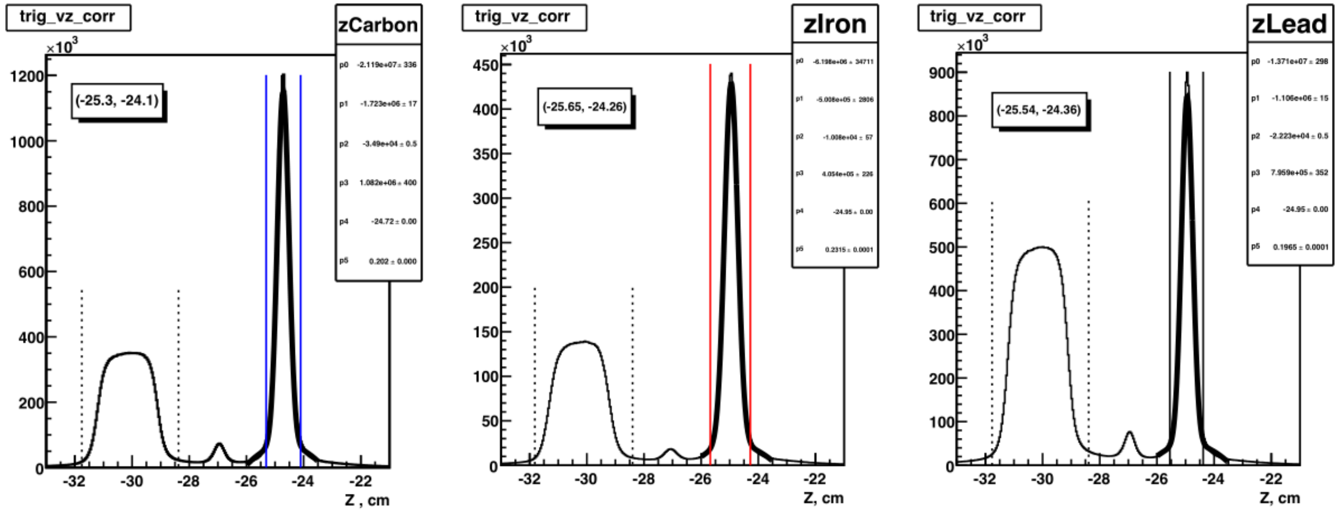
[a]T. Mineeva et al. *Neutral Pion Multiplicity Ratios from SIDIS Lepton-nuclear Scattering*. CLAS Analysis Note
[b]O. Soto. *Hadronization studies of η mesons using the CLAS spectrometer*. Ph.D. Thesis (2018)

CLAS6 EG2 Experiment

This experiment consisted of a 5 GeV electron beam incident on a double-target system where the beam passed through a **liquid target D (Deuterium)** and a **solid heavy target $A(C, Fe, Pb)$** simultaneously positioned in the **beam line**.

Main features: same luminosity for different nuclei, and reduction of systematic uncertainties.





T. Mineeva et al. *Neutral Pion Multiplicity Ratios from SIDIS Lepton-nuclear Scattering*. CLAS Analysis Note

Particle ID Scheme

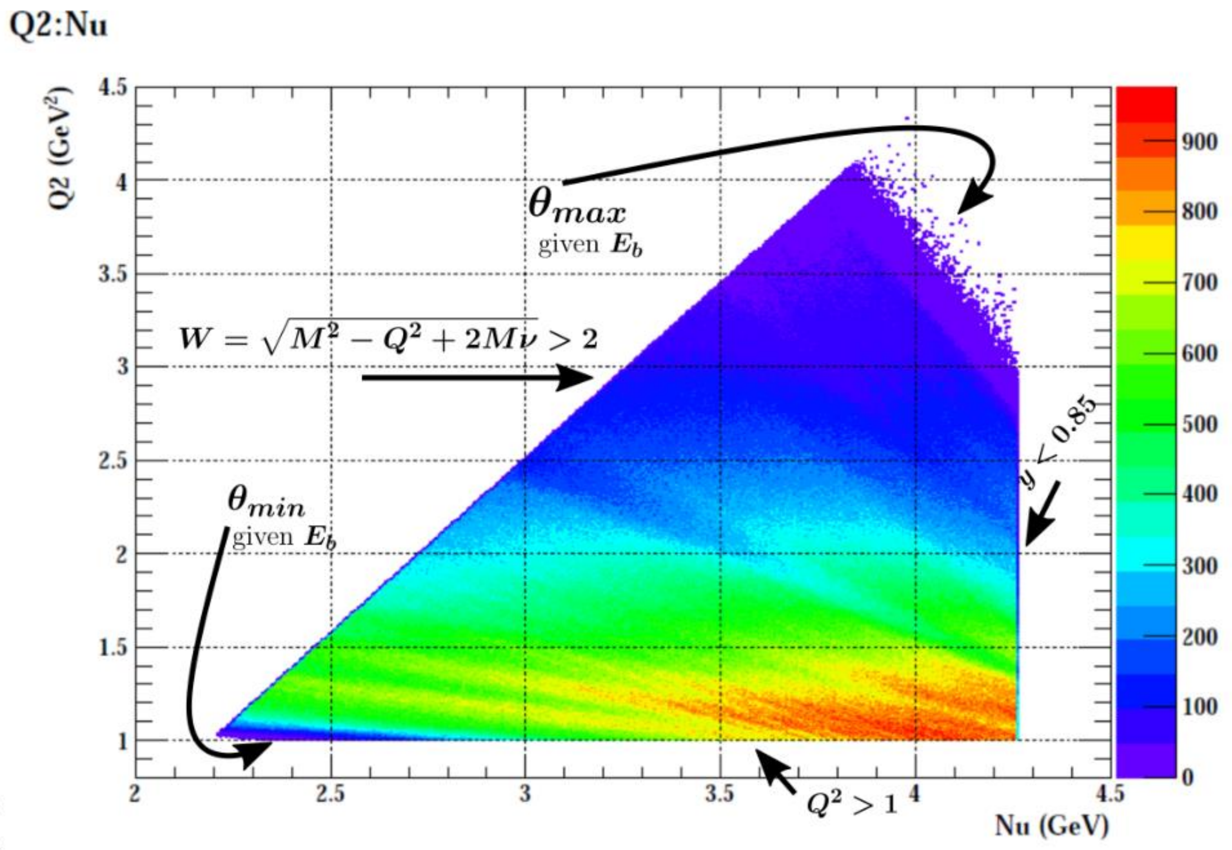
Electron ID and **Charged Pions ID** are based on Sebastián Moran's (*et al.*) analysis, recently submitted for a CLAS Analysis Note review.

Photons ID is based on Taisiya Mineeva's approved CLAS Analysis Note.

Kinematic Cuts

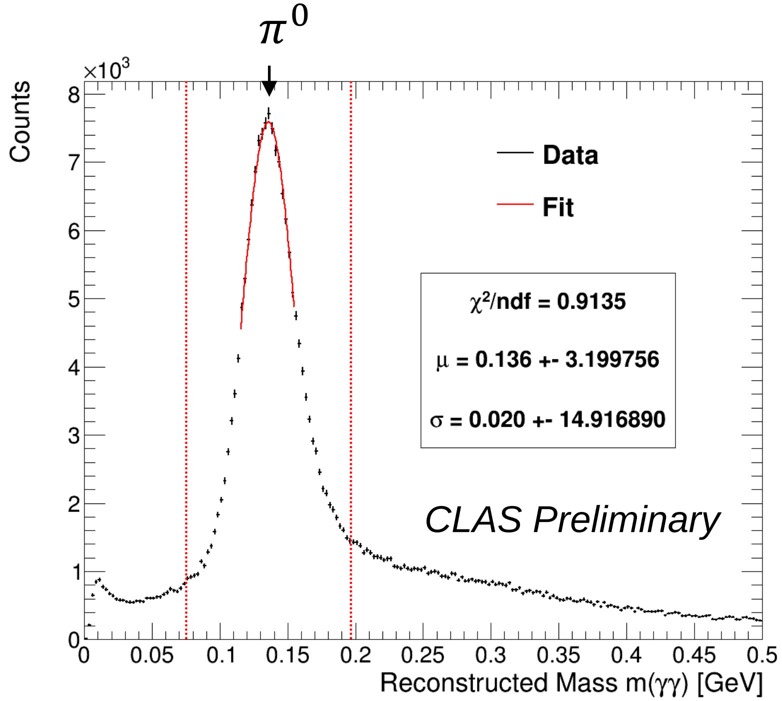
The **kinematic region** of the **DIS** regime is:

- $Q^2 > 1\ \mathrm{GeV}^2$, necessary virtuality to probe nucleon substructure.
- $W > 2$ GeV, to avoid contamination from resonance region.
- $y_B = \nu/E_b < 0.85$, to reduce size of radiative effects.



