Validation of MC generators using new extractions of ^{12}C electromagnetic longitudinal and transverse response functions

We extract $^{12}\mathbf{C}$ Longitudinal ($\mathbf{R_L}$) and ($\mathbf{R_T}$) Nuclear Electromagnetic Response Functions from *all* Electron Scattering Measurements on Carbon for:

1. Testing first principle nuclear theory predictions
2. Provide a platform for verification of electron and neutrino MC generators over the entire kinematic range of interest

A. Bodek[1], M. E. Christy[2], Zihao Lin[1], and A. Ankowski[3]

[1]The University of Rochester, Rochester, NY, USA

[2]Thomas Jefferson National Accelerator Facility, Newport News VA, USA

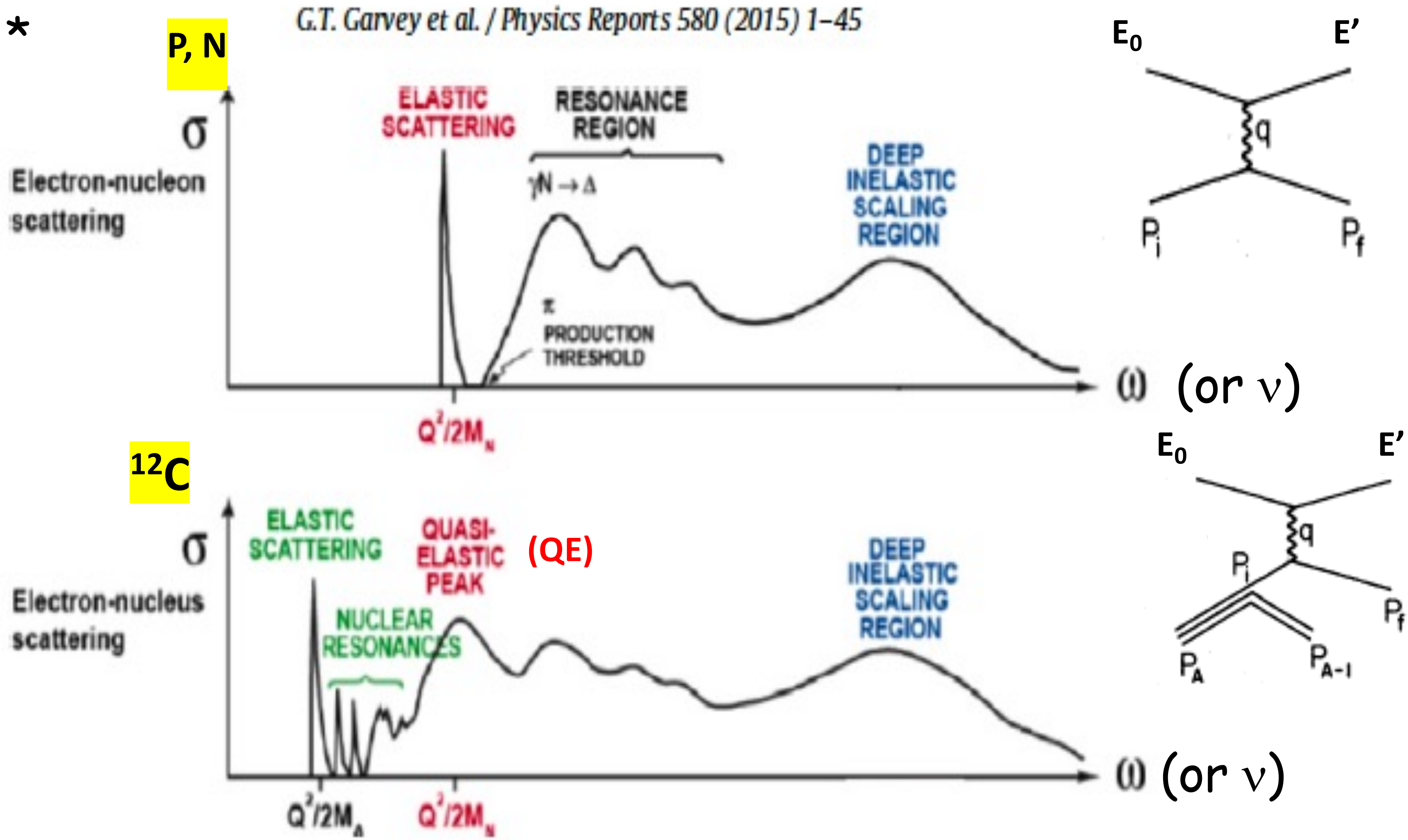
[3]University of Wroclaw, Wroclaw, Poland

Presented by A. Bodek

2nd Short-Baseline Experiment-Theory Workshop 2024, April 2-5, Santa Fe, NM

25 min + 5 min questions

*



Nuclear corrections affect enhance the Transverse Response (R_T) and quench the Longitudinal Response (R_L) in QE scattering. There are three different formalisms to parametrize these two responses. (1) R_L and R_T (2) F_1 and F_L (3) σ_L and σ_T.

In this analysis we use R_L and R_T.

*

Nuclear Physics

This description is primarily used in the nuclear excitation and QE regions. The electron scattering differential cross section is written in terms of longitudinal ($\mathcal{R}_L(Q^2,\nu)$) and transverse ($\mathcal{R}_T(Q^2,\nu)$) nuclear response functions [24]

energy transfer = ν (or ω)

$$\frac{d\sigma}{d\nu d\Omega} = \sigma_M[A\mathcal{R}_L(Q^2,\nu) + B\mathcal{R}_T(Q^2,\nu)] \qquad (20)$$

where σ_M is the Mott cross section, $A = (Q^2/\mathbf{q}^2)^2$ and $B = \tan^2(\theta/2) + Q^2/2\mathbf{q}^2$.

Particle Physics

This description is primarily used in the inelastic continuum region. In the one-photon-exchange approximation, the spin-averaged cross section for inclusive electron-proton scattering can be expressed in terms of two structure functions as follows

$$\frac{d\sigma}{d\Omega dE'} = \sigma_M[\mathcal{W}_2(W^2,Q^2) + 2\tan^2(\theta/2)\mathcal{W}_1(W^2,Q^2)]$$

$$\sigma_M = \frac{\alpha^2\cos^2(\theta/2)}{[2E_0 sin^2(\theta/2)]^2} = \frac{4\alpha^2 E'^2}{Q^4}\cos^2(\theta/2) \qquad (10)$$

Q^2 = 4-momentum transfer squared

$$Q^2 = (-q)^2 = 4E_0E'\sin^2\frac{\theta}{2},$$

$$\nu = E_0 - E'.$$

W^2 =final state invariant mass squared

$$W^2 = M^2 + 2M\nu - Q^2$$

$\mathbf{q}^2$ = 3-momentum transfer squared

$$\mathbf{q}^2 = Q^2 + \nu^2$$

E_x = Excitation energy

$$E_x = \nu - \nu_{elastic}$$

$$x = Q^2/(2M\nu).$$

$$\mathcal{F}_1 = M\mathcal{W}_1 \text{ and } \mathcal{F}_2 = \nu\mathcal{W}_2.$$

$$\mathcal{F}_L(x,Q^2) = \mathcal{F}_2\left(1+\frac{4M^2x^2}{Q^2}\right) - 2x\mathcal{F}_1,$$

$$\mathcal{R}_T(\mathbf{q},\nu) = \frac{2\mathcal{F}_1(\mathbf{q},\nu)}{M}$$

$$\mathcal{R}_L(\mathbf{q},\nu) = \frac{\mathbf{q}^2}{Q^2}\frac{\mathcal{F}_L(\mathbf{q},\nu)}{2Mx}$$

σ_L and σ_T.

A. Description in terms of longitudinal and transverse virtual photon cross sections

This description is often used in the resonance region. In the one-photon-exchange approximation, the

spin-averaged cross section for inclusive electron-proton scattering can be expressed in terms of the photon helicity coupling as

$$\frac{d\sigma}{d\Omega dE'} = \Gamma\left[\sigma_T(W^2, Q^2) + \epsilon\sigma_L(W^2, Q^2)\right], \qquad (6)$$

where σ_T (σ_L) is the cross section for photo-absorption of purely transverse (longitudinal) polarized photons,

$$\Gamma = \frac{\alpha E'(W^2 - M_N^2)}{(2\pi)^2 Q^2 M E_0 (1-\epsilon)} \qquad (7)$$

is the flux of virtual photons, $\alpha = 1/137$ is the fine structure constant, and

$$\epsilon = \left[1 + 2(1 + \frac{\nu^2}{Q^2})\tan^2\frac{\theta}{2}\right]^{-1} \qquad (8)$$

is the relative flux of longitudinal virtual photons (sometimes referred to as the virtual photon polarization). Since Γ and ϵ are purely kinematic factors, it is convenient to define the reduced cross section

$$\sigma_r = \frac{1}{\Gamma}\frac{d\sigma}{d\Omega dE'} = \sigma_T(W^2, Q^2) + \epsilon\sigma_L(W^2, Q^2). \qquad (9)$$

All the hadronic structure information is therefore, contained in σ_T and σ_L, which are only dependent on W^2

$$K = \frac{Q^2(1-x)}{2Mx} = \frac{2M\nu - Q^2}{2M} \qquad (13)$$

$$\mathcal{F}_1 = \frac{MK}{4\pi^2\alpha}\sigma_T \qquad (14)$$

$$\mathcal{F}_2 = \frac{\nu K(\sigma_L + \sigma_T)}{4\pi^2\alpha(1 + \frac{Q^2}{4M^2x^2})} \qquad (15)$$

$$\mathcal{F}_L(x, Q^2) = \mathcal{F}_2\left(1 + \frac{4M^2x^2}{Q^2}\right) - 2x\mathcal{F}_1, \qquad (16)$$

$$\mathcal{R}_T(\mathbf{q}, \nu) = \frac{2\mathcal{F}_1(\mathbf{q}, \nu)}{M} = \frac{K}{2\pi^2\alpha}\sigma_T \qquad (21)$$

$$\mathcal{R}_L(\mathbf{q}, \nu) = \frac{\mathbf{q}^2}{Q^2}\frac{\mathcal{F}_L(\mathbf{q}, \nu)}{2Mx} = \frac{\mathbf{q}^2}{Q^2}\frac{K}{4\pi^2\alpha}\sigma_L \qquad (22)$$

*

- **We have initiated a program to extract RL and RT values on various nuclei using all available data**.
  Here we report on our extraction for Carbon.

- We extract extract RL and RT in all regions, nuclear elastic, nuclear excitations, quasielastic, resonance region and inelastic scattering.

- We extract at 18 values of fixed Q^2 values $0 < Q^2 < 3.45$ GeV^2 as a function of energy transfer ν .
- And at 18 values of fixed values of 3-momentum transfer $0.1 < \mathbf{q} < 2.78$ GeV as a function of ν

- We energy transfer ν, from ν=0 to the end of the resonance region W=2.0 GeV

For Carbon we use 16,000 electron scattering and photproduction cross sections

Goals:

- Test first-principle nuclear theories at fixed values of Q^2 and **q**.

- Use extracted RL and RT values to validate MC generators
  Since we covers all kinematic regions this is a much preferable way than comparison with a few cross section measurements in a limited sets of kinematic regions.

- **Where there is no data, we provide the values from our universal fit to all electron scattering data.**
  The fit will be also be made available for validation of electron and neutrino MC generators

*

First Step: Christy- Bodek Universal Fit (needed for this analysis))

- We update the Bosted-Christy fit to **all of the world's electron scattering data** on H, D and nuclear targets to include the lo**west values of energy transfer ν and q^2** (for ^{12}C **we fit ~16,000 electron scattering and photoabsorption cross sections**.

- We fit for: **QE cross section (including Transverse Enhancement/MEC and longitudinal low q Quenching). Resonance and pion production**, **DIS, nuclear excitations,** elastic scattering data. Since the cross sections span a large range of energies and scattering angles, we **extract both the longitudinal RL and transverse RT** contributions, and also get the Coulomb Sum Rule.

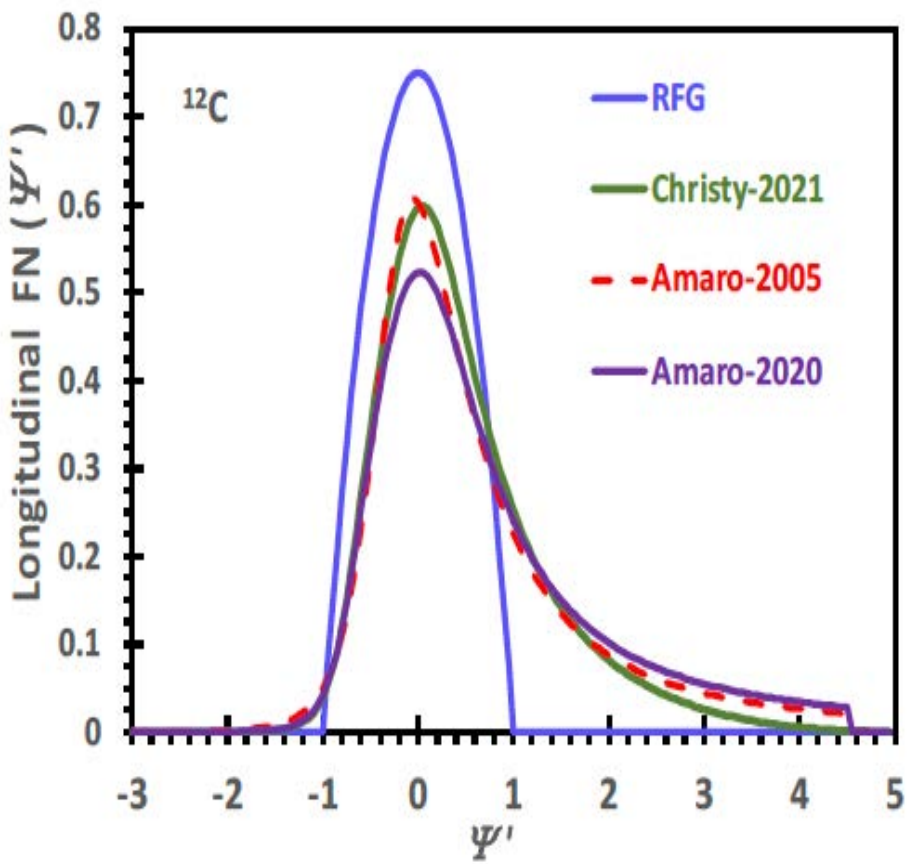
- We parameterize both the **Enhancement of the Transverse QE cross section** and the **Quenching of the Longitudinal QE cross** section. **We extract the most precise Coulomb Sum rule as a function of q and compare to theoretical calculations.**

-

- The fit can be used **in lieu of data to benchmark Monte Carlo predictions** (e.g. for e-H, e-D and e-^{12}C and e-^{1}O cross sections, and to is being used **compute radiative corrections for electron scattering** experiments..

