2p-2h Excitations in Electron and Neutrino Scattering: Past, Present and Future

T. W. Donnelly
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OUTLINE:

- Past
- Present
- Future

OUTLINE:

- Past meaning prior to about 2000
- Present meaning work over the past decade or so
- Future some suggestions for future studies

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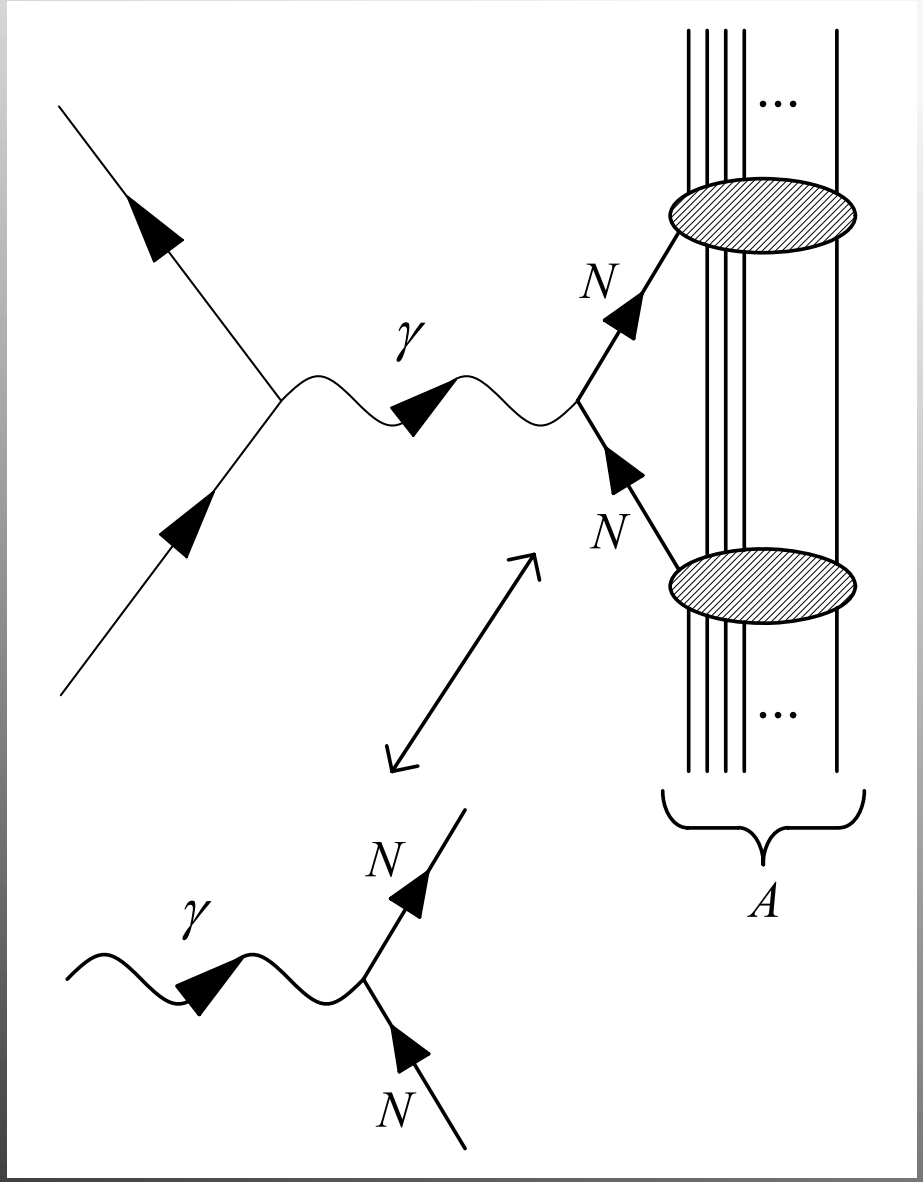
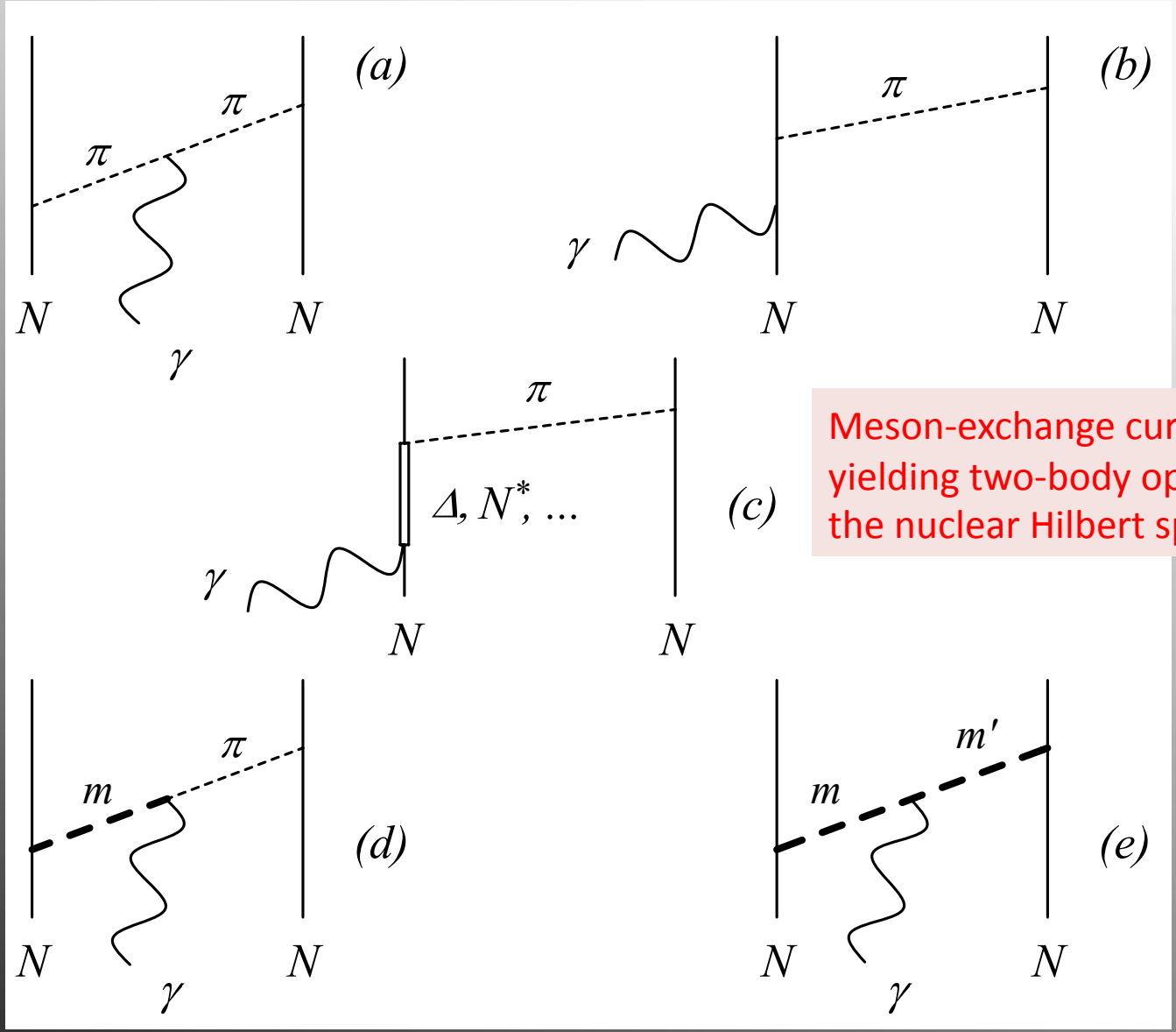
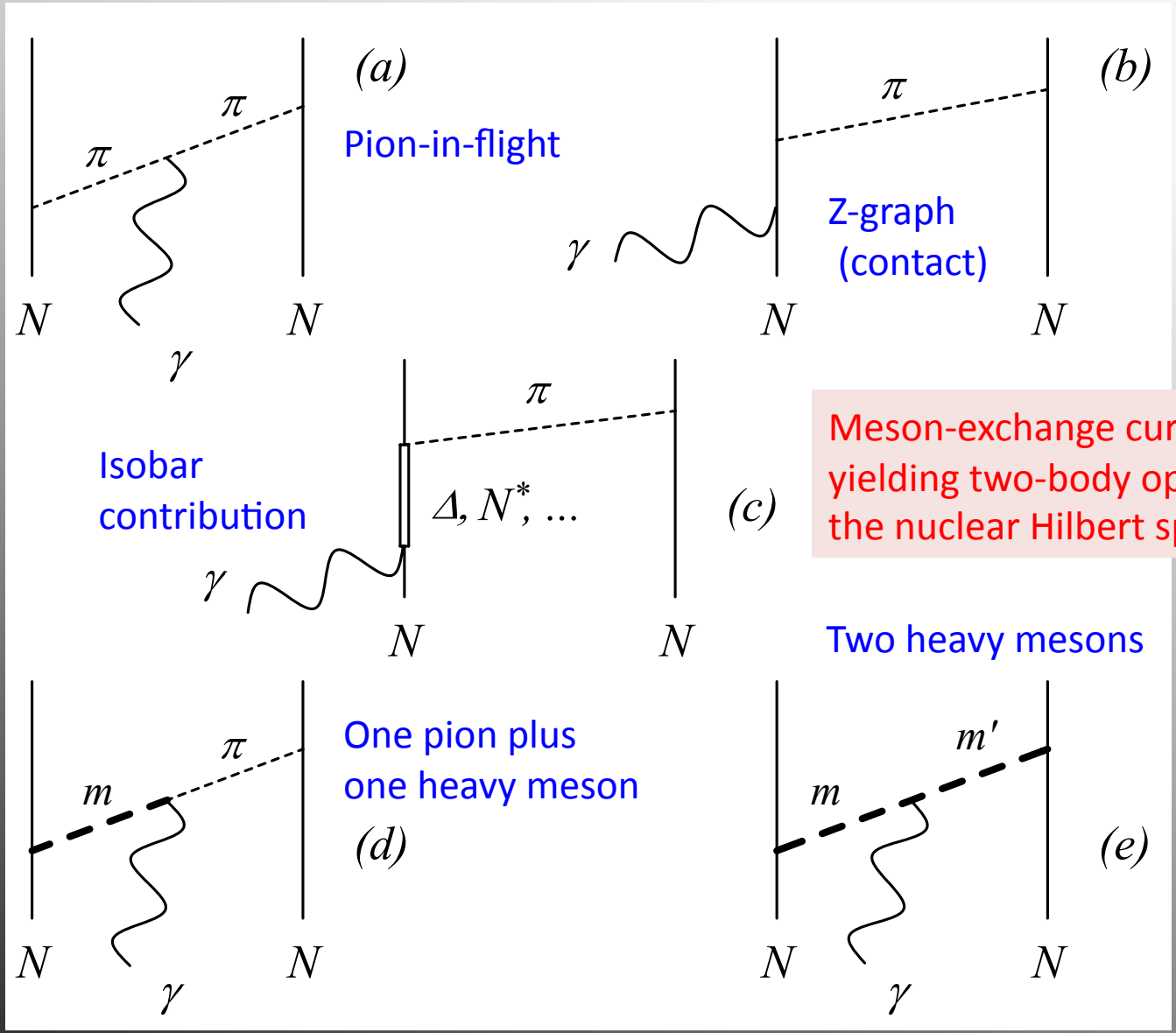