π^0 Reconstruction

Gaussian fit around π^0 peak.
Horizontal lines represent 3σ cut around obtained μ.

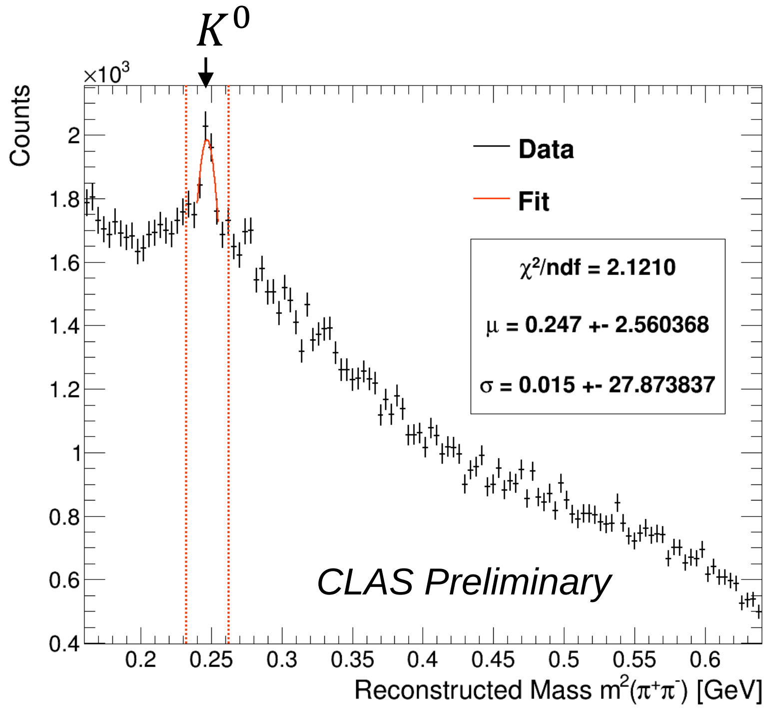


$$m(\gamma\gamma) = 4\,E_{\gamma_1}E_{\gamma_2}\sin^2\left(\frac{\theta_{\gamma_1\gamma_2}}{2}\right)$$

$$0.076 < m_{\gamma\gamma} < 0.196\text{ GeV}$$

K^0 Exclusion

Gaussian fit around K^0 peak.
Horizontal lines represent 1σ cut around obtained μ.

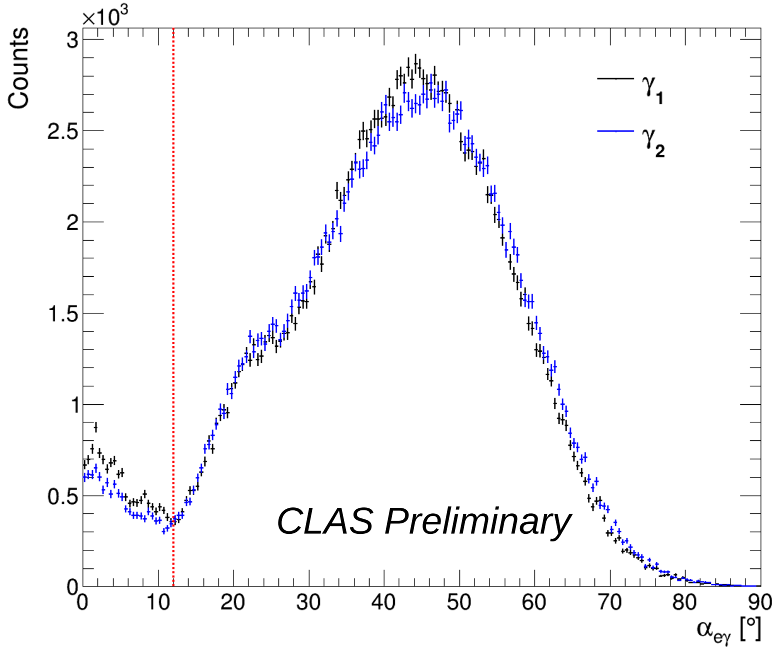


$$m^2(\pi^+\pi^-) = 2M_{\pi^\pm} + 2E_{\pi^+}E_{\pi^-} - 2(p_x^{\pi^+}p_x^{\pi^-} + p_y^{\pi^+}p_y^{\pi^-} + p_z^{\pi^+}p_z^{\pi^-})$$

$$m^2_{\pi^+\pi^-} < 0.232\text{ GeV}^2$$
or
$$m^2_{\pi^+\pi^-} > 0.262\text{ GeV}^2$$

Removal of bremsstrahlung photons

"Most of the bremsstrahlung photons from the electron are emitted either in the direction of incoming or scattered electron." **[Schiff, 1952]**



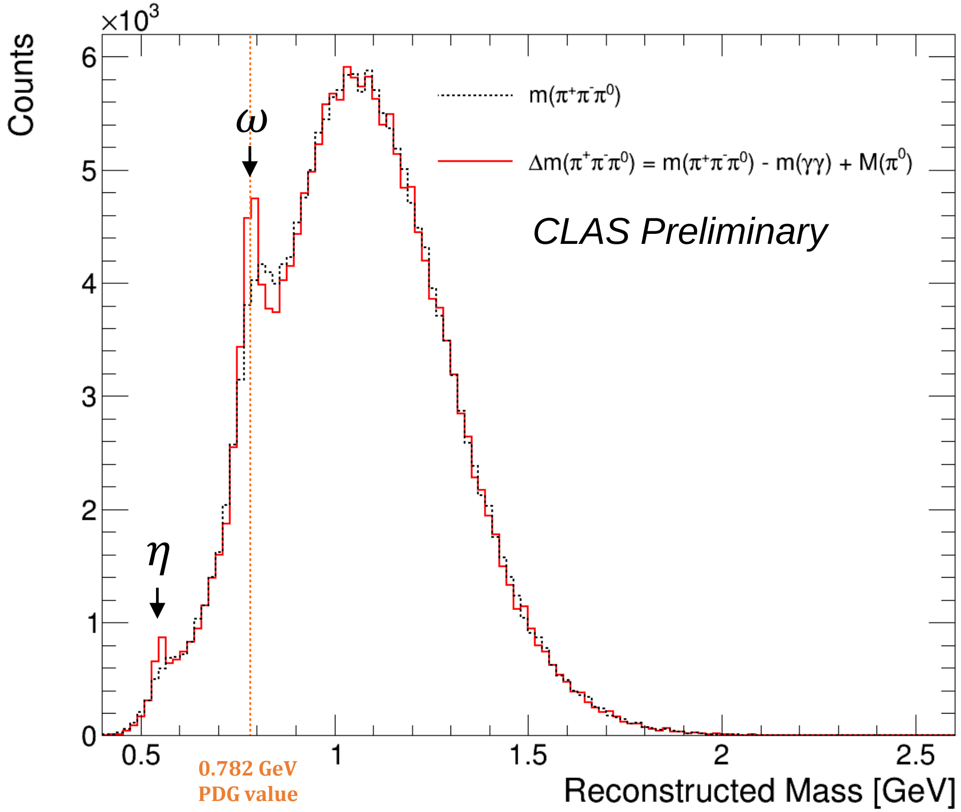
$\alpha_{e\gamma}$: angle between scattered electron and detected photon