Modeling QE:

Use superscaling- Fit for the longitudinal scaling function parameters in the overall fit

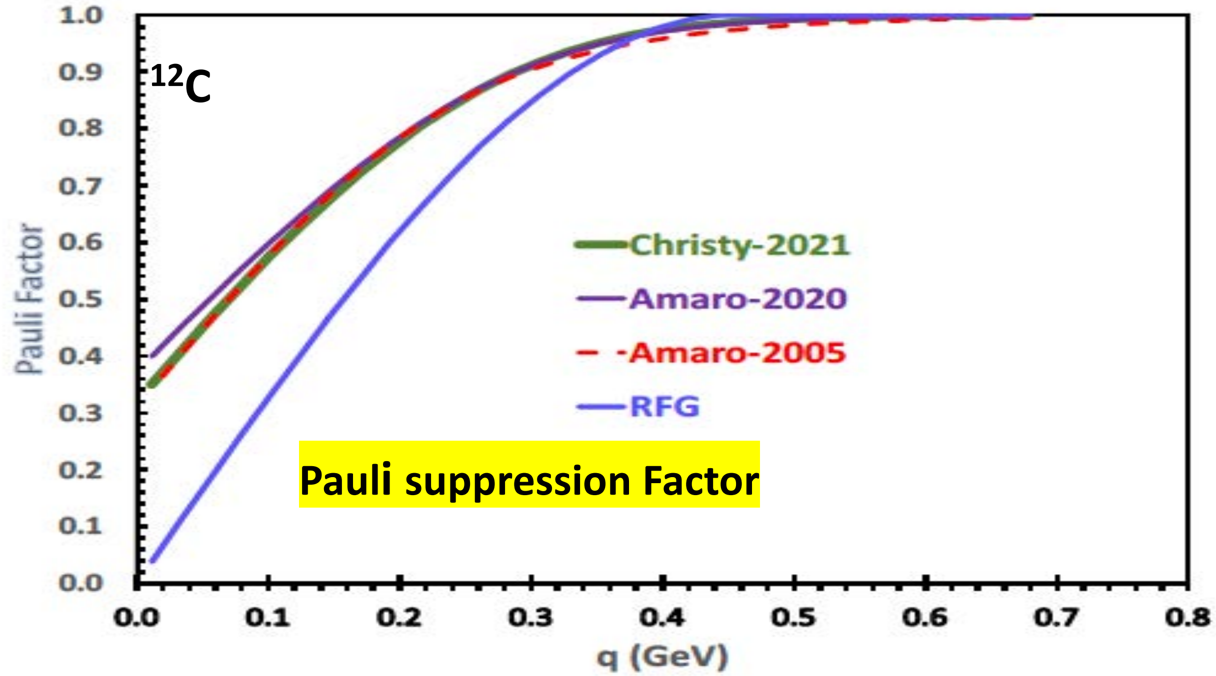


The ψ' superscaling variable is given by the following expression:

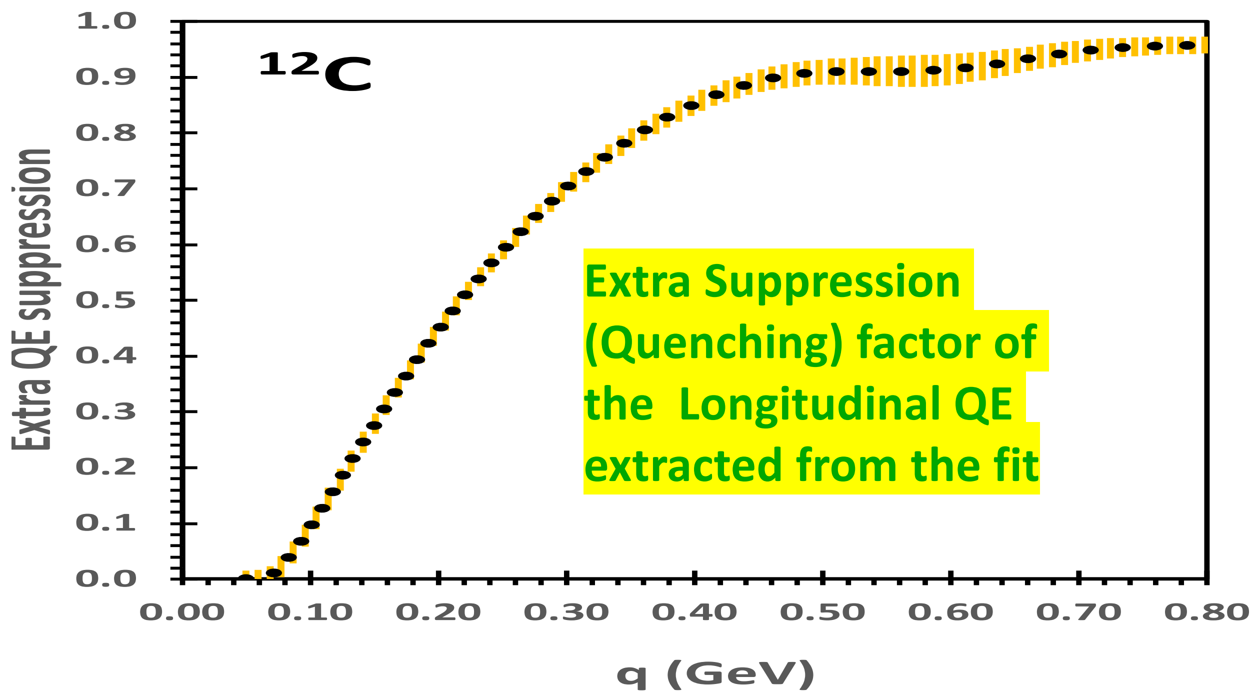
$$\psi' \equiv \frac{1}{\sqrt{\xi_F}} \frac{\lambda' - \tau'}{\sqrt{(1+\lambda')\tau' + \kappa\sqrt{\tau'(1+\tau')}}}, \qquad (16)$$

where $\xi_F \equiv [\sqrt{1+\eta_F^2} - 1]$, $\eta_F \equiv K_F/M_n$, $\lambda \equiv \nu/2M_n$, $\kappa \equiv |\mathrm{q}|/2M_n$ and $\tau \equiv |Q^2|/4M_n^2 = \kappa^2 - \lambda^2$.

Pauli Suppression Factor. We use the Rosenfelder method.



We find that there is Quenching of the Longitudinal QE cross section (in addition to Pauli) extracted from our fit



*Christy- Bodek Universal Fit: Carbon In the Nuclear excitation region

Cross sections for excitations less than 10 MeV multiplied by (1/6)

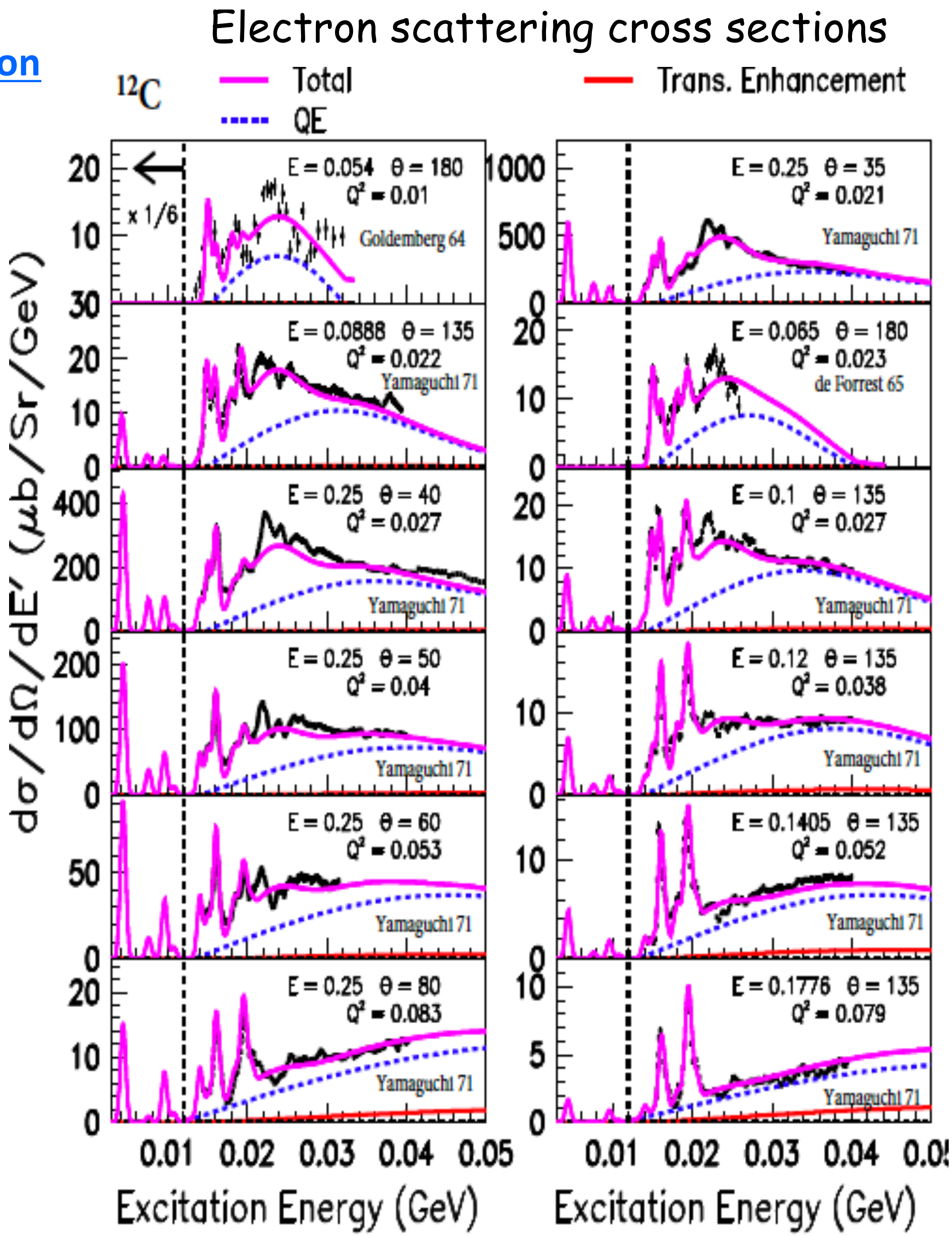
Nuclear excitation region
Ex < 50 MeV

Comparison of our fit to representative e-C12 data for **$0.01 < q^2 < 0.08$ GeV^2** .

Shown: Total including excitations : solid -------

Quasielastic (QE) contribution: dashed------

Transverse Enhancement at large angles accounts for Meson Exchange Currents and Enhancement of Transverse QE response dashed------



Christy- Bodek Universal Fit

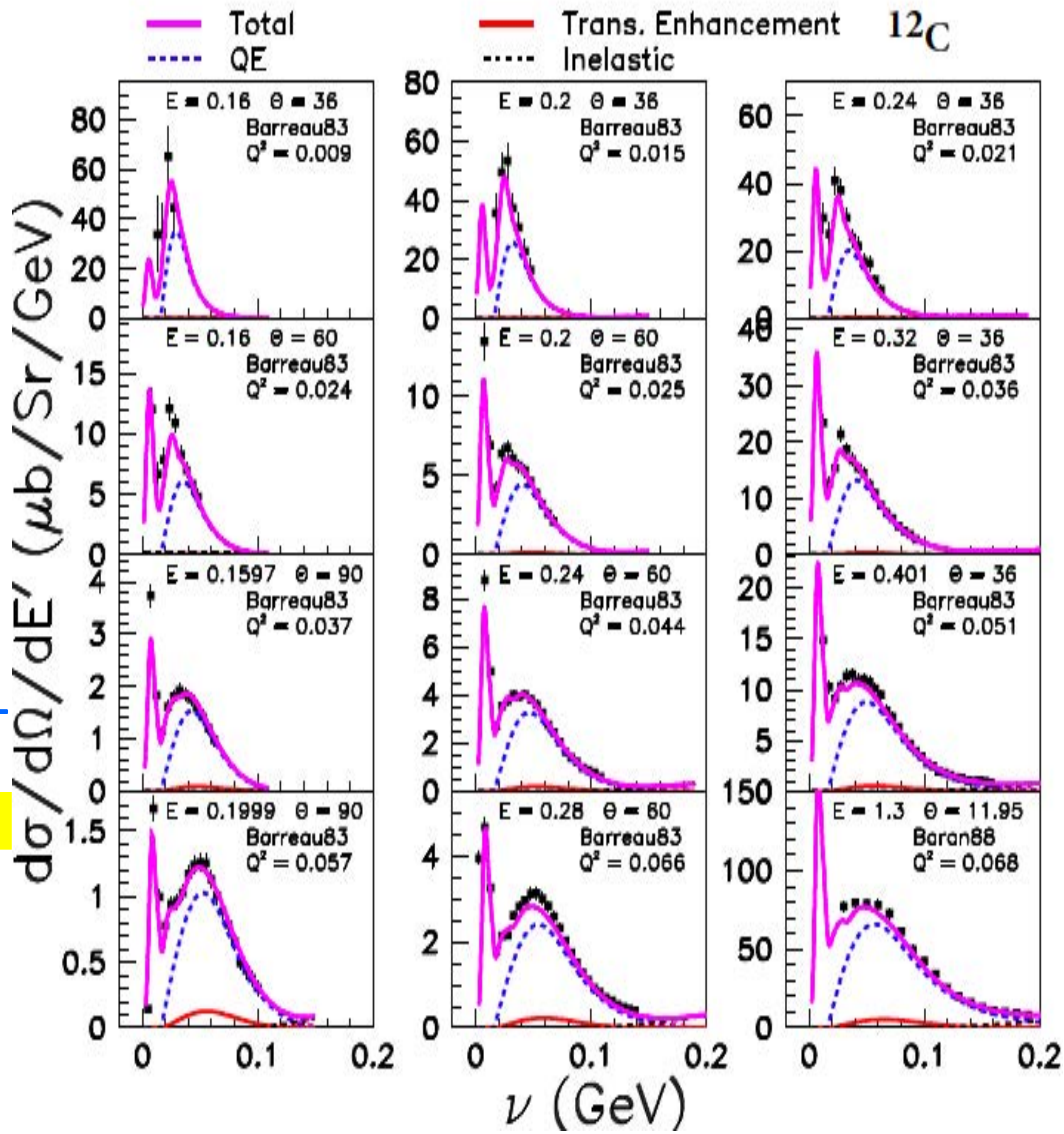
Quasielastic (QE) Region-I

Comparison of our fit to representative e-C12 data **For ν < 0.2 GeV and 0.01 <q^2< 0.068 GeV^2** .

