^{3}He (e,e') Response Functions in the Quasielastic Region

V.D. Efros, W.L., G. Orlandini, E.L. Tomusiak

The unpolarized (e,e') cross section is governed by the longitudinal and transverse response functions $R_L(\omega,q)$ and $R_T(\omega,q)$ induced by operators for nuclear charge ρ and current **J**, respectively

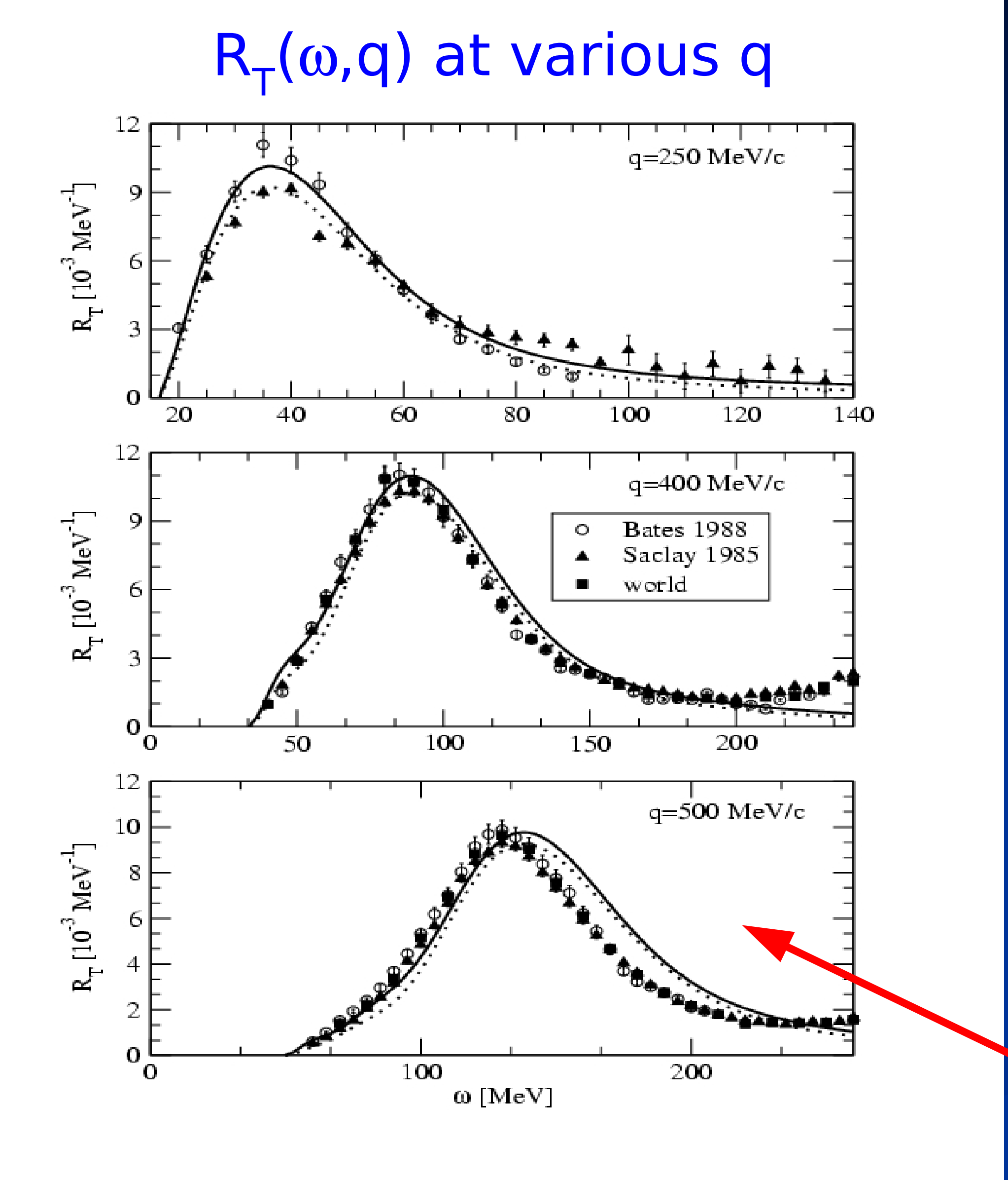
The quasielastic region is dominated by the one-body parts of ρ and **J**, but relativistic contributions become increasingly important with growing momentum transfer q

Our aim: non-rel. calculation + rel. corrections

with realistic nuclear forces

following the lines of the d(e,e') calculations by Arenhövel et al.

Motivation



Potential: BonnRA +TM'

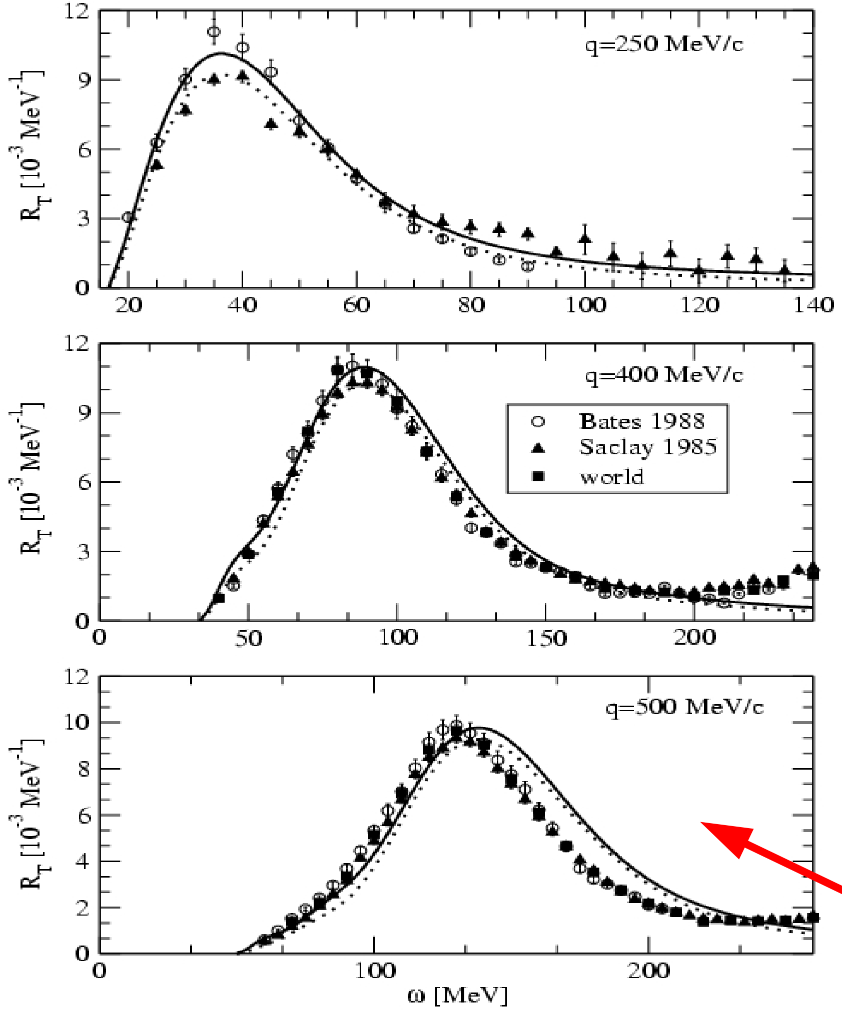
one-body current: dashed
one+two-body current: full