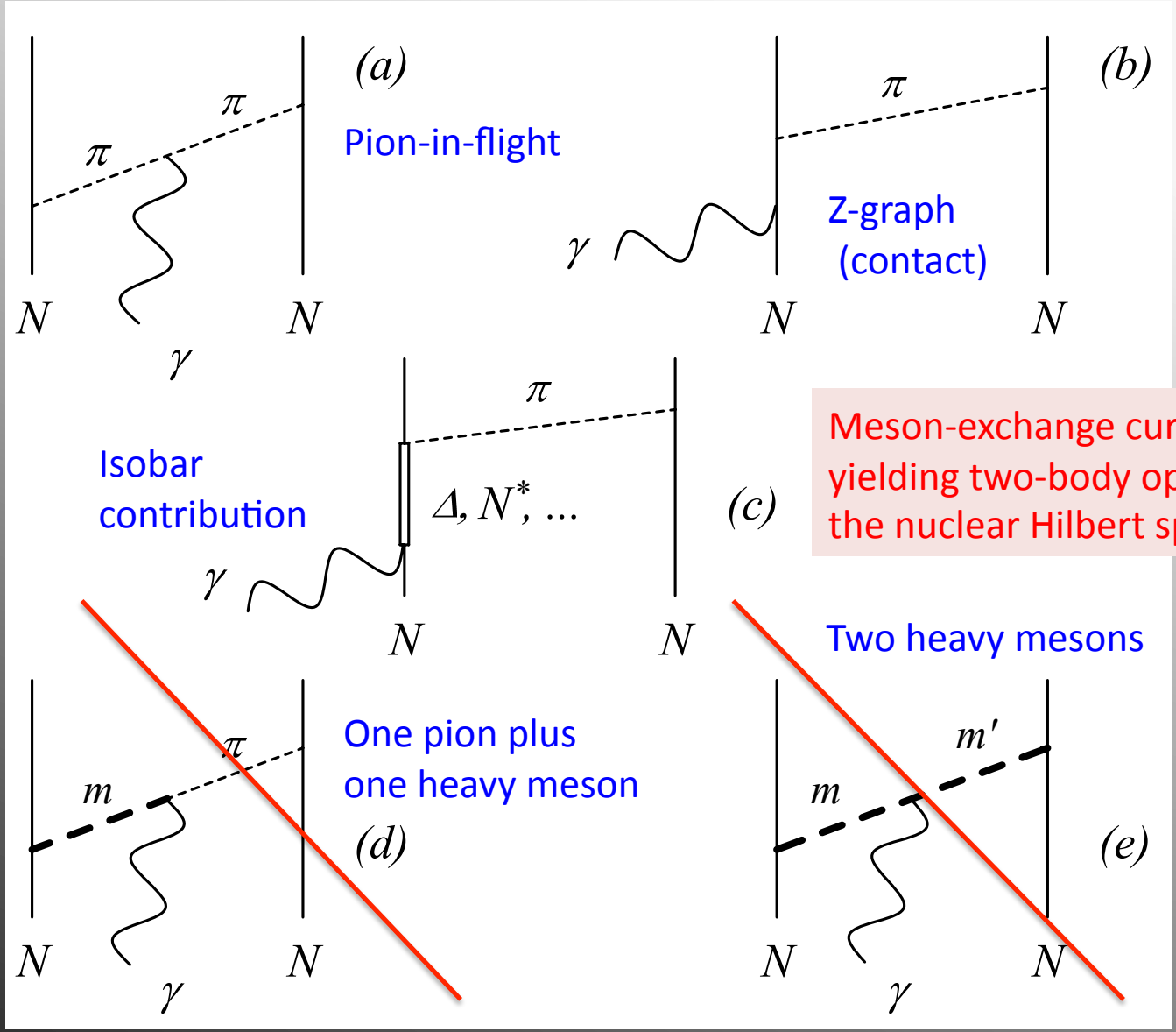
One-body operator
In the nuclear
Hilbert space