Shown: Total including excitations solid -------

Quasielastic (QE) contribution dashed ------

Transverse Enhancement at large angles accounts for Meson Exchange Currents and Enhancement of Transverse QE response dashed------



Christy- Bodek Universal Fit

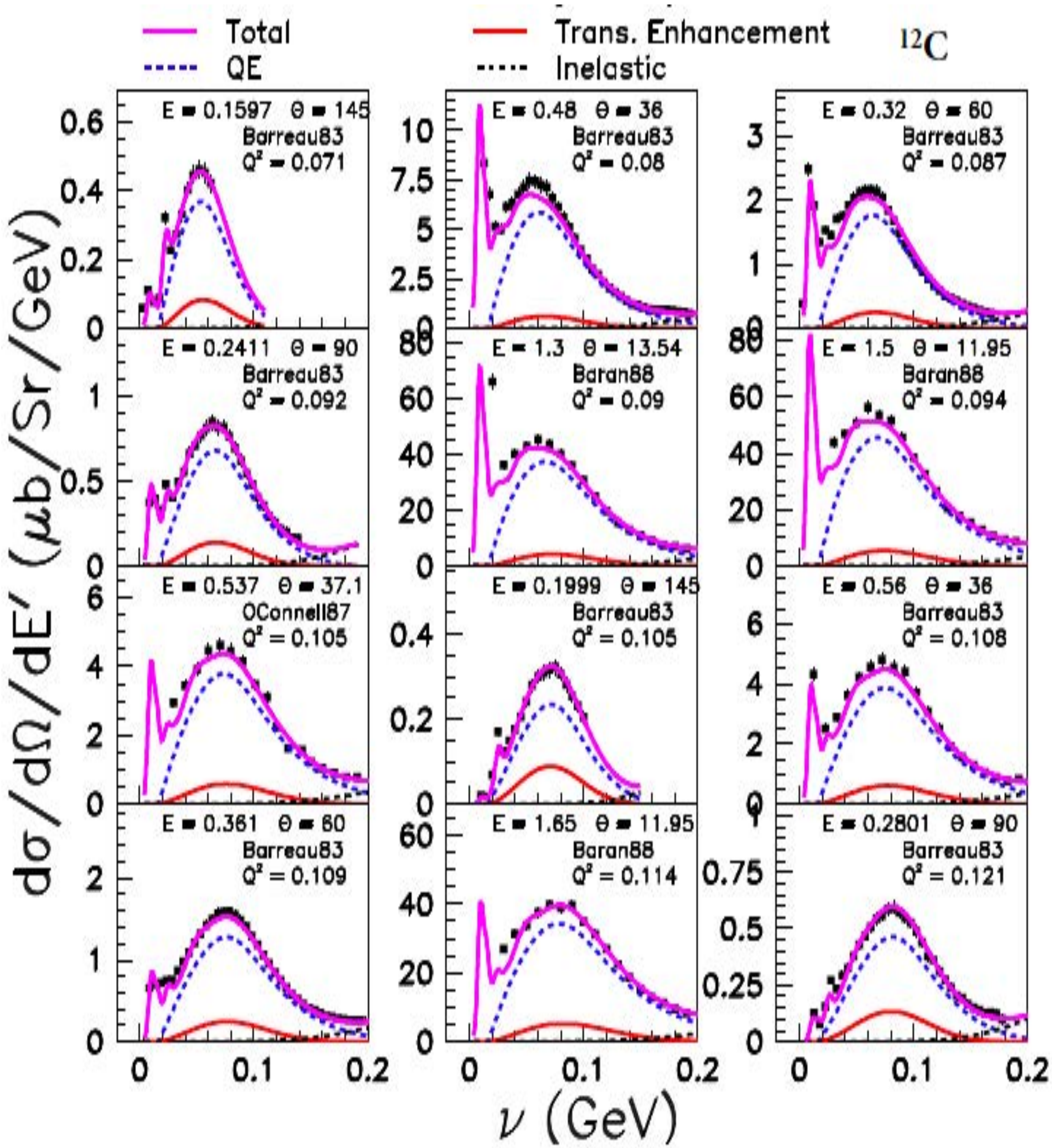
Quasielastic (QE) Region II

Comparison of our fit to representative e-C12 data for **< 0.2 GeV and 0.071 <q^2< 0.121 GeV^2** .

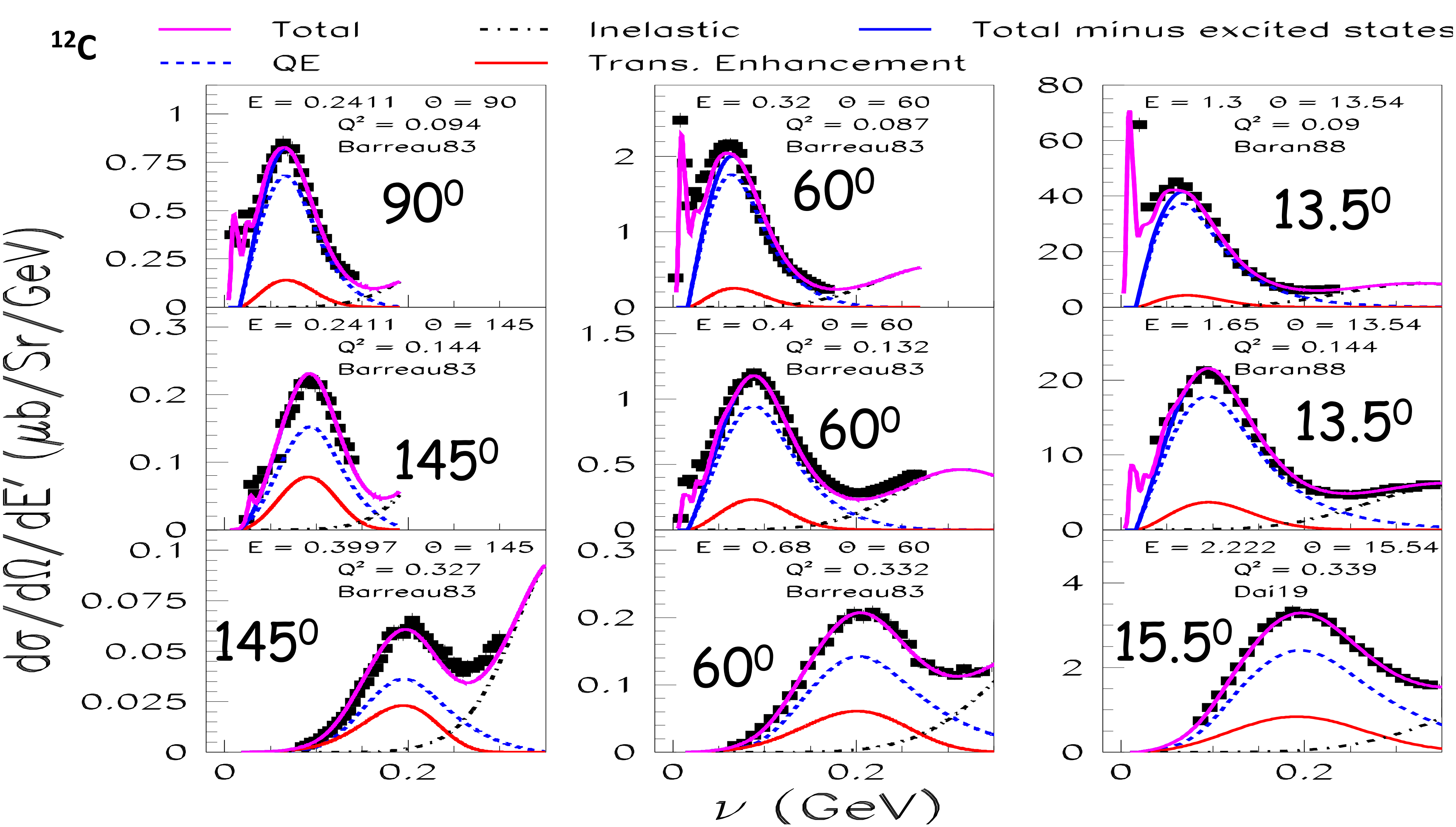
Shown: Total including excitations solid -------

Quasielastic (QE) contribution dashed ------

Transverse Enhancement at large angles accounts for Meson Exchange Currents and Enhancement of Transverse QE reponse dashed------



Christy- Bodek Universal Fit - Fit functional forms for RL RT



The overall fit provides R_L and R_T at all values of q

Shown are **large and small angle cross sections at the same q** that provide the major contribution to the extraction of R_L and R_T at

q^2=0.09, 0.15 and 0.35 GeV^2 (q=0.3, 0.38 and 0.57 GeV)

* NEW: Individual R_L R_T extractions (Rosenbluth plots)

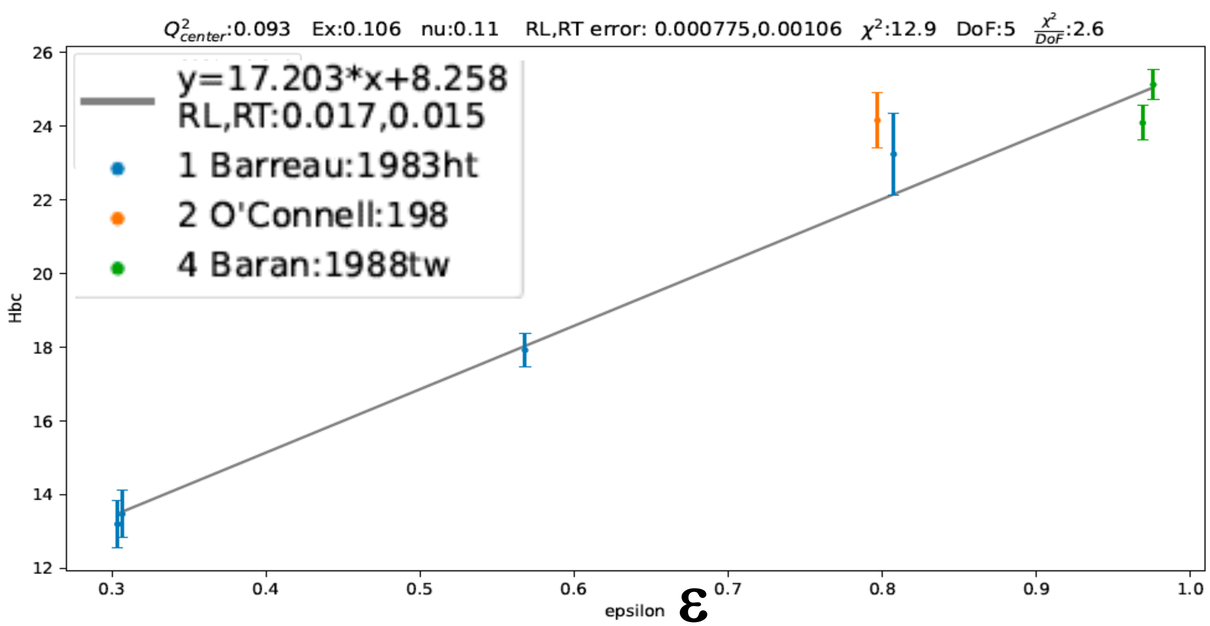
We apply Coulomb corrections in the analysis. We bin all cross sections in bins of q (we also do it for bins in Q^2) and apply bin centering corrections using the universal fit. Bin centers are at:

18 **q** values: 0.100, 0.148, 0.167, 0.205, 0.240, 0.300, 0.380, 0.475, 0.570, 0.649, 0.756, 0.991, 1.659, 1.921, 2.213, 2.500, 2.783, 3.500 GeV

18 Q^2. values: 0.00 (photoproduction), 0.010, 0.020, 0.026, 0.040, 0.056, 0.093, 0.120, 0.160, 0.265, 0.38, 0.50, 0.80, 1.25, 1.75, 2.25, 2.75, 3.25, 3.75 GeV^2

2. Bin centering correction in **q** (or Q^2). **For ν< 50 MeV** we bin-center the data in bins of Excitation energy $\mathbf{E_x}$, and for ν >50 MeV we bin-center the data in bins of $\mathbf{W^2}$. We then perform Rosenbluth fits versus virtual photon polarization ε extract $\mathbf{R_L}$ **and** $\mathbf{R_T}$. Later convert Ex and $\mathbf{W^2}$ to ν.