(S. Della Monaca et al., PRC 77, 044007 (2008))

Bad agreement between theory and experiment because of non considered relativistic effects

Motivation

$R_T(\omega,q)$ at various q



Potential: BonnRA +TM'

one-body current: dashed
one+two-body current: full

Quasi-elastic kinematics (q=500 MeV/c),
Kinetic energy of outgoing nucleon:

non-rel. : $T = q^2/2m = 133$ MeV
rel.: $T= (m^2+q^2)^{1/2} - m = 125$ MeV

Bad agreement between theory and experiment because of non considered relativistic effects

We already considered this problem for R_L and studied R_L in various reference frames:

Laboratory: $P_T = 0$

Breit: $P_T = -q/2$

Anti-Lab: $P_T = -q$

Active Nucleon Breit: $P_T = -Aq/2$

non-rel.: $\omega_{frame} + (P_T)^2/2Am = E_{internal} + (P_T+q)^2/2Am$

$R_L(\omega,q)$ at higher q

Frame dependence

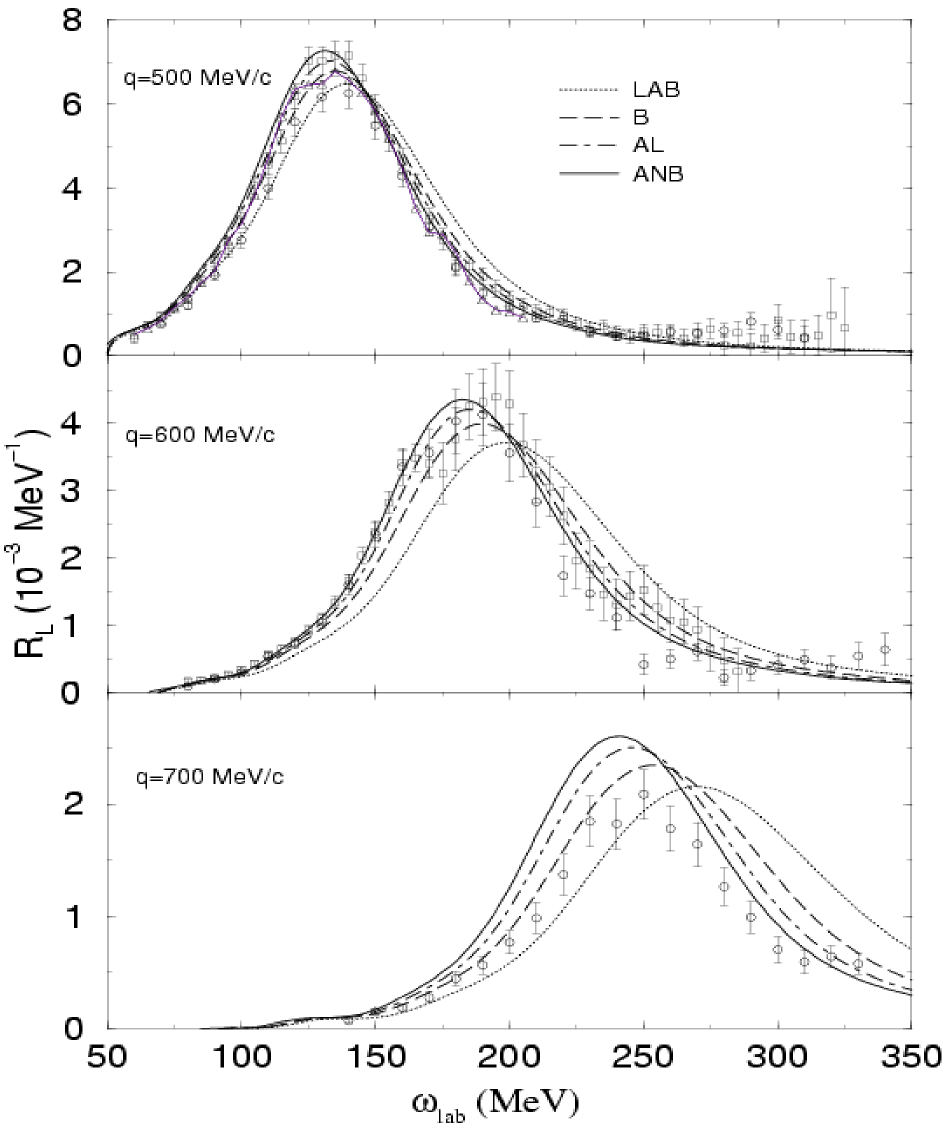
calculation in various frames:

Laboratory:	$P_T = 0$
Breit:	$P_T = -q/2$
Anti-Lab:	$P_T = -q$
Active Nucleon Breit:	$P_T = -Aq/2$

Potential: AV18+UIX

Result in LAB frame

$$R_L(\omega,q) = \frac{q^2}{(q_{fr})^2}\frac{E_T^{fr}}{M_T} R_L^{fr}(\omega^{fr},q^{fr})$$



Exp: Marchand 1985, Dow 1988, Carlson 2002

V. Efros, W.L., G. Orlandini, E. Tomusiak
PRC 72 (2005) 011002(R)

How to get more frame independent results?