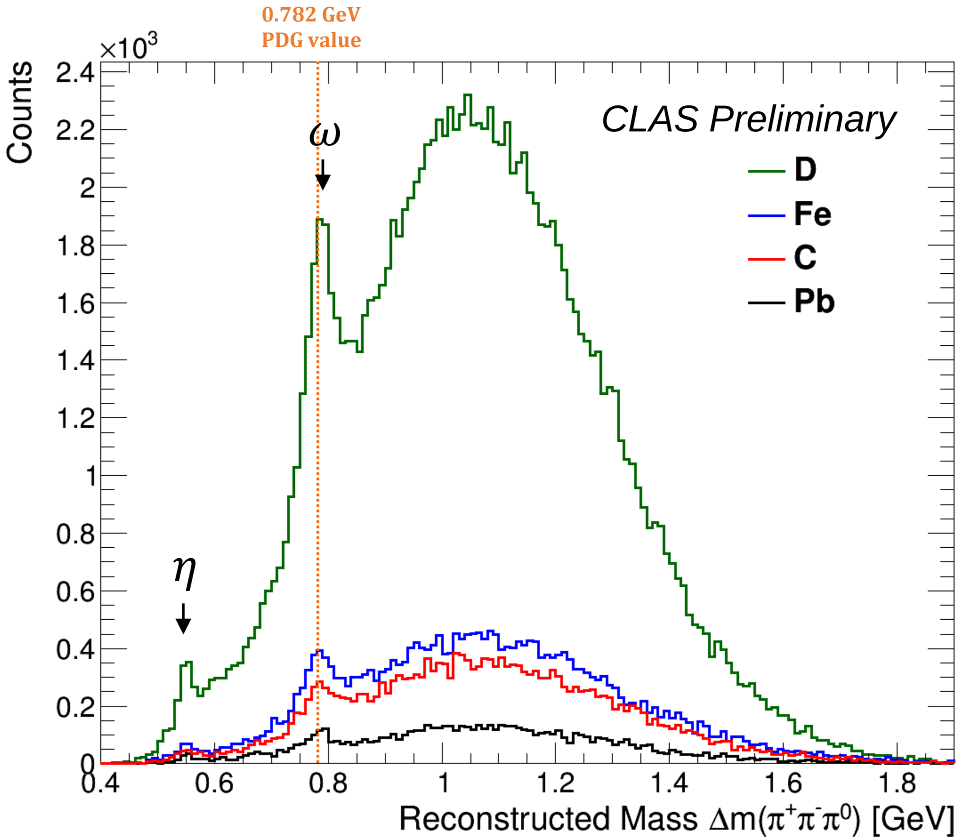
$$\alpha_{e\gamma} > 12°$$

ω Invariant Mass Reconstruction

After keeping all the ω candidates from the events with the required multiplicity of final-state particles, **at least $(1\pi^+, 1\pi^-, 2\gamma)$,** we can reconstruct the ω mass with a 4-particle system.

$$m(\pi^+\pi^-\pi^0) = \sqrt{E^2(\pi^+\pi^-\gamma\gamma) - p^2(\pi^+\pi^-\gamma\gamma)}$$

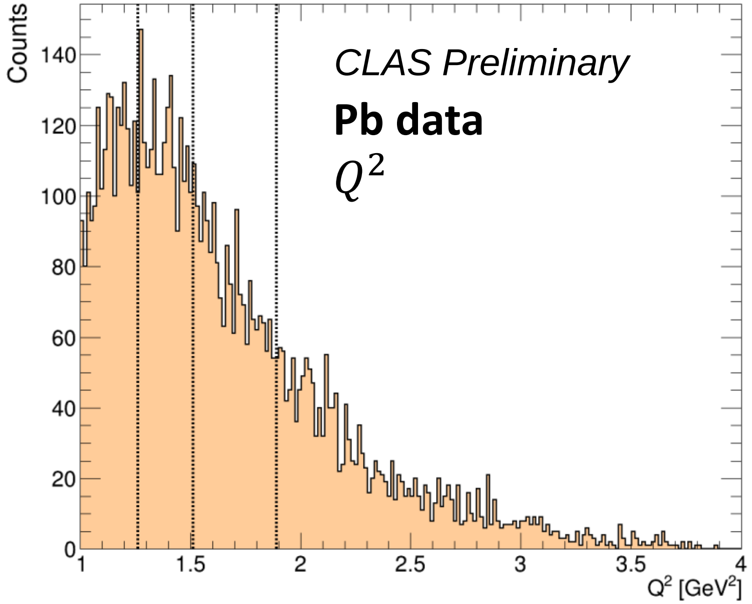


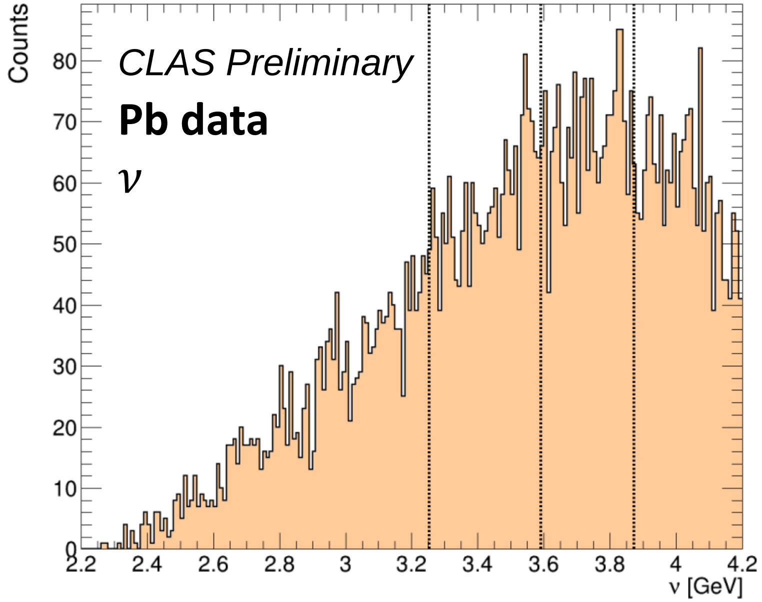


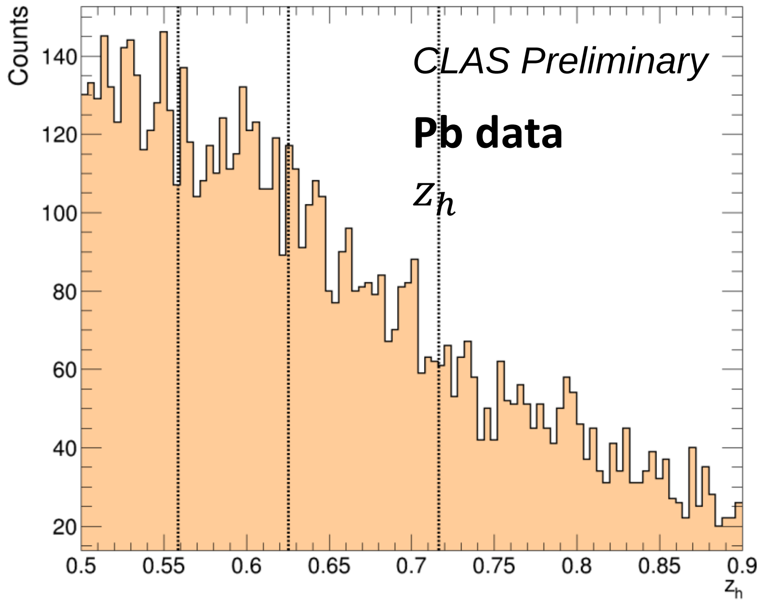
Binning

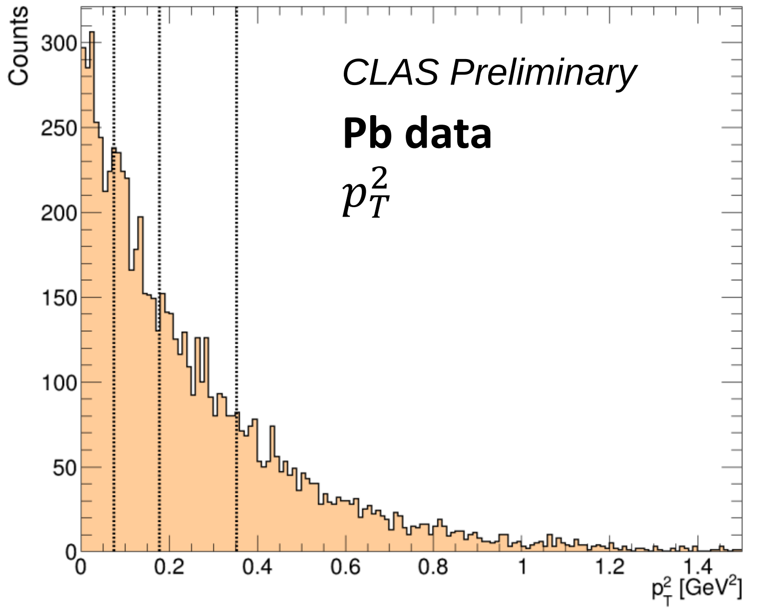
The binning to present the **multiplicity ratios** is one-dimensional and equally distributed.