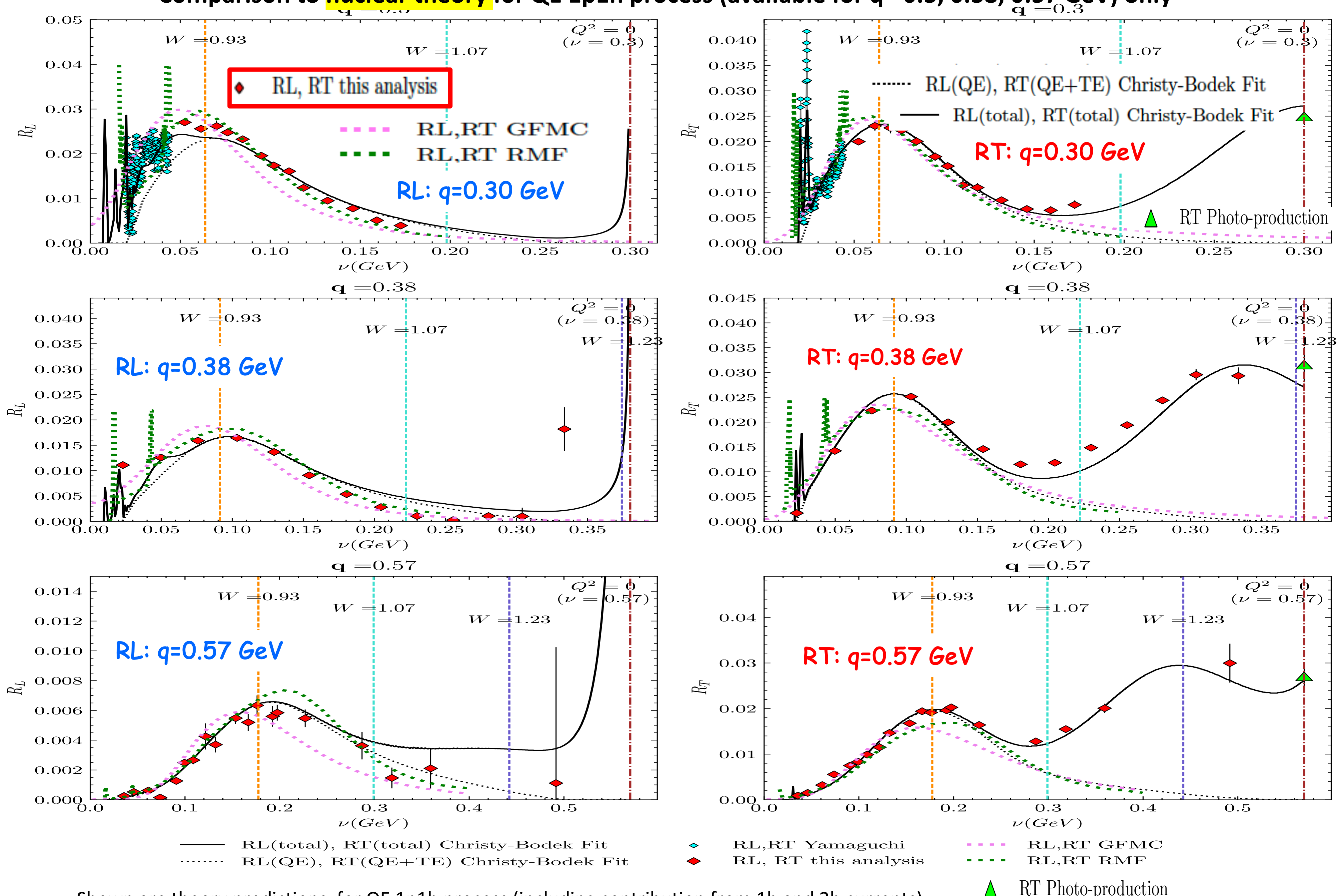
2. The universal fit includes all **16,000 cross sections**, The individual R_L R_T only use a **subset of the data** in which for the same values ν and Q^2 there is data spanning a a significant range of angles. Therefore the Universal Fit provide RL and RT for a more extended kinematic range



ε = virtual photon polarization

$$\epsilon = \left[1 + 2(1 + \frac{\nu^2}{Q^2})\tan^2\frac{\theta}{2}\right]^{-1}$$

*Comparison to nuclear theory for QE 1p1h process (available for q= 0.3, 0.38, 0.57 GeV) only



Shown are theory predictions for QE 1p1h process (including contribution from 1b and 2b currents).

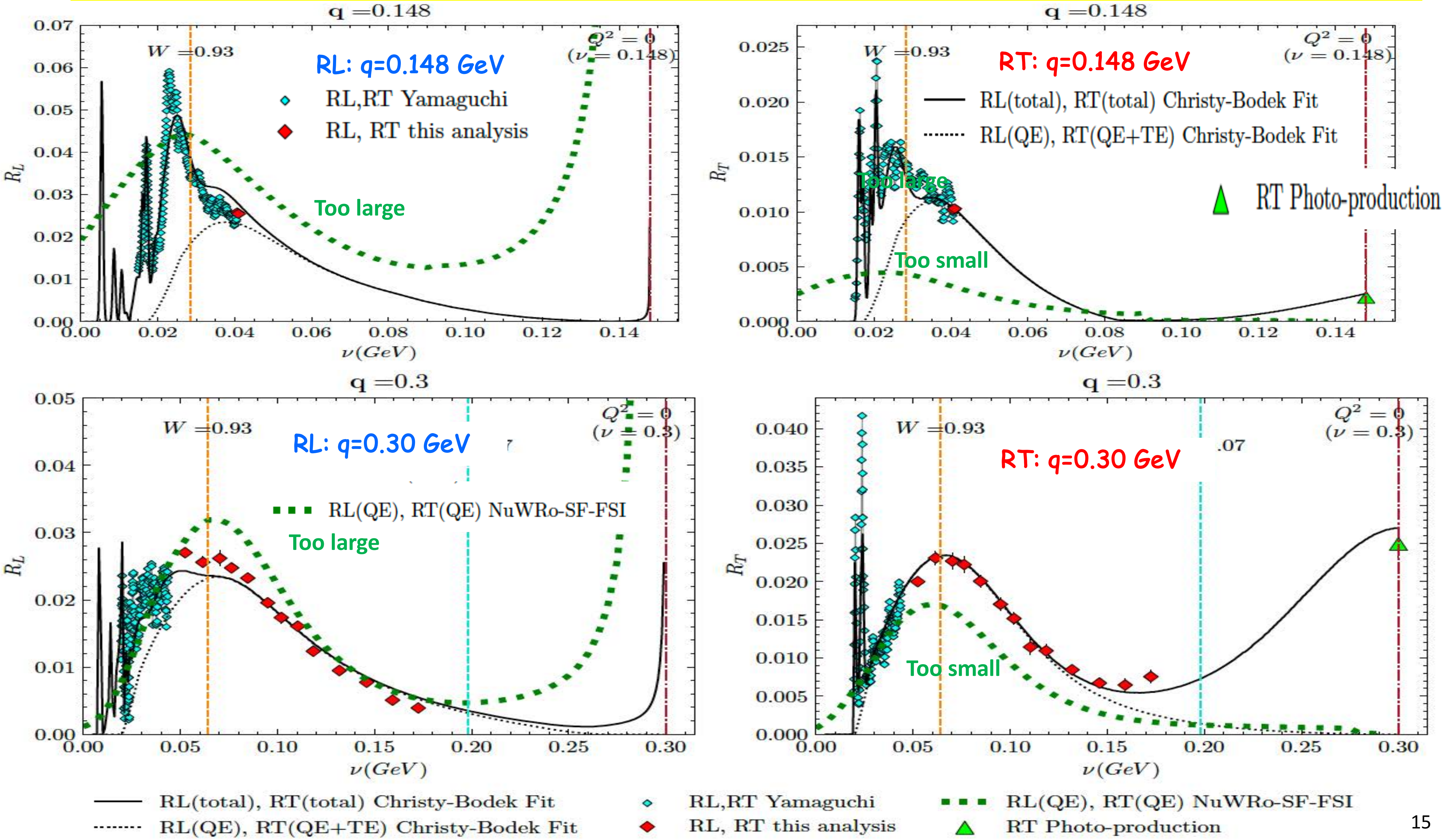
GFMC (Green's Function Monte Carlo – first principle).......... No nuclear states

ED-RMF (Energy Depending Relativistic mean field .... Nuclear states grouped at 2 values of fixed

QE predictions reasonable but not perfect

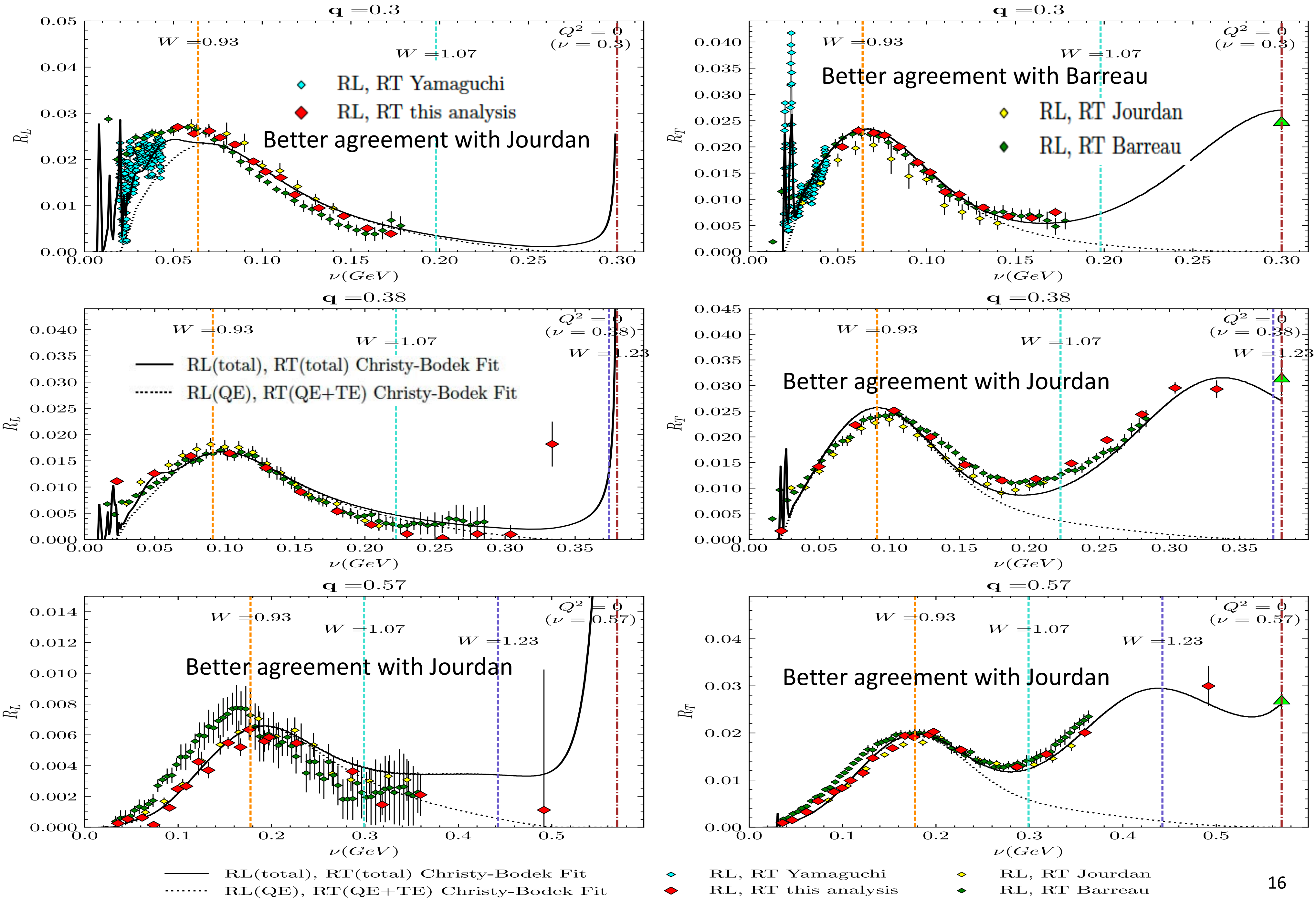
* Comparison to NuWRo Neutrino MC generator for QE (in electron scattering mode)

NuWRo; R_L **is too high (needs longitudinal quenching),** R_T **is too low (needs Transverse Enhancement/ME**C). No nuclear excitations are modeled in any NuWRo. Note: **NuWRo has Transverse Enhancement/MEC in neutrino but not in electron mode**. **---If MEC is implemented in electron mode, these data can be used to validate the model**.

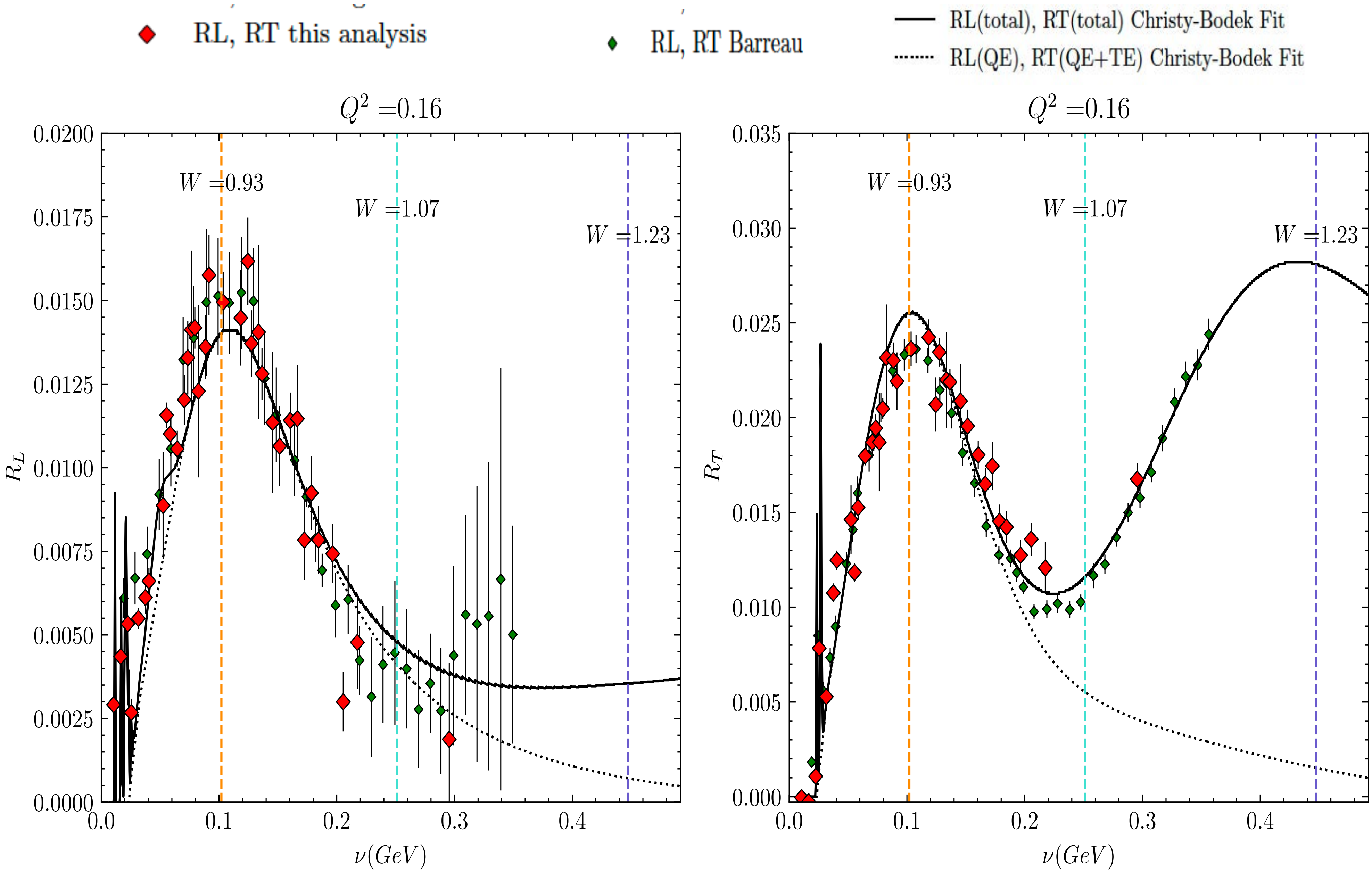


Comparisons with GENIE (in electron mode) will be available shortly

Comparison to previous R_L R_T extractions q = 0.3, 0.38, 0.57 GeV



Comparison to previous R_L R_T extractions Q^2= 0. 16 GeV^2



RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL,RT this analysis
RL, RT Barreau