Assume quasi-elastic kinematics:

whole energy and momentum transfer taken by the knocked out nucleon (residual two-body system is in its lowest energy state)

$\Longrightarrow$ Effective two-body problem
Treat kinematics relativistically correct

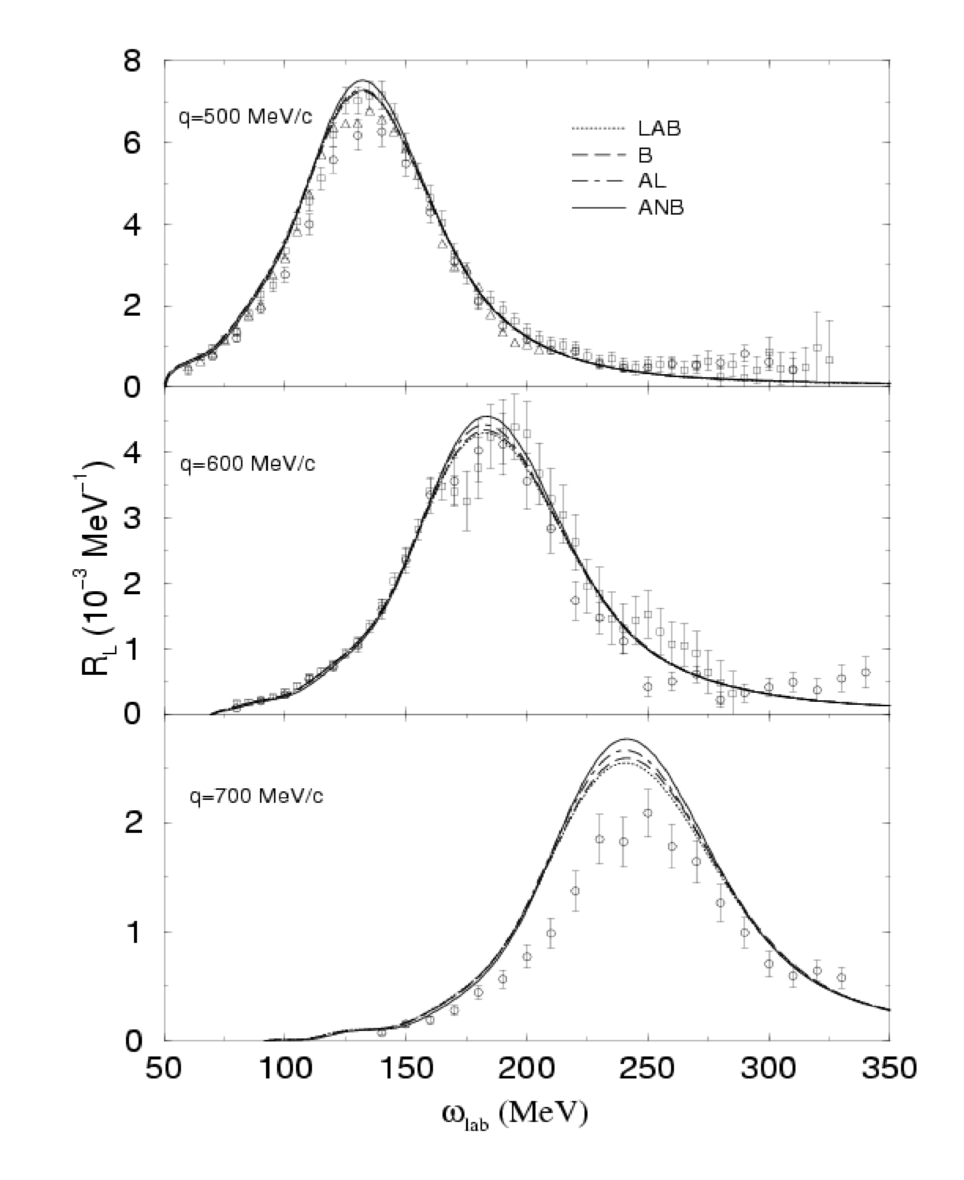
Take the correct relativistic relative momentum k_{rel} and calculate the corresponding non-relativistic relative energy

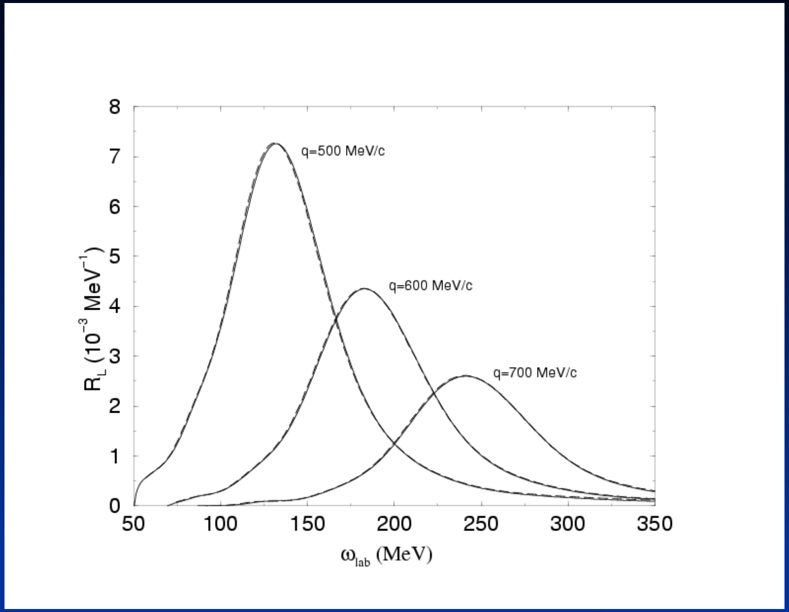
$$E_{nr} = (k_{rel})^2/2\mu$$

with reduced mass μ of nucleon and residual system

use E_{nr} as internal excitation energy in your calculation

$R_L(\omega,q)$ at higher q





R_L calculated in ANB frame with (dashed) and without (full) assumption of a two-body break-up