$Q^2\ (GeV^2)$	1.0	1.25	1.50	1.87	4.0
$\nu\ (GeV)$	2.2	3.23	3.57	3.86	4.2
z_h	0.5	0.56	0.62	0.72	0.9
$p_T^2\ (GeV^2)$	0.0	0.07	0.18	0.35	1.5









Event-mixing rules

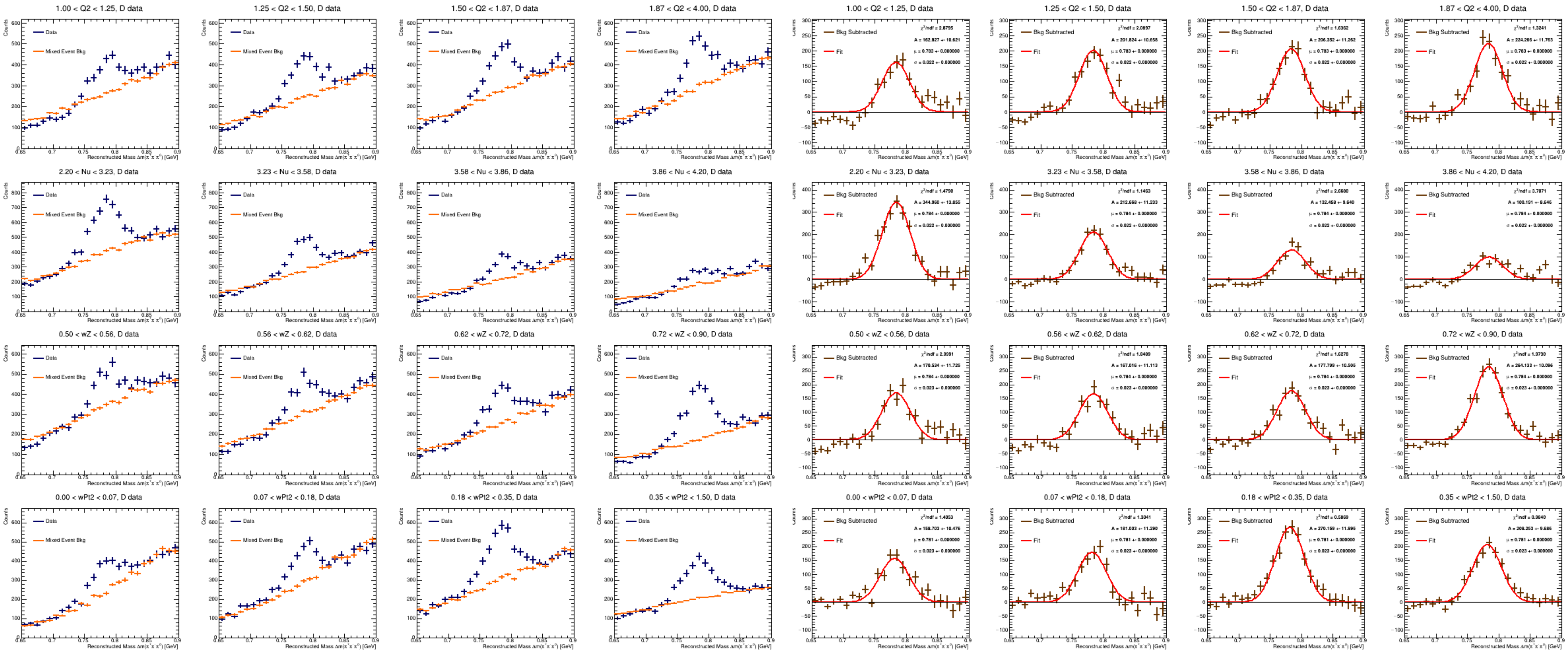
Decay channel: $\boldsymbol{\omega \rightarrow \pi^{+}\pi^{-}\pi^{0} \rightarrow \pi^{+}\pi^{-}\gamma\gamma}$

- Keep all events with the minimum amount of final-state particles. (**“candidate event”**)
- Combine and form all the possible $\boldsymbol{\omega}$ candidates.
- For each formed $\boldsymbol{\omega}$ candidate,
  1. swap the $\boldsymbol{\pi^{+}}$ by a **random** $\boldsymbol{\pi^{+}}$ from **candidate events** from **same target**
  2. swap the $\boldsymbol{\pi^{-}}$ by a **random** $\boldsymbol{\pi^{-}}$
  3. swap the $\boldsymbol{\pi^{0}}$ by a **random** $\boldsymbol{\pi^{0}}$
  4. swap the three pions with **random** $\boldsymbol{\pi^{+}, \pi^{-}, \pi^{0}}$ (all from different events)
- Add the new 4 distributions.

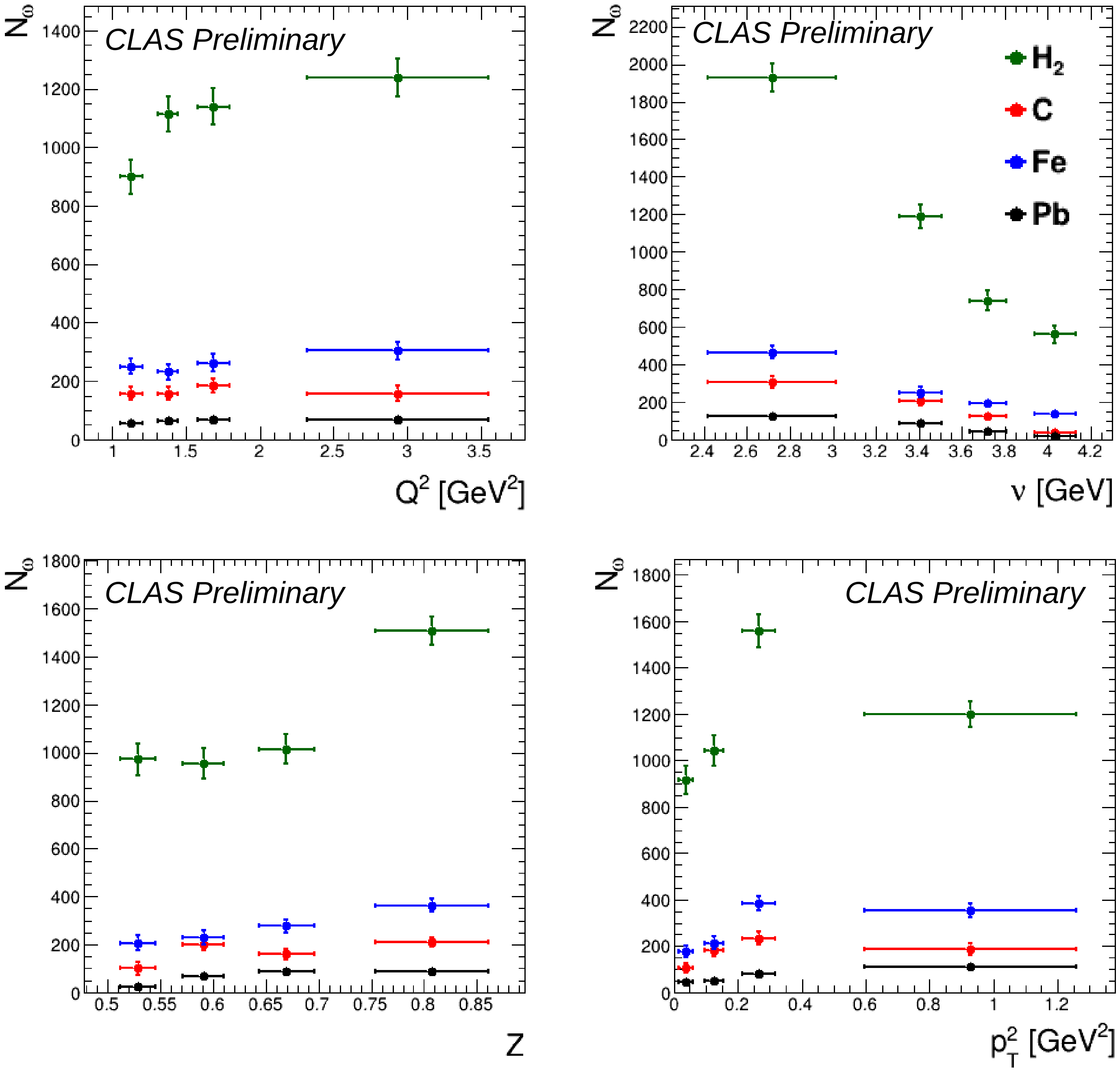
[CERN-THESIS-2018-313]