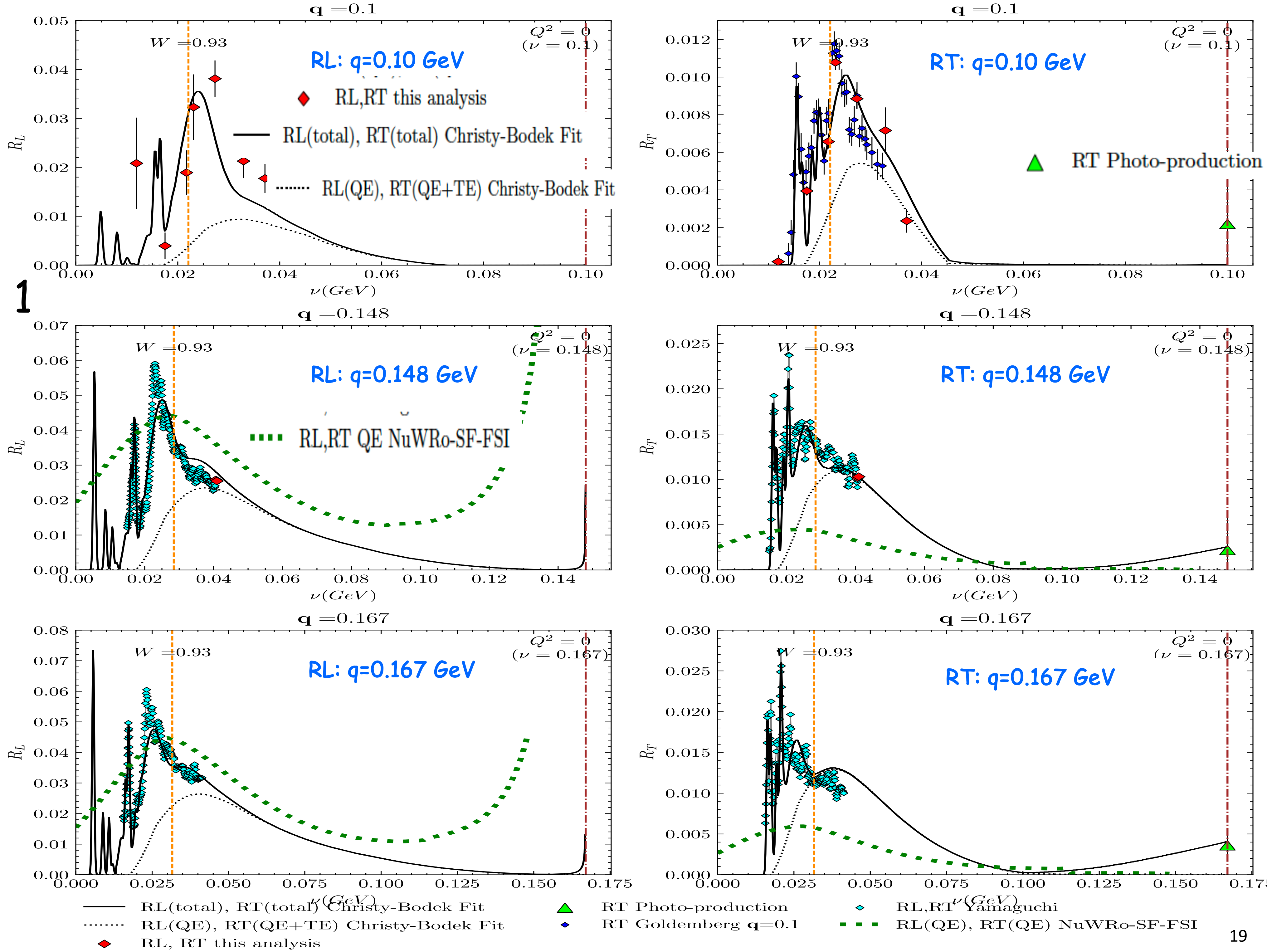
Extraction of Individual Measurements of R_L and R_T

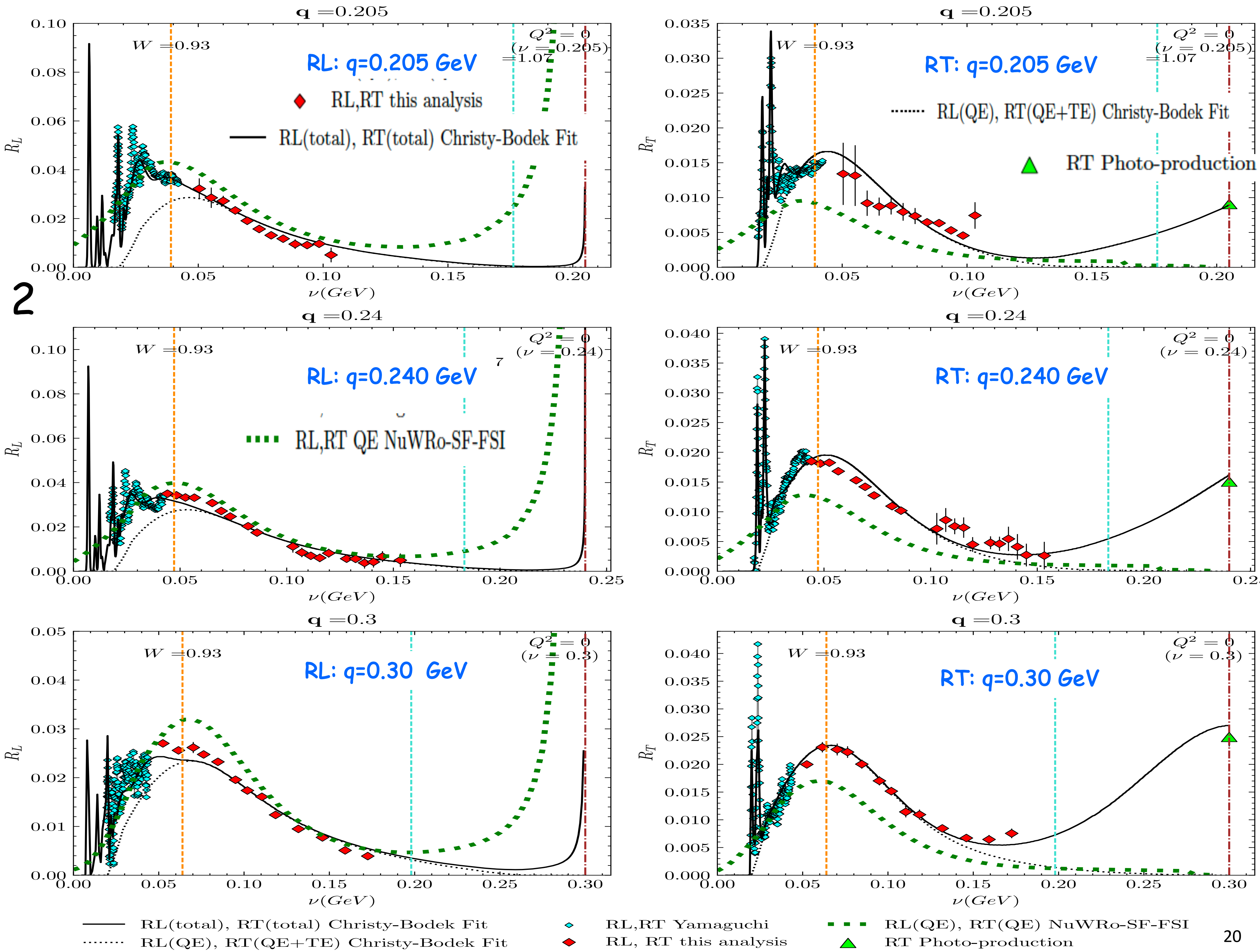
- The most effective way to validate **theoretical models** and neutrino and electron scattering MC generators is to compare to R_L and R_T measurements at fixed values of **q** (or Q^2) versus ν. This way, the entire kinematic range at all scattering angles can be validated.

- The Christy-Bodek universal fit provides fits to R_L and R_T everywhere. However, it is also important to validate the universal fit everywhere.

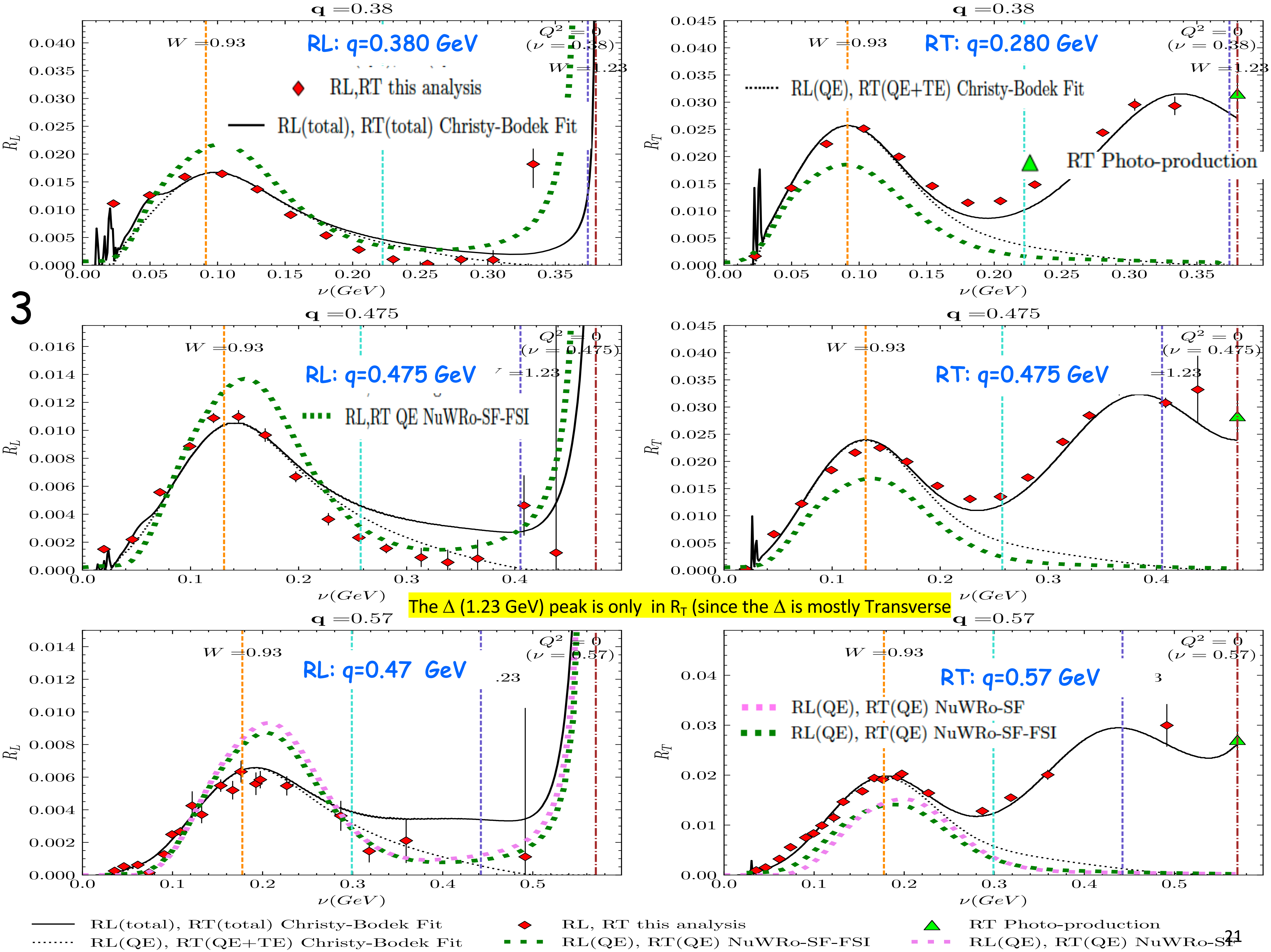
- The Christy-Bodek universal fit includes all 16,000 cross sections measurements. In order to extract we need cross section measurements at the same **q** (or Q^2) and ν , but at both at small and large.