Quasielastic region: assume two-body break-up and use the correct relativistic relative momentum

Details for the R_T calculation

- Full consideration of final state interaction via LIT method

Details for the R_T calculation

- Full consideration of final state interaction via LIT method
- Nuclear Force model: Argonne V18 two-nucleon potential and Urbana IX three-nucleon force
-
-
-
-

Details for the R_T calculation

- Full consideration of final state interaction via LIT method
- Nuclear Force model: Argonne V18 two-nucleon potential and Urbana IX three-nucleon force
- Calculation of bound state wave function and solution of LIT equation with help of expansions in correlated hyperspherical harmonics

Details for the R_T calculation

- Full consideration of final state interaction via LIT method
- Nuclear Force model: Argonne V18 two-nucleon potential and Urbana IX three-nucleon force
- Calculation of bound state wave function and solution of LIT equation with help of expansions in correlated hyperspherical harmonics
- Consideration of isovector meson exchange currents consistent with AV18 potential

Details for the R_T calculation

- Full consideration of final state interaction via LIT method
- Nuclear Force model: Argonne V18 two-nucleon potential and Urbana IX three-nucleon force
- Calculation of bound state wave function and solution of LIT equation with help of expansions in correlated hyperspherical harmonics
- Consideration of isovector meson exchange currents consistent with AV18 potential
- Calculation in active nucleon Breit (ANB) frame (P_T=−Aq/2) and subsequent transformation to laboratory system

Details for the R_T calculation

- Full consideration of final state interaction via LIT method
- Nuclear Force model: Argonne V18 two-nucleon potential and Urbana IX three-nucleon force
- Calculation of bound state wave function and solution of LIT equation with help of expansions in correlated hyperspherical harmonics
- Consideration of isovector meson exchange currents consistent with AV18 potential
- Calculation in active nucleon Breit (ANB) frame ($P_T = -Aq/2$) and subsequent transformation to laboratory system
- One-body current operator includes all relativistic corrections up to the order M^{-3} (leading order M^{-1}) as made for deuteron electrodisintegration (F. Ritz et al, PRC 55, 02214)
- .

.

Details for the R_T calculation

- Full consideration of final state interaction via LIT method
- Nuclear Force model: Argonne V18 two-nucleon potential and Urbana IX three-nucleon force
- Calculation of bound state wave function and solution of LIT equation with help of expansions in correlated hyperspherical harmonics
- Consideration of isovector meson exchange currents consistent with AV18 potential
- Calculation in active nucleon Breit (ANB) frame ($P_T = -Aq/2$) and subsequent transformation to laboratory system
- One-body current operator includes all relativistic corrections up to the order M^{-3} (leading order M^{-1}) as made for deuteron electrodisintegration (F. Ritz et al, PRC 55, 02214)
- Multipole expansion of current (maximal j_f q dependent, e.g, j_f =35/2 for q=700 MeV/c)

Further calculation details

The current operator **J**

$\mathbf{J} = \mathbf{J}^{(1)} + \mathbf{J}^{(2)}$

$\mathbf{J}^{(1)} = \mathbf{J}^{(1)}(q,\omega,P_T) = \mathbf{J}_{spin} + \mathbf{J}_{p} + \mathbf{J}_{q} + (\omega/M)\,\mathbf{J}_{\omega}$

for instance spin current

$\mathbf{J}_{spin} = \exp(i\mathbf{q}\cdot\mathbf{r})\; i\,\boldsymbol{\sigma}\times\mathbf{q}/2M\;[G_M(1-q^2/8M^2) - G_E\,\kappa^2 q^2/8M^2]$

with $\kappa=1+2P_T/Aq$

Further calculation details

The current operator **J**

$\mathbf{J} = \mathbf{J}^{(1)} + \mathbf{J}^{(2)}$

$\mathbf{J}^{(1)} = \mathbf{J}^{(1)}(q,\omega,P_T) = \mathbf{J}_{spin} + \mathbf{J}_p + \mathbf{J}_q + (\omega/M)\,\mathbf{J}_\omega$

for instance spin current

$\mathbf{J}_{spin} = \exp(i\mathbf{q}\cdot\mathbf{r})\; i\,\boldsymbol{\sigma}\times\mathbf{q}/2M\;[G_M(1-q^2/8M^2) - G_E\,\kappa^2 q^2/8M^2]$