F. Jonas. Measurement of ω and η mesons via their three pion decay with ALICE in pp collisions...

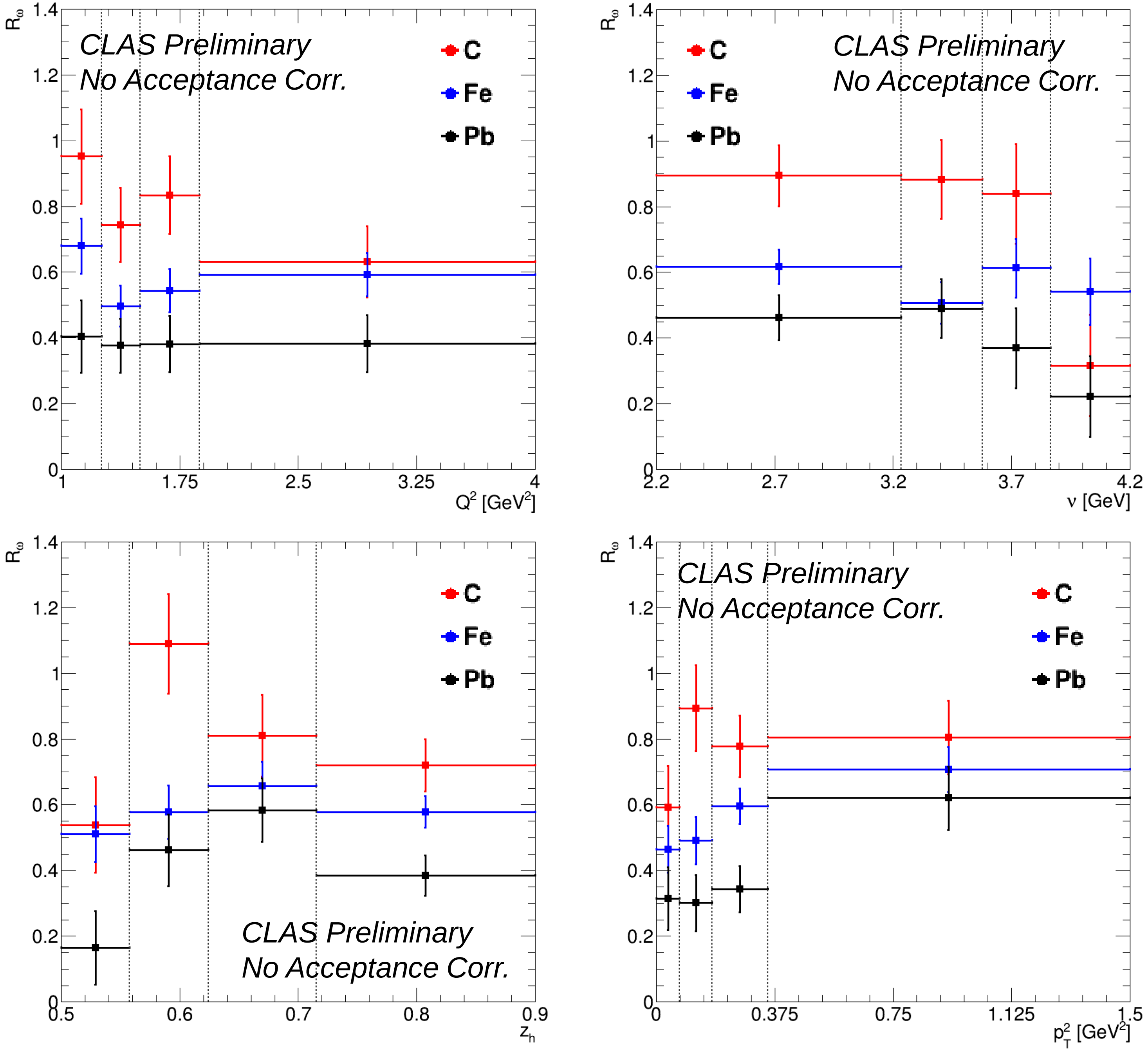
Event-mixing results – Deuterium data



Number of ω after integration of fit function



Multiplicity Ratios: ω



Acceptance Correction

Correction that covers the imperfections of the detector, such as: detection, track reconstruction and event selection efficiencies.

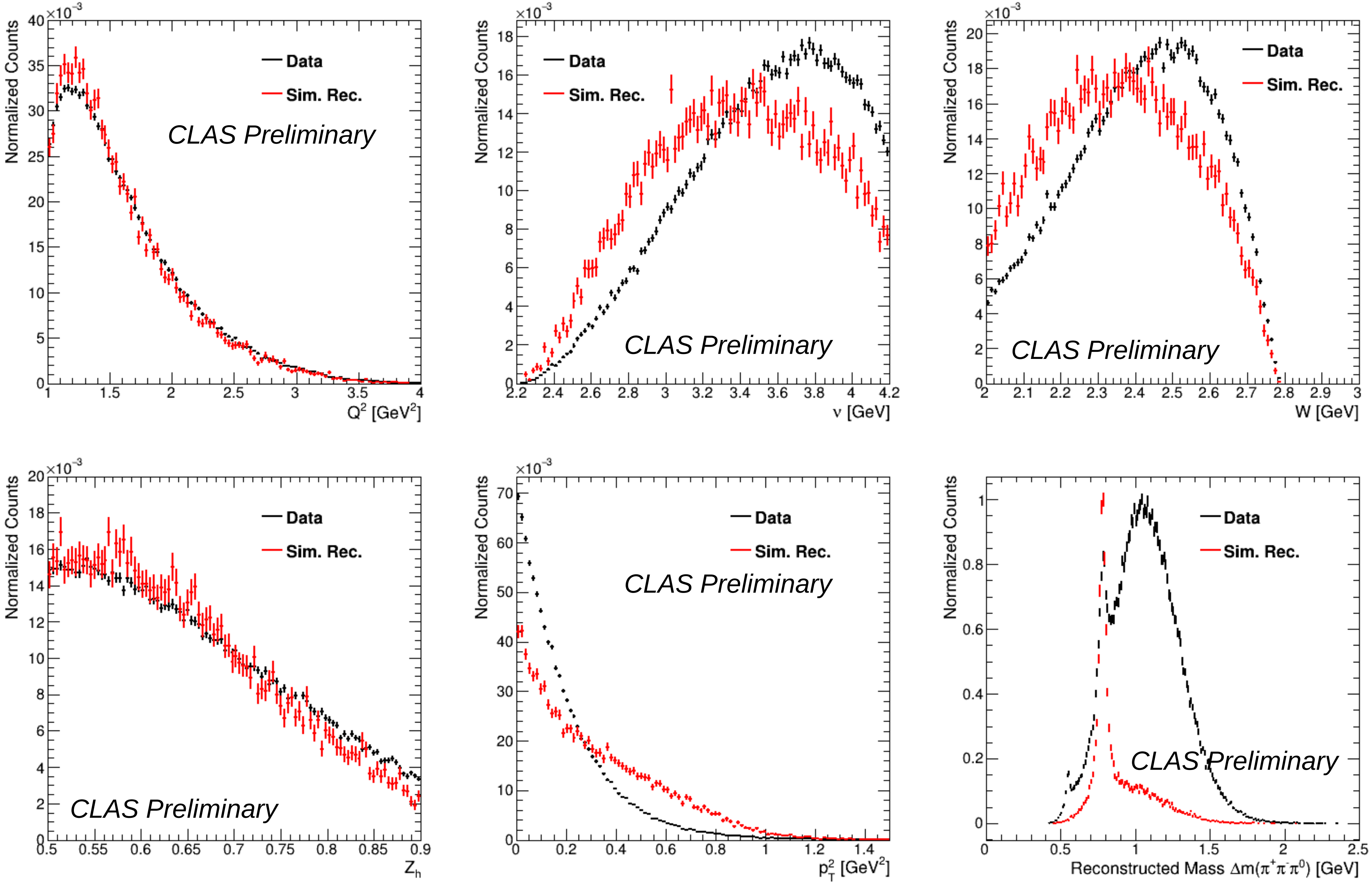
$$A = \frac{N_{\omega}^{rec}(Q^2, \nu, z_h, p_T^2)}{N_{\omega}^{gen}(Q^2, \nu, z_h, p_T^2)} \rightarrow N_{\omega}^{corr} = \frac{N_{\omega}}{A}$$