- Therefore, only a subset of the cross sections can be used in individual R_L and R_T extractions since some cross sections are **only measured at small angles** and some are **only measured at large angles** (but at different **q** (or Q^2) and ν). However, all cross sections are included in the Christy-Bodek universal fit .


q =0.1
RL: q=0.10 GeV
RL,RT this analysis
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
W =0.93
$Q^2 = 0$ ($\nu = 0.1$)
RT: q=0.10 GeV
RT Photo-production
q =0.148
RL: q=0.148 GeV
RL,RT QE NuWRo-SF-FSI
$Q^2 = 0$ ($\nu = 0.148$)
RT: q=0.148 GeV
q =0.167
RL: q=0.167 GeV
$Q^2 = 0$ ($\nu = 0.167$)
RT: q=0.167 GeV
R_L
R_T
$\nu(GeV)$
1
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL, RT this analysis
RT Photo-production
RT Goldemberg q=0.1
RL,RT Yamaguchi
RL(QE), RT(QE) NuWRo-SF-FSI

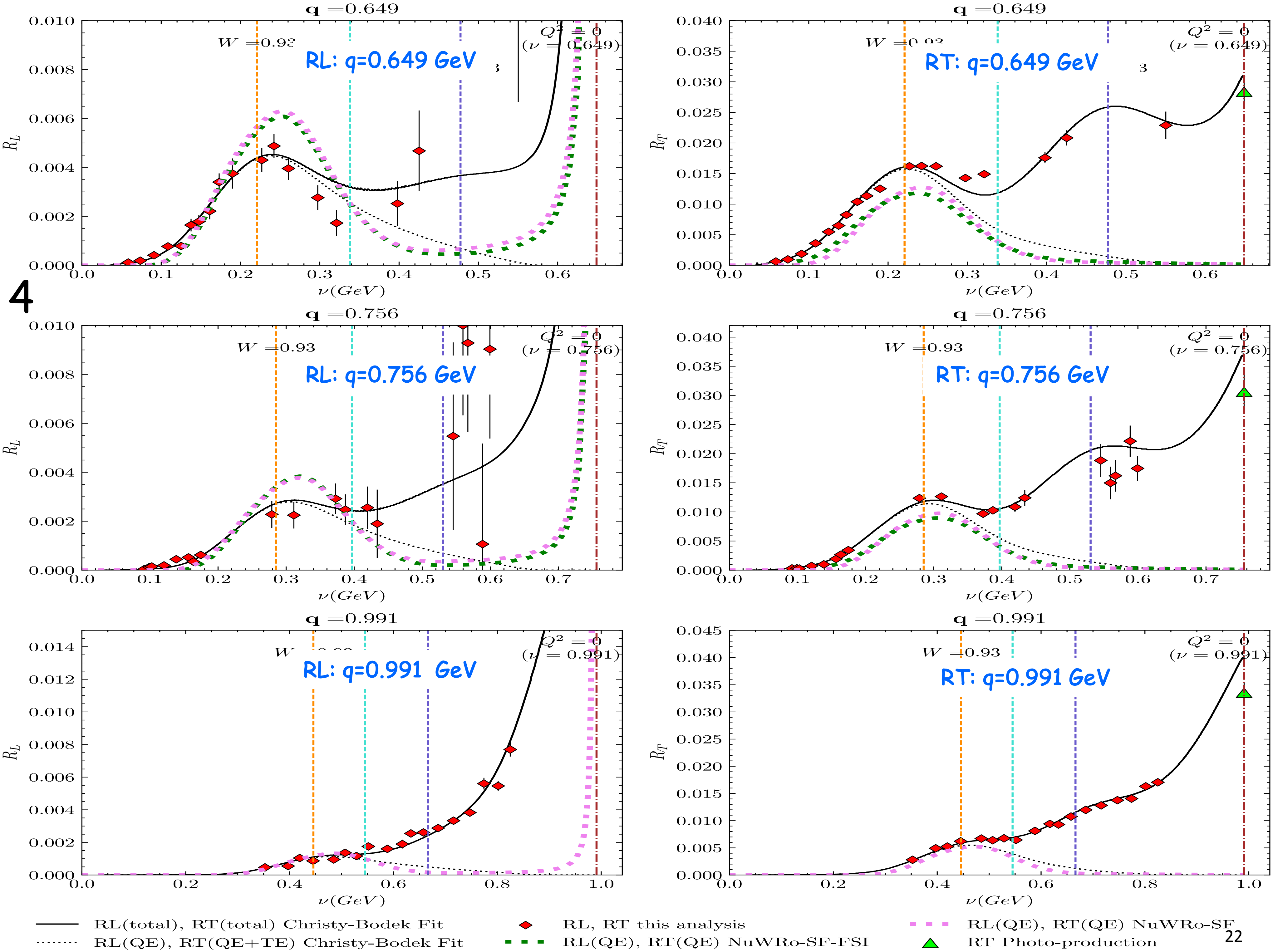


2
q =0.205
RL: q=0.205 GeV
RT: q=0.205 GeV
RL,RT this analysis
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RT Photo-production
q =0.24
RL: q=0.240 GeV
RT: q=0.240 GeV
RL,RT QE NuWRo-SF-FSI
q =0.3
RL: q=0.30 GeV
RT: q=0.30 GeV
W =0.93
Q² = 0
R_L
R_T
$\nu(GeV)$
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL,RT Yamaguchi
RL, RT this analysis
RL(QE), RT(QE) NuWRo-SF-FSI
RT Photo-production



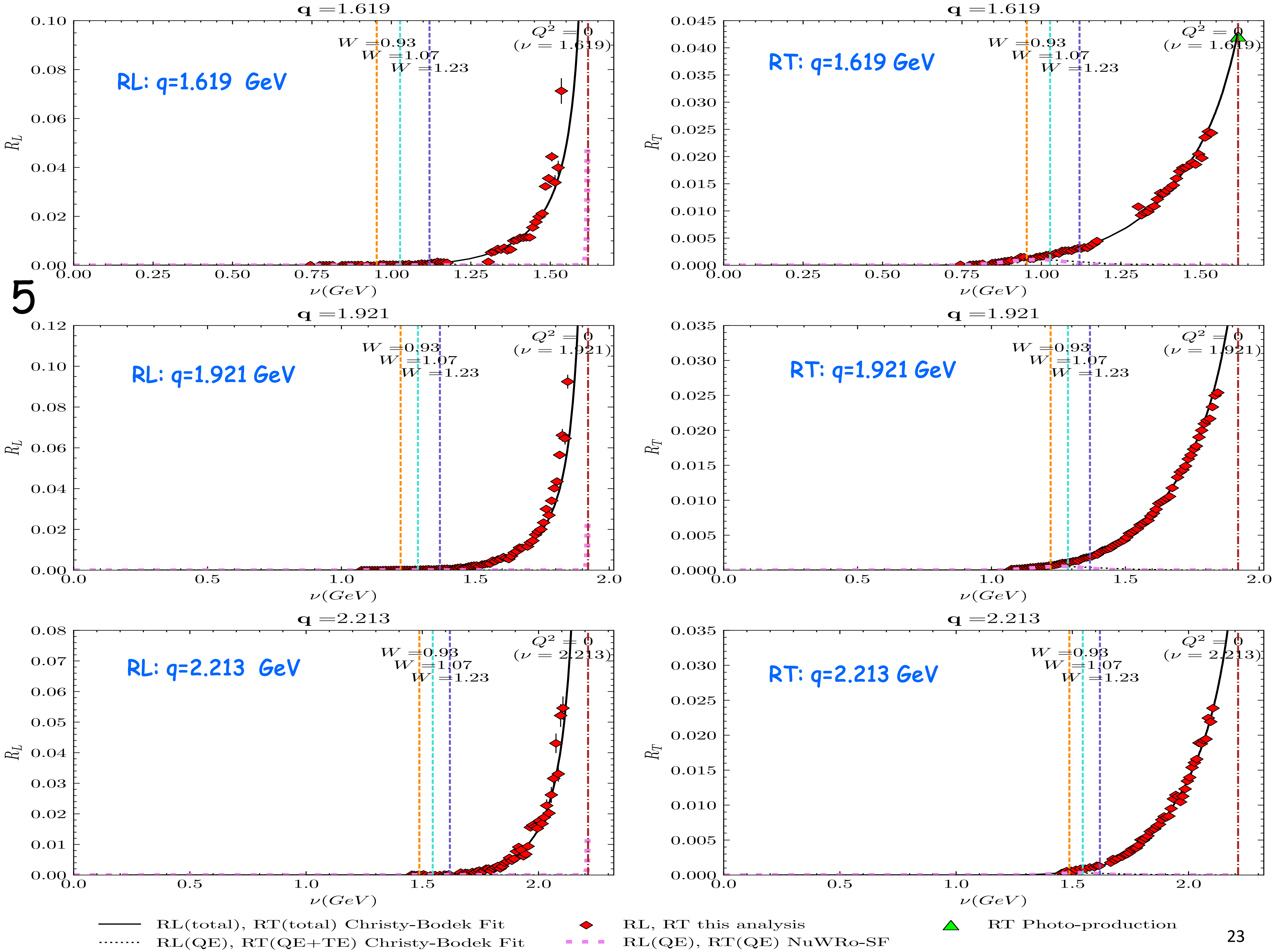
q =0.38
RL: q=0.380 GeV
RL,RT this analysis
RL(total), RT(total) Christy-Bodek Fit
RT: q=0.280 GeV
RL(QE), RT(QE+TE) Christy-Bodek Fit
RT Photo-production
3
q =0.475
RL: q=0.475 GeV
RL,RT QE NuWRo-SF-FSI
RT: q=0.475 GeV
The Δ (1.23 GeV) peak is only in R_T (since the Δ is mostly Transverse
q =0.57
RL: q=0.47 GeV
RT: q=0.57 GeV
RL(QE), RT(QE) NuWRo-SF
RL(QE), RT(QE) NuWRo-SF-FSI
W =0.93
W =1.23
Q² = 0
ν(GeV)
R_L
R_T
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL, RT this analysis
RL(QE), RT(QE) NuWRo-SF-FSI
RT Photo-production
RL(QE), RT(QE) NuWRo-SF