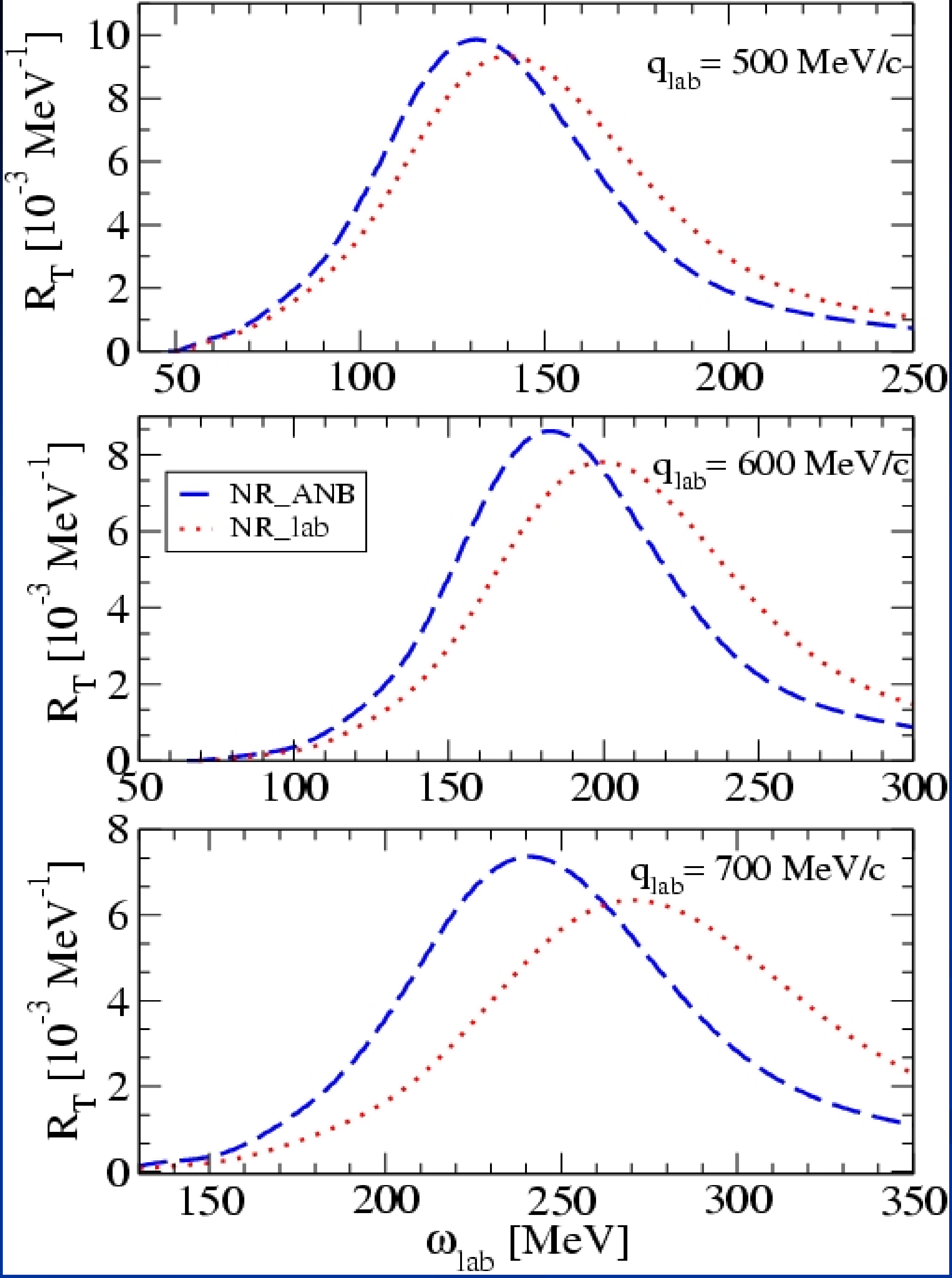
with $\kappa=1+2P_T/Aq$

Transformation from ANB frame to LAB frame

$R_T^{LAB}(\omega^{LAB},q^{LAB}) = R_T^{ANB}(\omega^{ANB},q^{ANB})\;\; E_T^{ANB}/M_T$