Simulation chain:

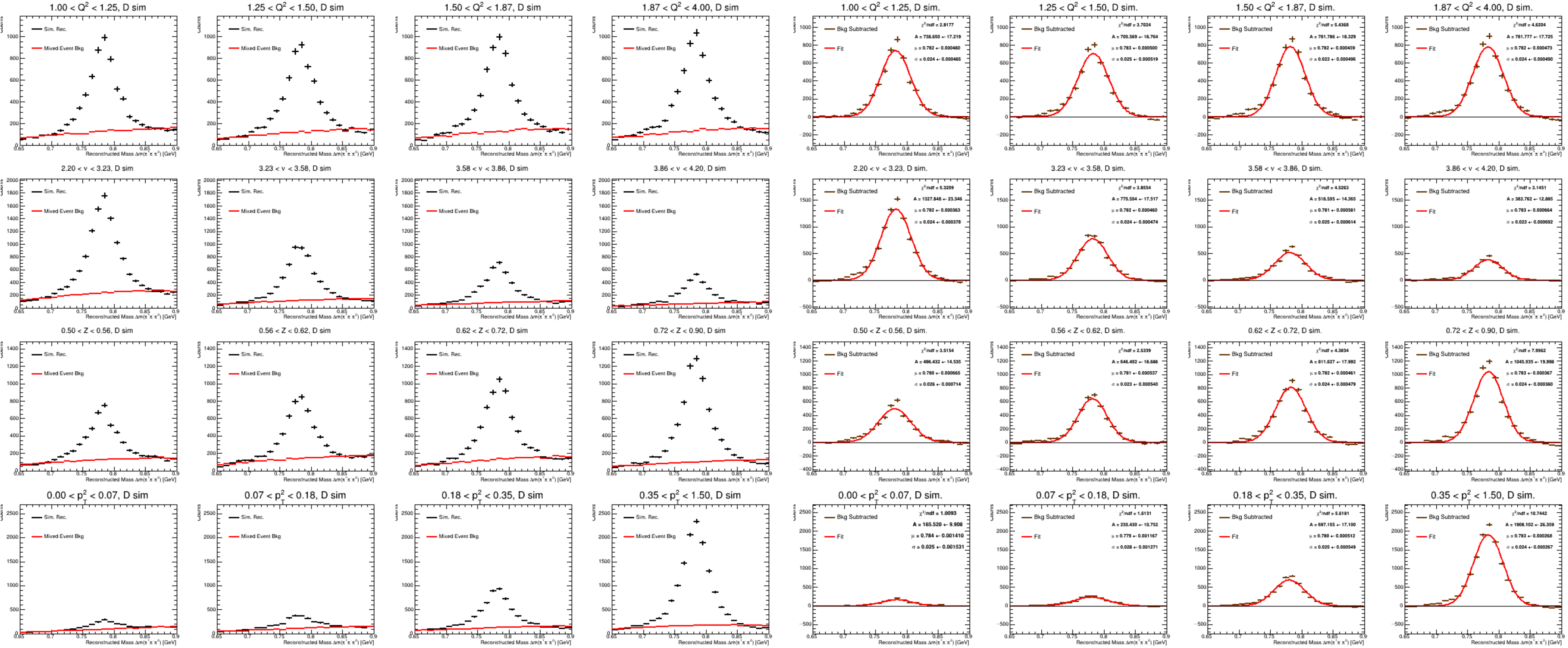
- **LEPTO**: MC event generator, slightly modified to keep all events with **at least one $\boldsymbol{\omega}$**.
- **GSIM**
- **GPP**
- **user_ana** or **recsis**
- **ClasTool**

(GSIM, GPP, user_ana or recsis, ClasTool:) **CLAS reconstruction chain**

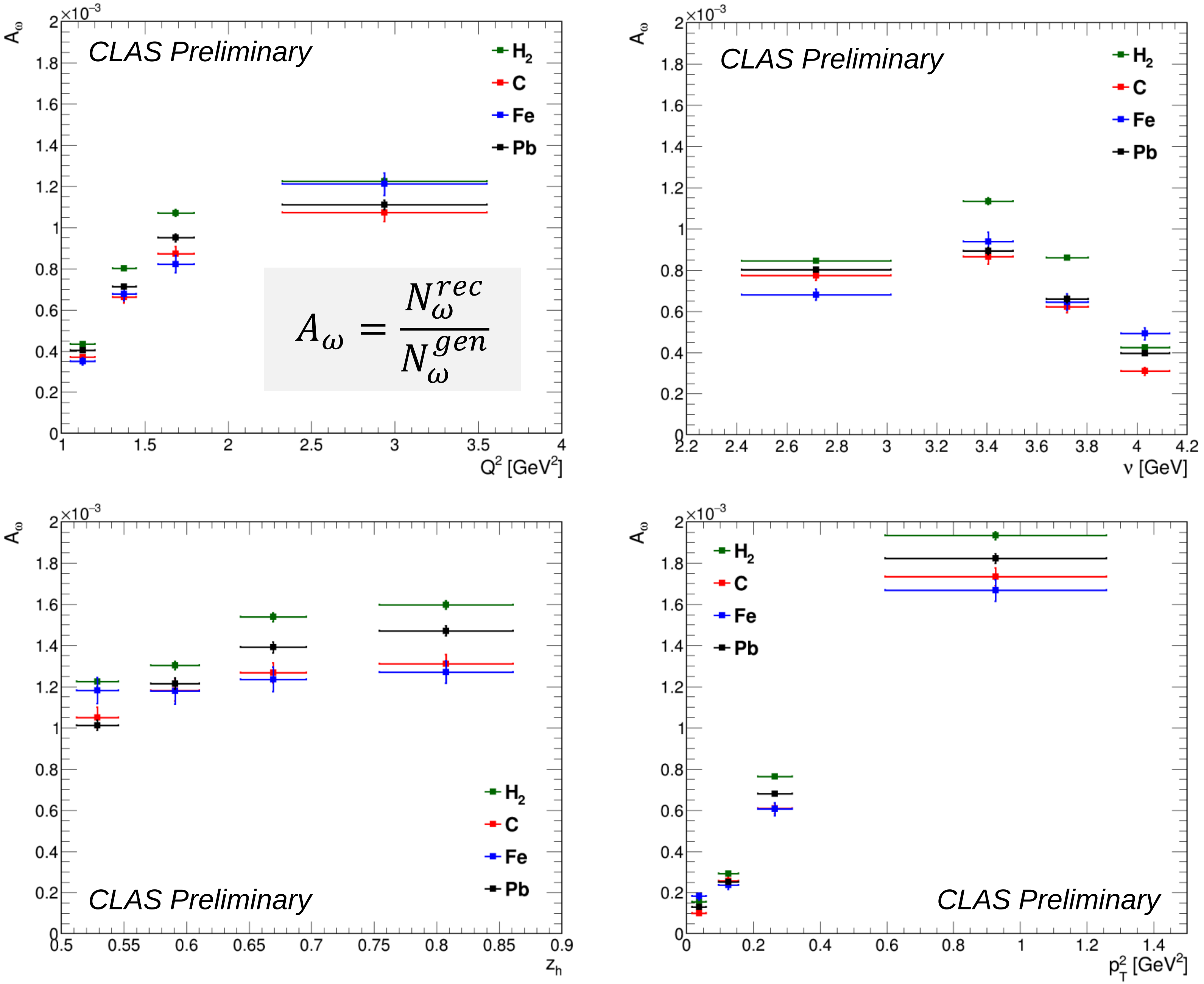
Comparison between Data and Sim. Reconstructed