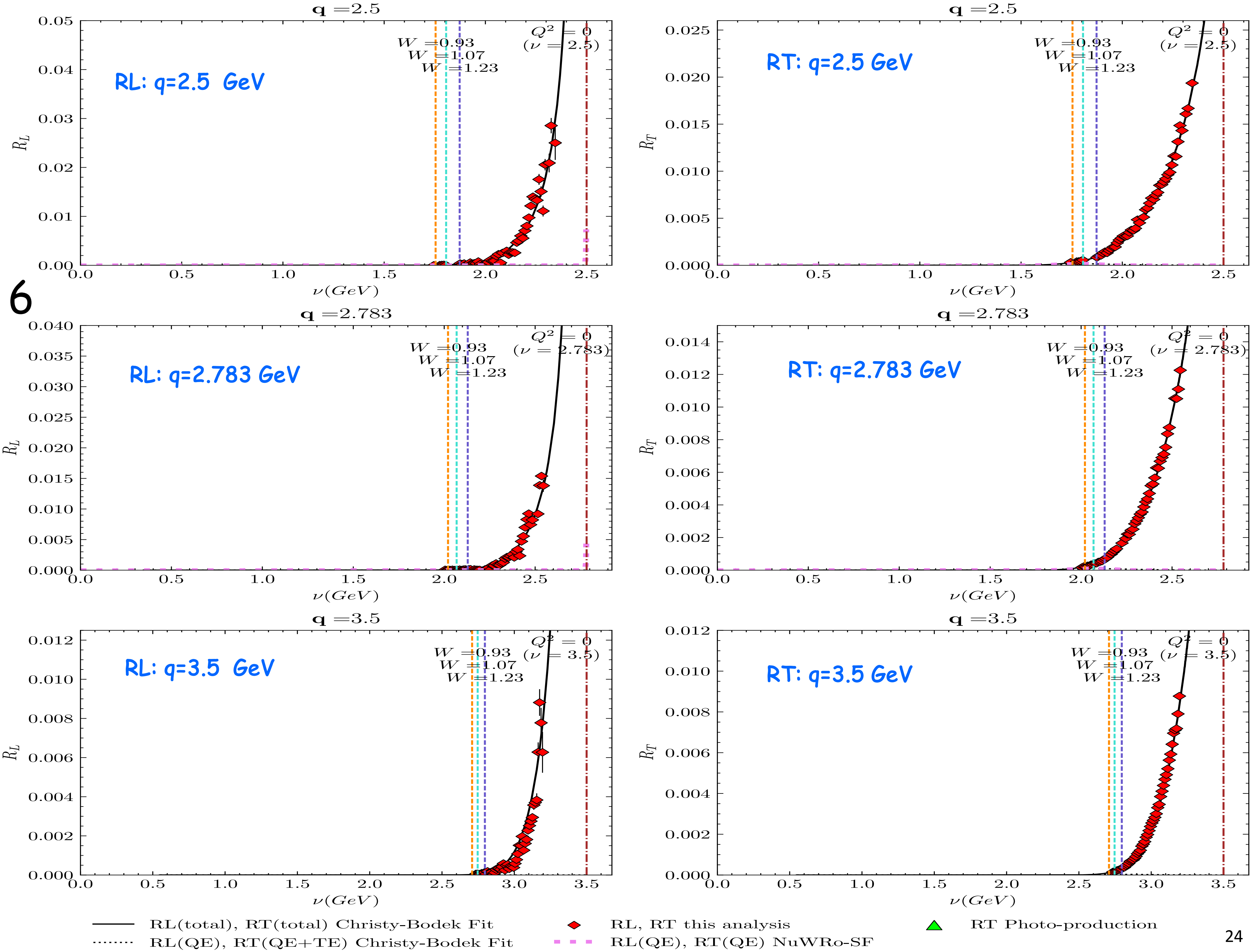
4



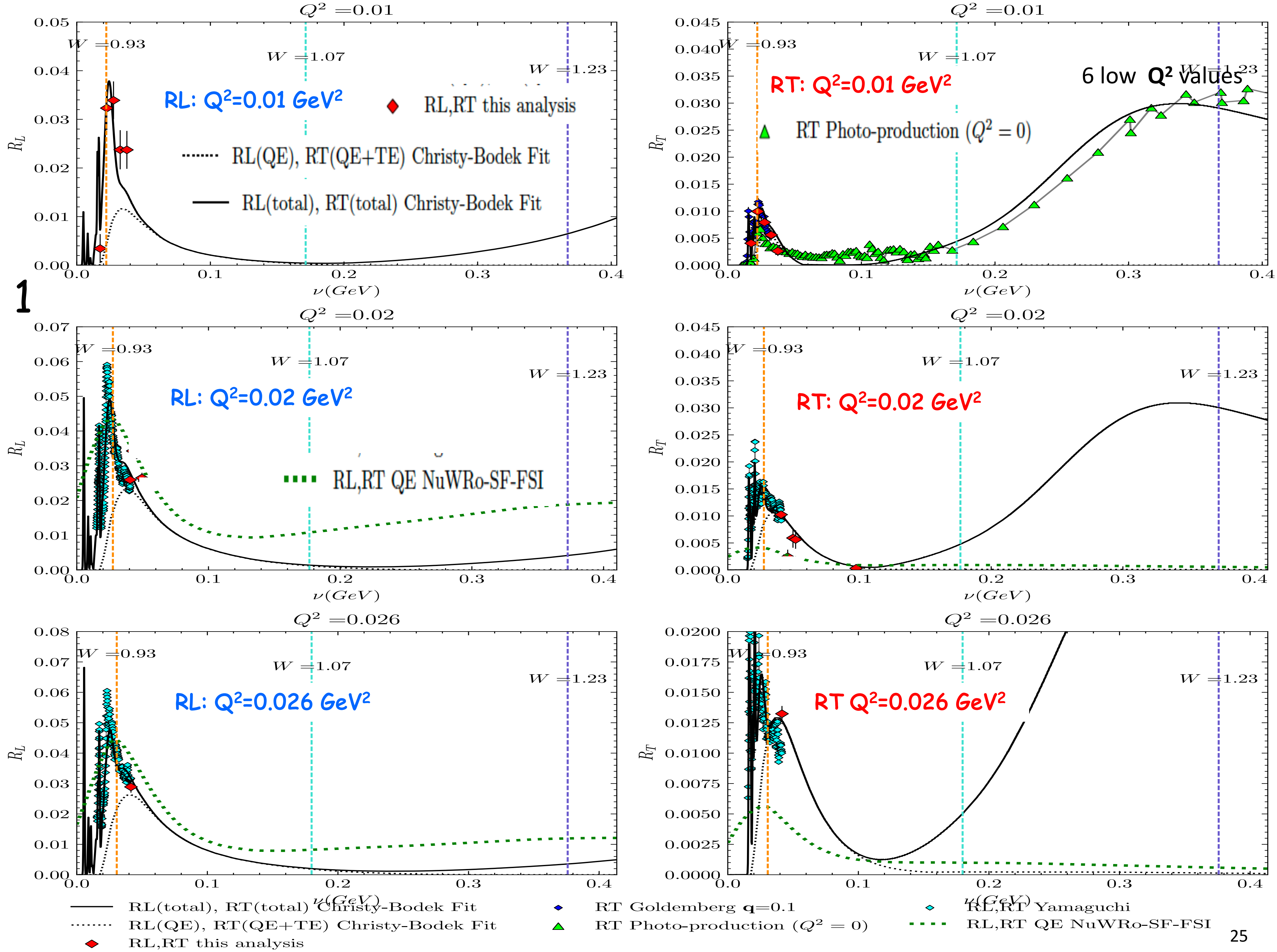
q =0.649
RL: q=0.649 GeV
RT: q=0.649 GeV
q =0.756
RL: q=0.756 GeV
RT: q=0.756 GeV
q =0.991
RL: q=0.991 GeV
RT: q=0.991 GeV
W =0.93
$Q^2 = 0$
(ν = 0.649)
(ν = 0.756)
(ν = 0.991)
R_L
R_T
$\nu(GeV)$
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL, RT this analysis
RL(QE), RT(QE) NuWRo-SF-FSI
RL(QE), RT(QE) NuWRo-SF
RT Photo-production

5


q =1.619
RL: q=1.619 GeV
RT: q=1.619 GeV
q =1.921
RL: q=1.921 GeV
RT: q=1.921 GeV
q =2.213
RL: q=2.213 GeV
RT: q=2.213 GeV
W =0.93
W =1.07
W =1.23
$Q^2 = 0$ (ν = 1.619)
$Q^2 = 0$ (ν = 1.921)
$Q^2 = 0$ (ν = 2.213)
R_L
R_T
$\nu(GeV)$
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL, RT this analysis
RL(QE), RT(QE) NuWRo-SF
RT Photo-production

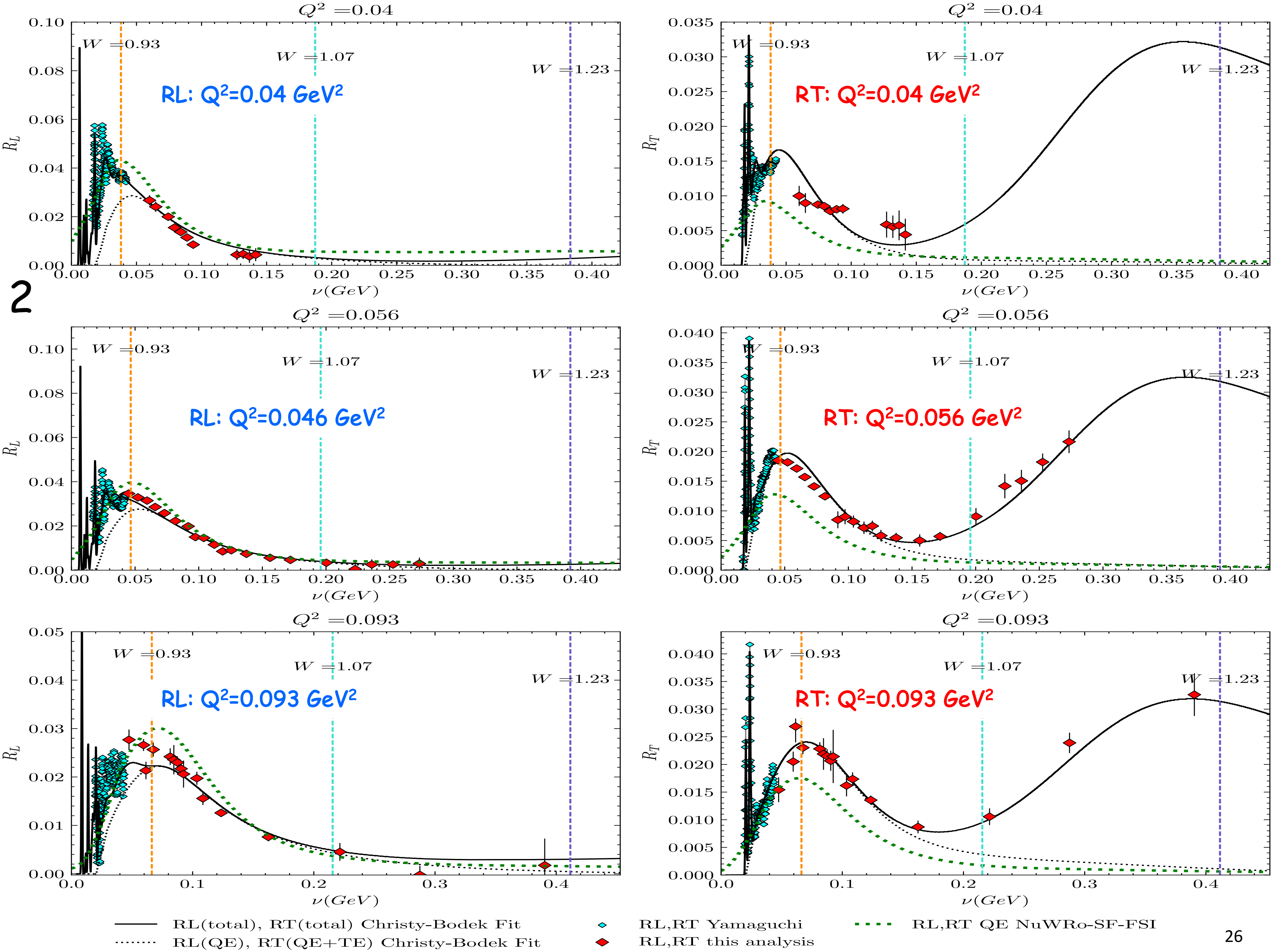


q =2.5
RL: q=2.5 GeV
RT: q=2.5 GeV
W =0.93
W =1.07
W =1.23
$Q^2 = 0$ ($\nu = 2.5$)
q =2.783
RL: q=2.783 GeV
RT: q=2.783 GeV
$Q^2 = 0$ ($\nu = 2.783$)
q =3.5
RL: q=3.5 GeV
RT: q=3.5 GeV
$Q^2 = 0$ ($\nu = 3.5$)
R_L
R_T
$\nu(GeV)$
6
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL, RT this analysis
RL(QE), RT(QE) NuWRo-SF
RT Photo-production



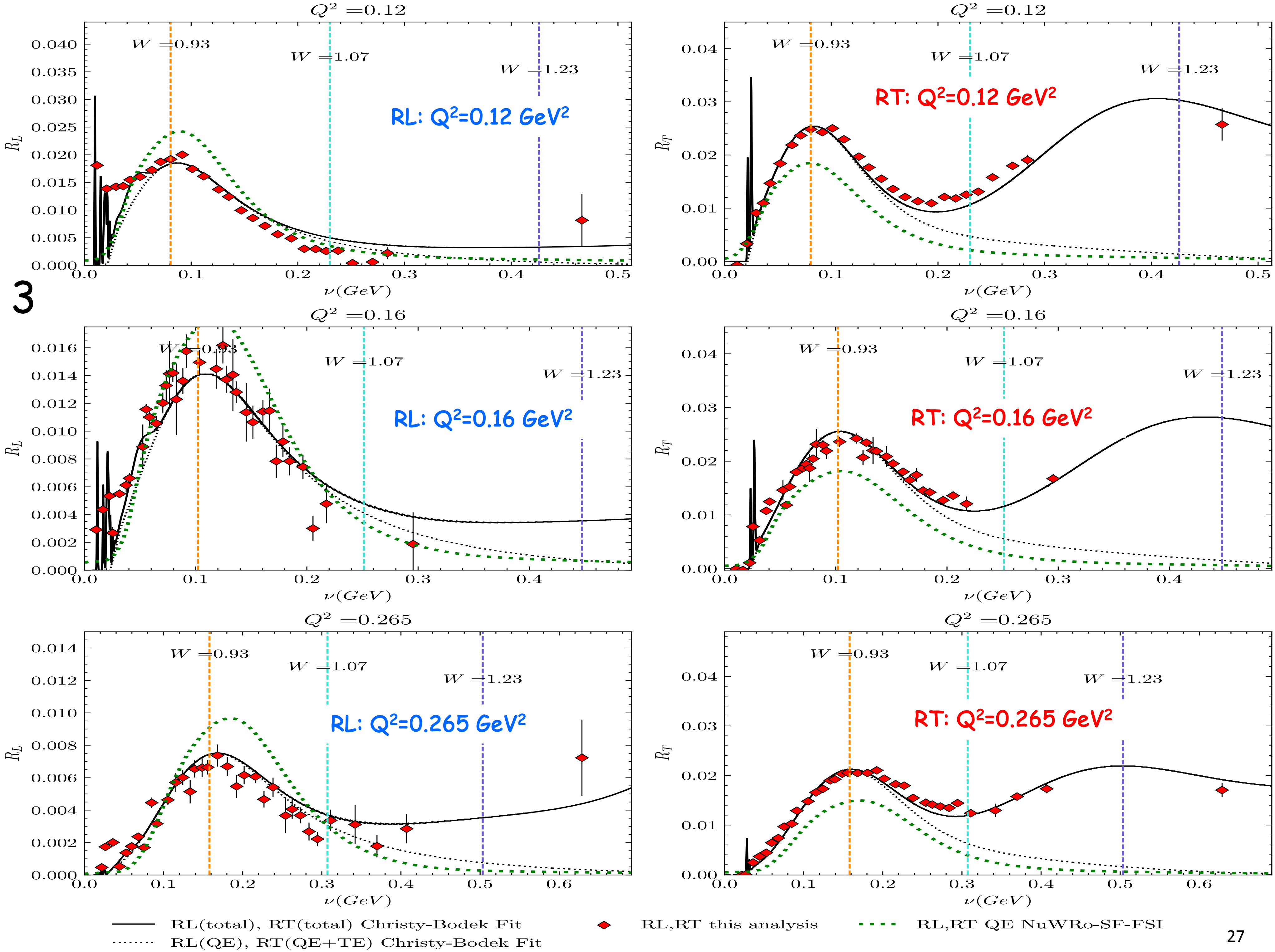
1
6 low Q^2 values
RL: Q^2=0.01 GeV^2
RT: Q^2=0.01 GeV^2
RL: Q^2=0.02 GeV^2
RT: Q^2=0.02 GeV^2
RL: Q^2=0.026 GeV^2
RT Q^2=0.026 GeV^2
Q^2 =0.01
Q^2 =0.02
Q^2 =0.026
W =0.93
W =1.07
W =1.23
R_L
R_T
$\nu(GeV)$
RL,RT this analysis
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL(total), RT(total) Christy-Bodek Fit
RT Photo-production ($Q^2 = 0$)
RL,RT QE NuWRo-SF-FSI
RT Goldenberg q=0.1
RL,RT Yamaguchi