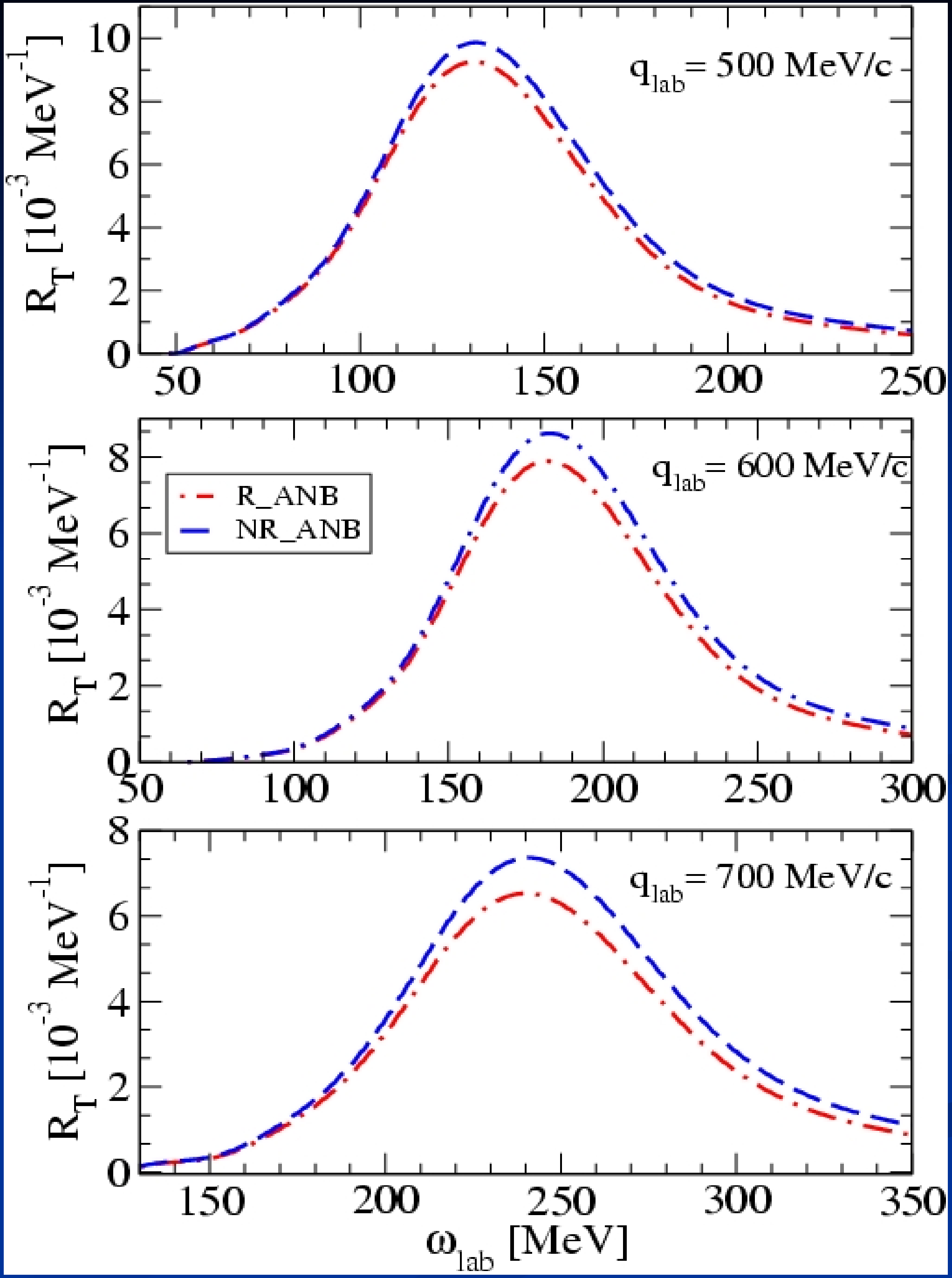
Results

- Comparison of ANB and LAB calculation: strong shift of peak to lower energies! (8.7, 16.7, 29.3 MeV at q=500, 600, 700 MeV/c)



Results

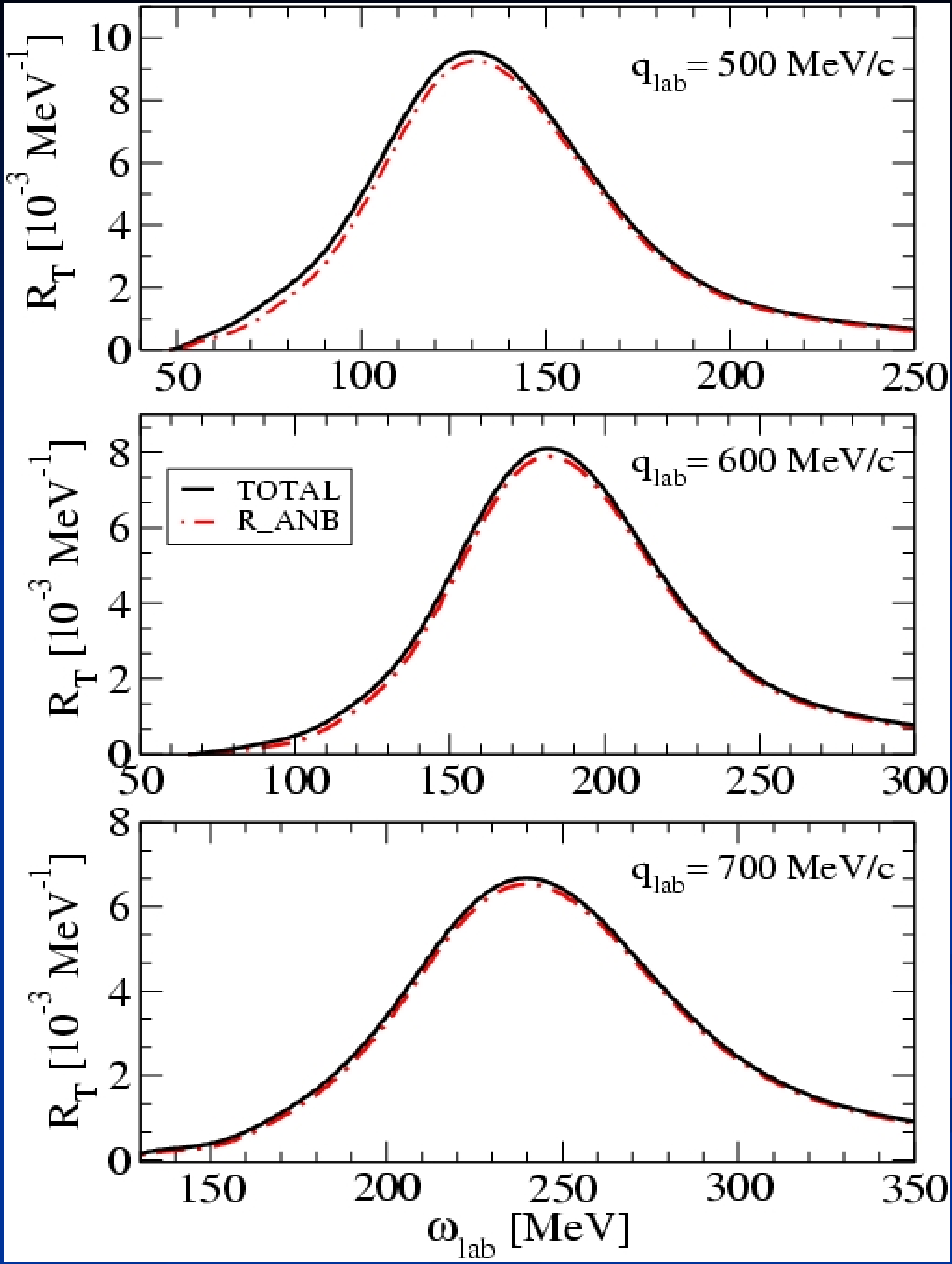
- Rel. contribution: reduction of peak height (6.2%, 8.5%, 11.3 % at q=500, 600, 700 MeV/c)