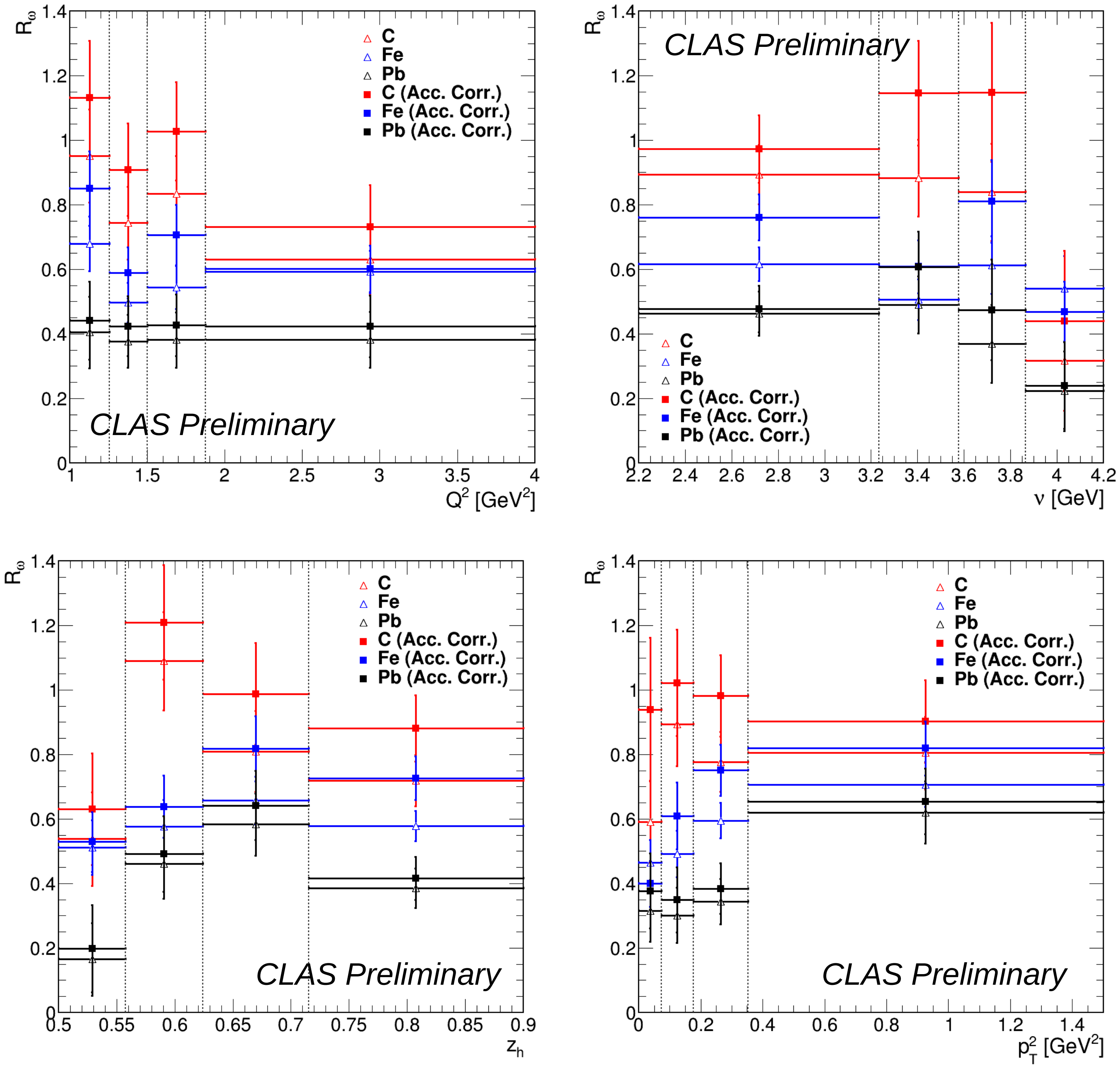
Event-mixing – Deuterium sim. reconstructed



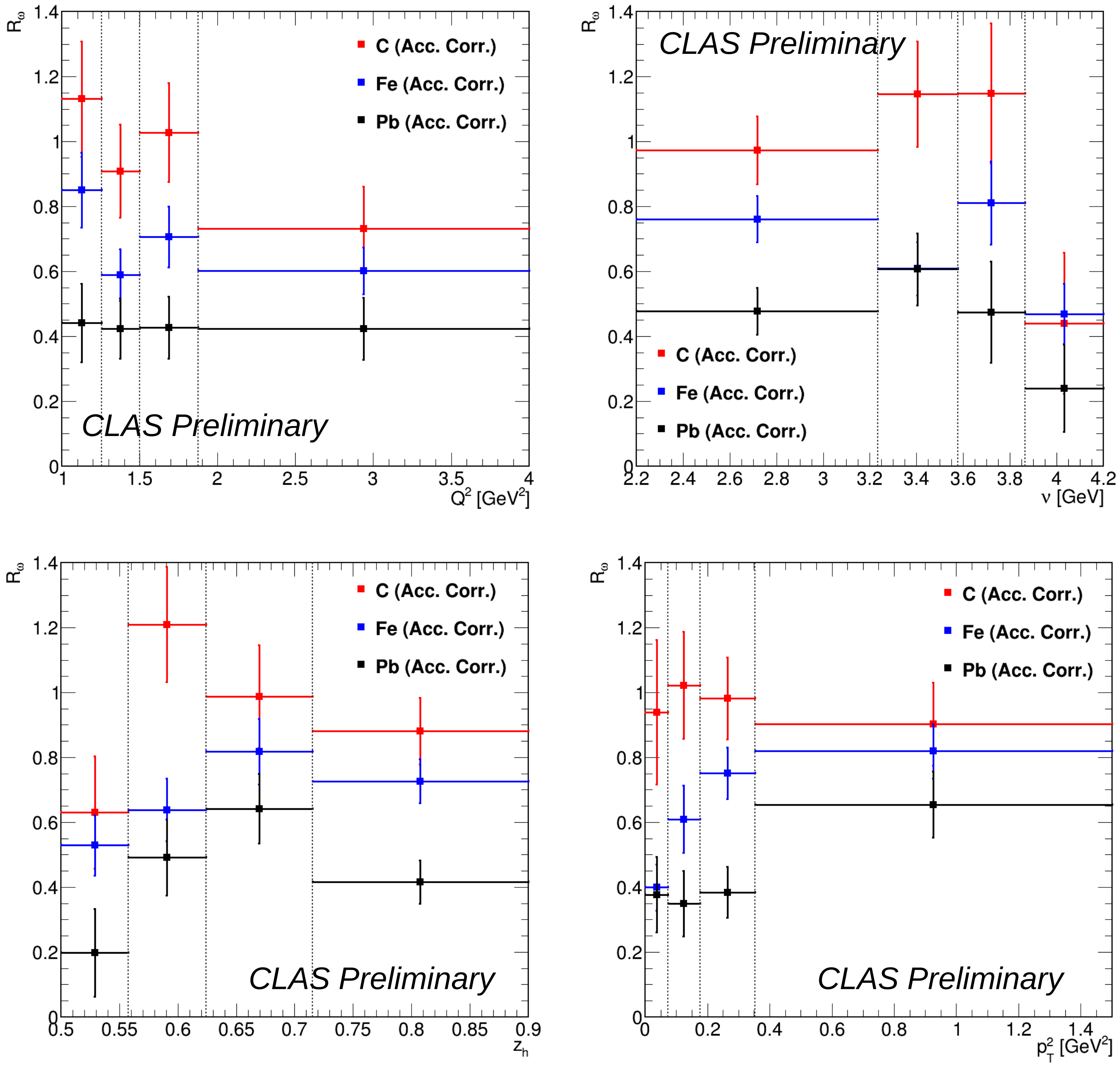
Acceptance Factors: ω



Multiplicity Ratios: ω – Acceptance Corrected (Comparison)