2

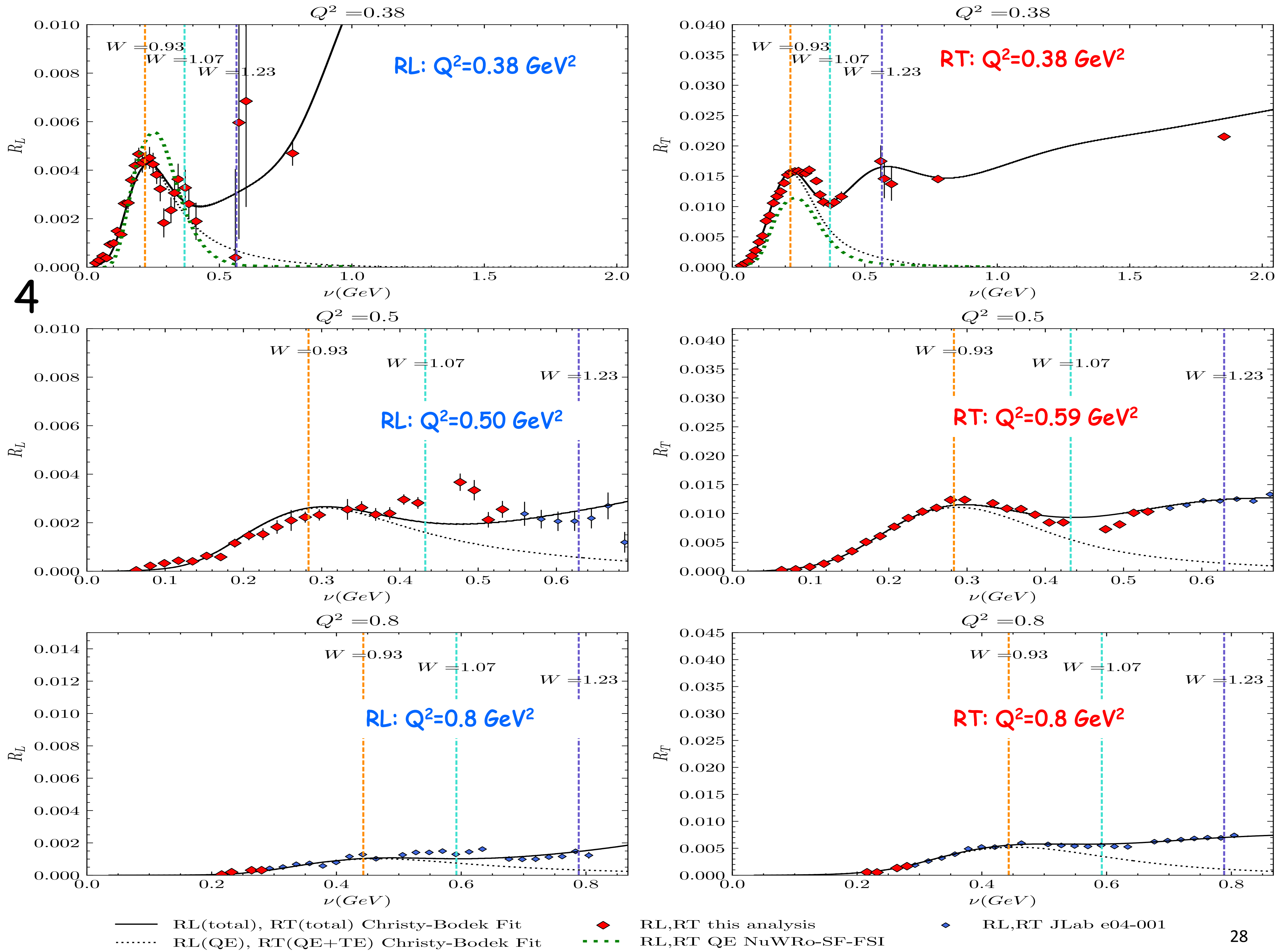


Q^2 =0.04
W =0.93
W =1.07
W =1.23
RL: Q²=0.04 GeV²
R_L
$\nu(GeV)$
Q^2 =0.04
RT: Q²=0.04 GeV²
R_T
Q^2 =0.056
RL: Q²=0.046 GeV²
RT: Q²=0.056 GeV²
Q^2 =0.093
RL: Q²=0.093 GeV²
RT: Q²=0.093 GeV²
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL,RT Yamaguchi
RL,RT this analysis
RL,RT QE NuWRo-SF-FSI

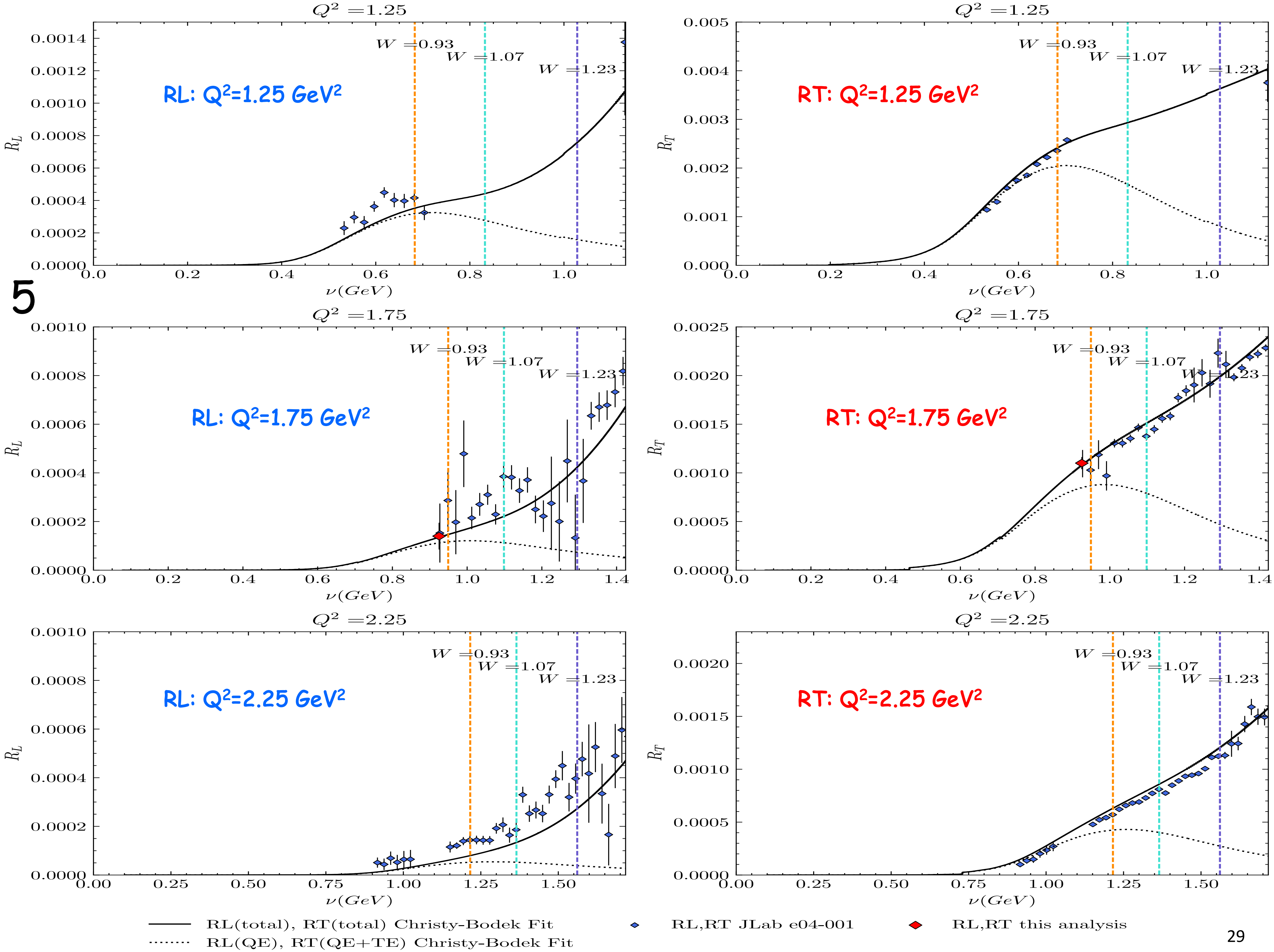
3



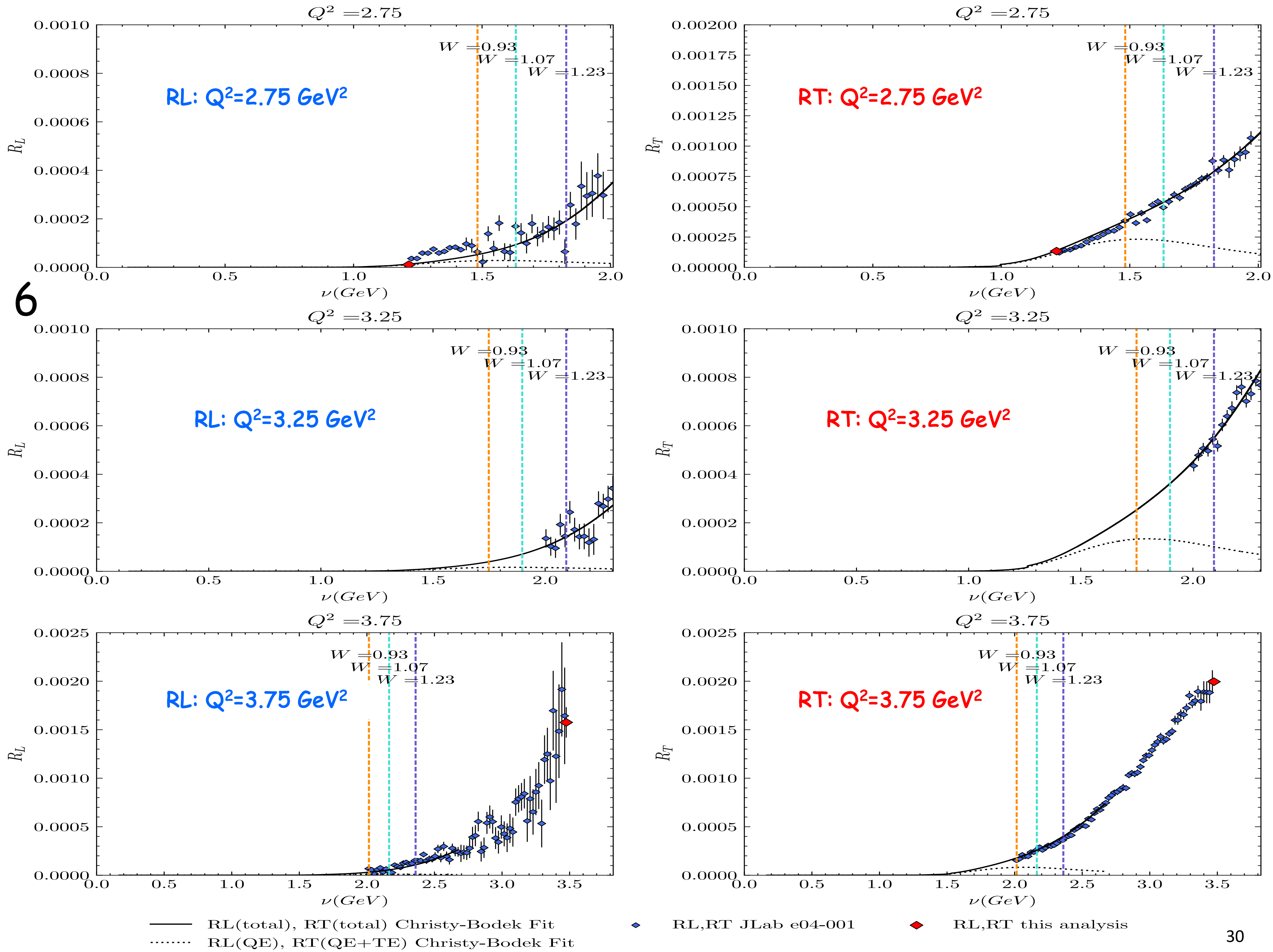
$Q^2 = 0.12$
RL: Q²=0.12 GeV²
RT: Q²=0.12 GeV²
$Q^2 = 0.16$
RL: Q²=0.16 GeV²
RT: Q²=0.16 GeV²
$Q^2 = 0.265$
RL: Q²=0.265 GeV²
RT: Q²=0.265 GeV²
$W = 0.93$
$W = 1.07$
$W = 1.23$
R_L
R_T
$\nu(GeV)$
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL,RT this analysis
RL,RT QE NuWRo-SF-FSI



4
$Q^2 = 0.38$
RL: Q²=0.38 GeV²
RT: Q²=0.38 GeV²
$Q^2 = 0.5$
RL: Q²=0.50 GeV²
RT: Q²=0.59 GeV²
$Q^2 = 0.8$
RL: Q²=0.8 GeV²
RT: Q²=0.8 GeV²
$W = 0.93$
$W = 1.07$
$W = 1.23$
R_L
R_T
$\nu (GeV)$
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL,RT this analysis
RL,RT QE NuWRo-SF-FSI
RL,RT JLab e04-001



$Q^2 = 1.25$
RL: Q²=1.25 GeV²
RT: Q²=1.25 GeV²
$Q^2 = 1.75$
RL: Q²=1.75 GeV²
RT: Q²=1.75 GeV²
$Q^2 = 2.25$
RL: Q²=2.25 GeV²
RT: Q²=2.25 GeV²
$W = 0.93$
$W = 1.07$
$W = 1.23$
R_L
R_T
$\nu(GeV)$
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL,RT JLab e04-001
RL,RT this analysis



Q^2 =2.75
RL: Q²=2.75 GeV²
RT: Q²=2.75 GeV²
Q^2 =3.25
RL: Q²=3.25 GeV²
RT: Q²=3.25 GeV²
Q^2 =3.75
RL: Q²=3.75 GeV²
RT: Q²=3.75 GeV²
W =0.93
W =1.07
W =1.23
R_L
R_T
$\nu(GeV)$
6
RL(total), RT(total) Christy-Bodek Fit
RL(QE), RT(QE+TE) Christy-Bodek Fit
RL,RT JLab e04-001
RL,RT this analysis

Comments

*

- The extracted RL and RT are in good agreement with the Christy-Bodek Universal Fit. The fit can be used for validation of MC generators over a more extended range of **q** and ν.
- The Christy-Bodek fit includes **Longitudinal Quenching** at low **q** and **Transverse Enhancement** at intermediate q. It also includes nuclear excitations
- The Δ (1.23 GeV) peak is only seen in R_T (since the Δ is mostly Transverse)**.**
- For fixed **q** the maximum value of ν is $\boldsymbol{\nu}$**=q** (where R_T can also be extracted from photoproduction data).
- Validation of Neutrino Generator NuWRo in electron model: NuWRo only models QE with a spectral function, and adds Final State Interaction (FSI)
- NuWRo (spectral function) requires FSI for better agreement with the data.
- However, even with FSI for q<0.3 GeV NuWRo overestimates R_L **(requires Longitudinal Quenching)**
- NuWRo underestimates R_T (in neutrino mode it has Transverse Enhancement/MEC, but not in electron mode).
- Nuclear excitations are not included
- Comparisons with GENIE (in electron mode) will be available shortly.

(

*

Conclusions

- The 18 R_L and R_T extractions cover a large kinematic range. The values are in excellent agreement with the Christy-Bodek Universal fit to all cross section values. The universal fit covers an even larger kinematic range.

- The R_L and R_T measurements as well as the universal fit provide a simple way to validate electron and neutrino MC generators over the entire kinematic range of interest.
- Good agreement in the QE region with nuclear theory for 3 values of q. Predictions for all other values of q not yet available.

<u>In Supplemental Materials we will provide</u>

Tables of the extracted values of R_L and R_T

- Tables of the Christy-Bodek Universal fit values for R_L and R_T for the 18 q and Q^2 values. The contributions of nuclear excitations, QE, transverse enhancement and inelastic scattering will be listed separately.
- Code for the Christy-Bodek Universal fit

Backup