Results

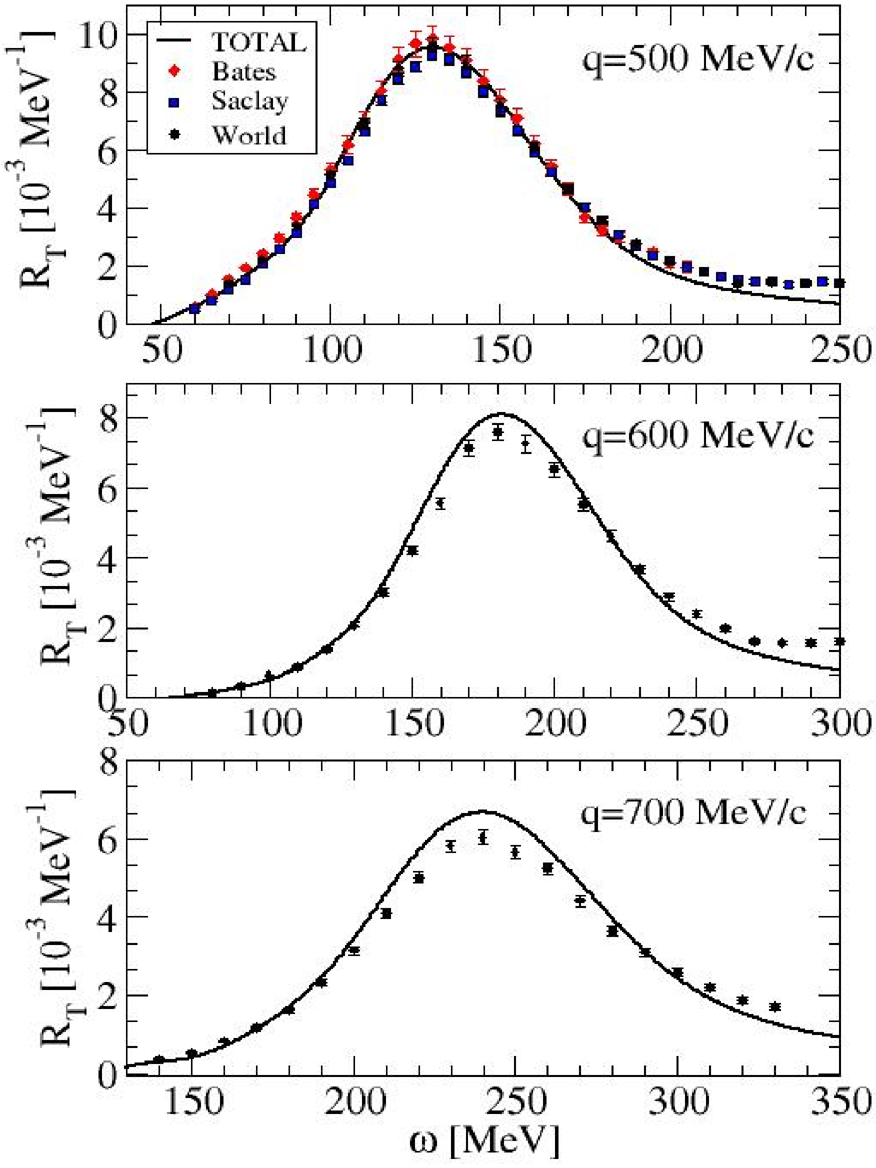
- MEC:

small increase of
peak height
(3.2%, 2.7%, 2.2% at
q=500, 600, 700 MeV/c)