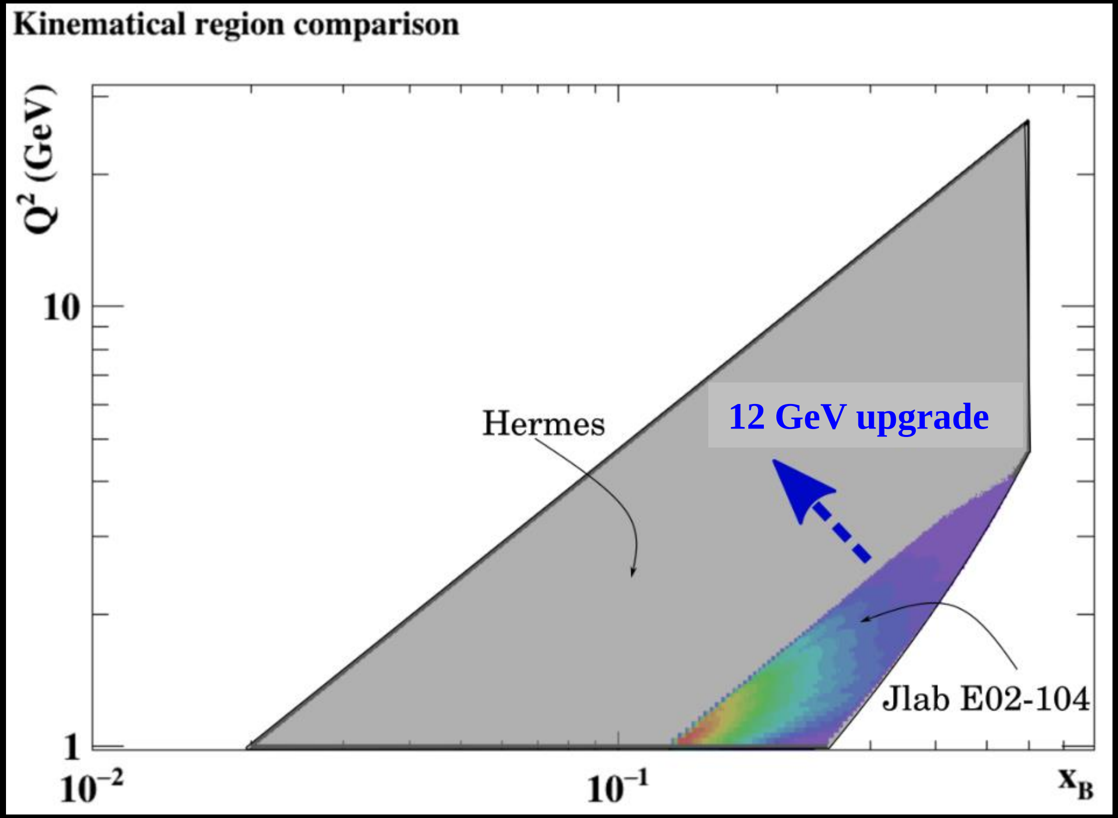
Multiplicity Ratios: ω – Acceptance Corrected



Next steps

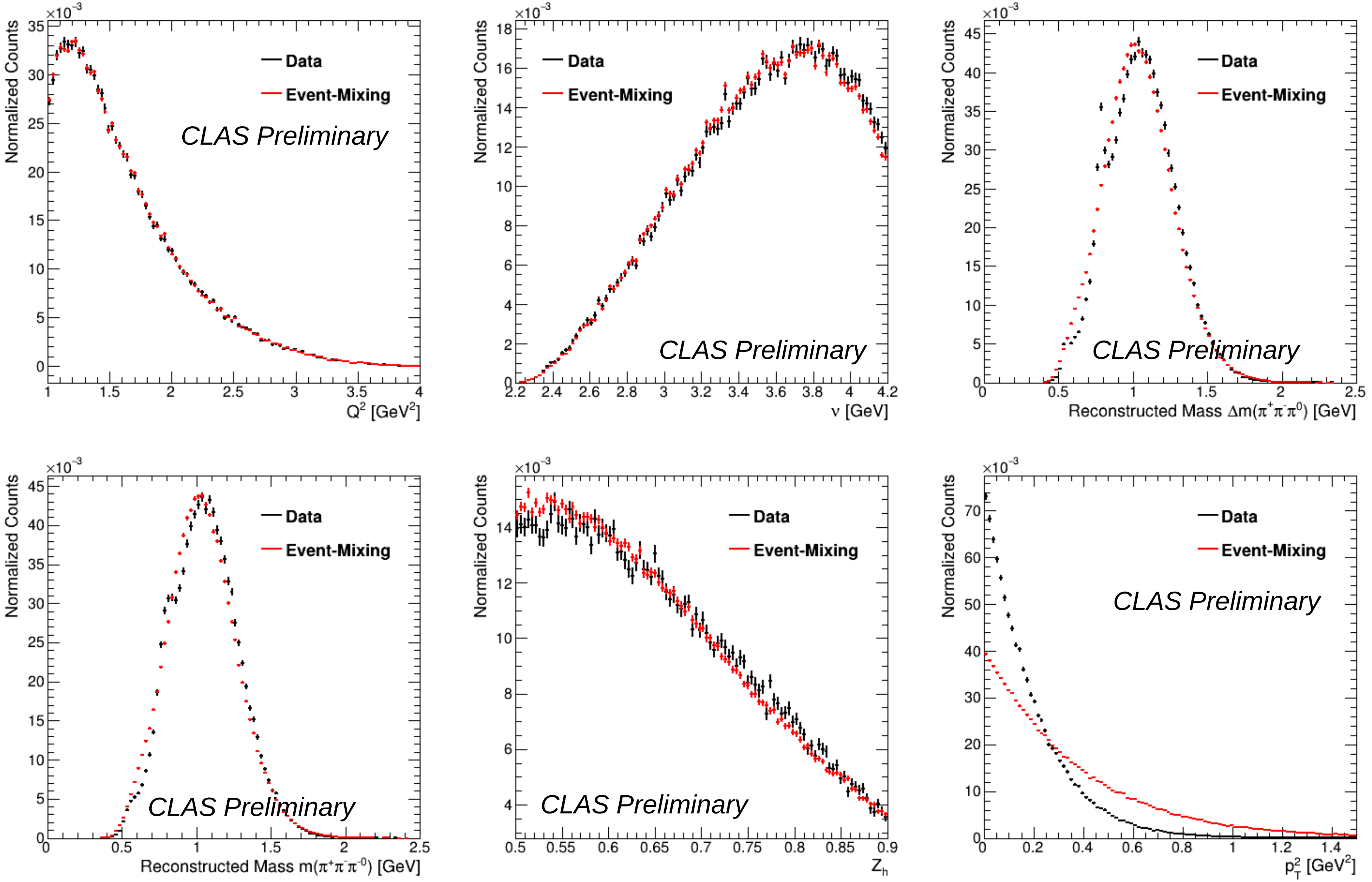
- Radiative corrections.
- Systematic studies.
- Submit η and ω CLAS Analysis Note.

Thank you for your attention.



Backup

Comparison between Data and Event-Mixing



Event-mixing results

- **Data**
- **Mixed Event Bkg**

To **normalize** the **mixed-event background** to the **data**, it is scaled by the following factor:

$$\frac{integral_{R1}^{data} + integral_{R2}^{data}}{integral_{R1}^{bkg} + integral_{R2}^{bkg}}$$

Where **R1** and **R2** stand for the left and right sidebands, respectively.