Results

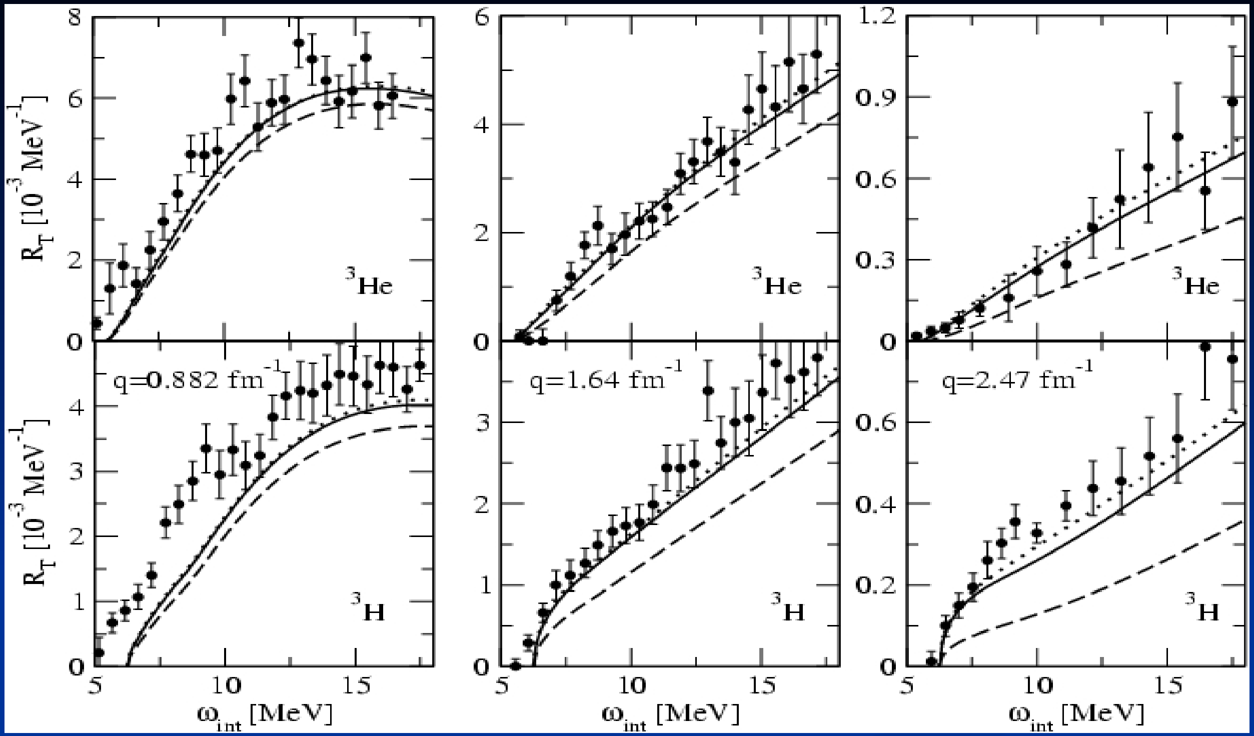
Comparison with experiment



NR: dashed

NR+MEC: dotted

Rel.+MEC: full

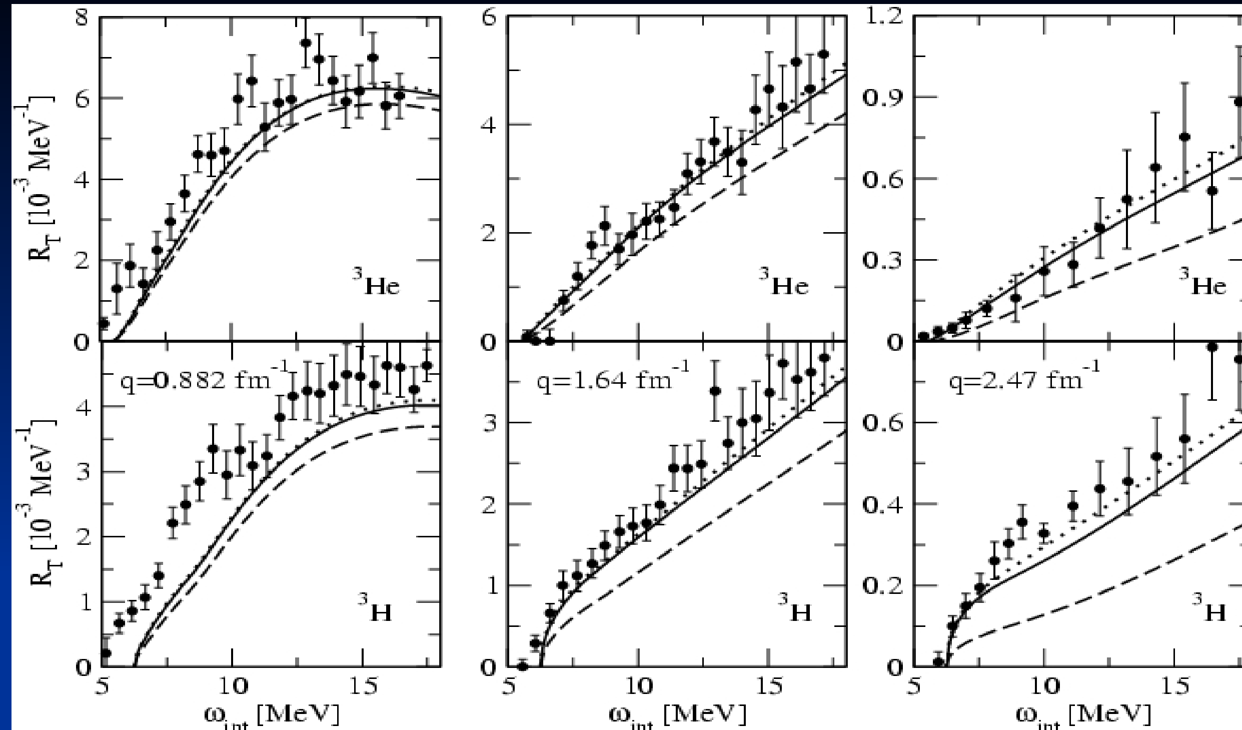


q = 174 MeV/c q = 324 MeV/c q = 487 MeV/c

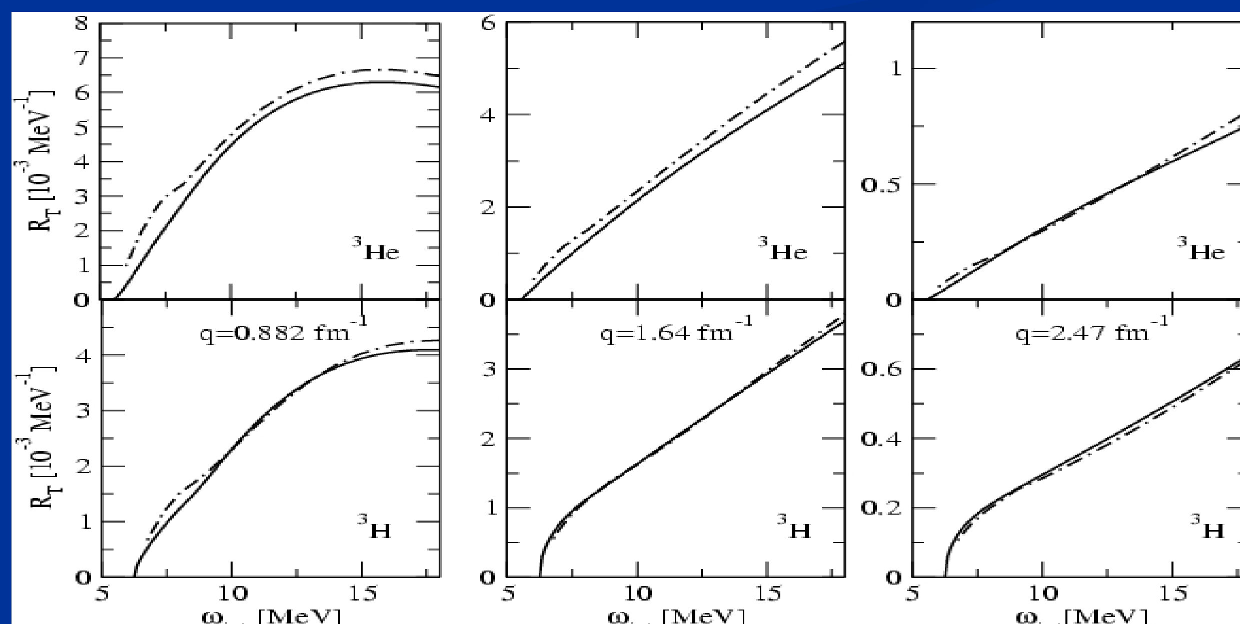
R_T close to break-up threshold

(Few-Body Syst., in print; arXiv:0906.0663)

NR+MEC: dotted
Rel.+MEC: full



Golak et al.: dash-dotted
our NR+MEC calc.: full



Conclusion

Comparison of theory and experiment for R_T in quasielastic region:

- Excellent agreement of peak positions
- Good agreement of peak height at q=500 MeV/c and increasing overestimation with growing q (10% at q=700MeV/c)
- Relativistic effects are important at q ≥ 500 MeV/c
- MEC contribution is rather small at q ≥ 500 MeV/c

Improvement of theory and experiment by consideration of additional rel. effects (wave function boost, dynamical effects)?