Free space
current



Meson-exchange currents (MEC): yielding two-body operators in the nuclear Hilbert space


(a)
Pion-in-flight
(b)
Z-graph
(contact)
Isobar
contribution
(c)
Meson-exchange currents (MEC):
yielding two-body operators in
the nuclear Hilbert space
Two heavy mesons
One pion plus
one heavy meson
(d)
(e)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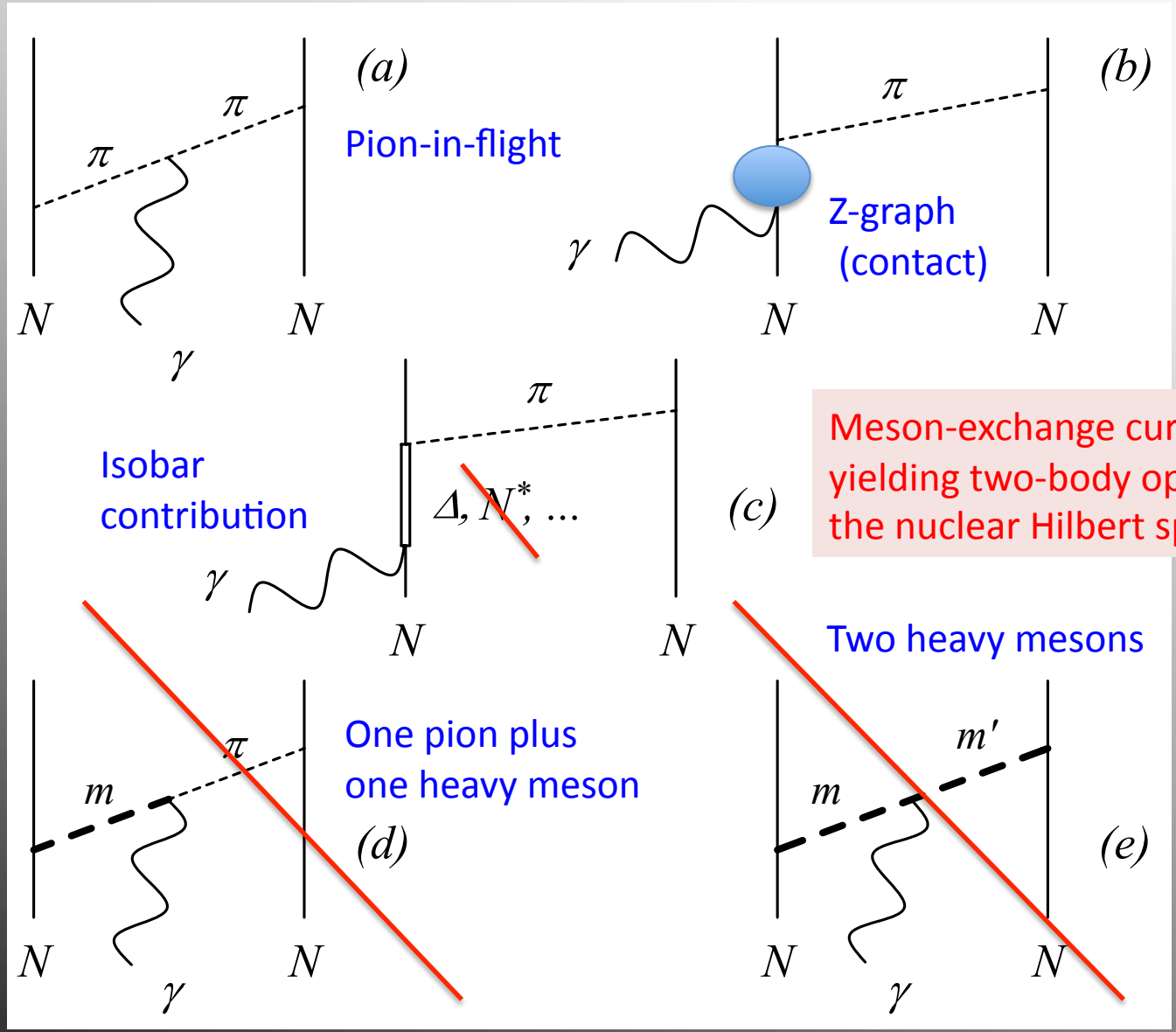
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Early work:

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Phys. Lett. 76B (1978) 393

J. W. Van Orden, PhD thesis, Stanford University, 1978

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… see also
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RFG for QE, but non-relativistic approximation for 2p-2h MEC

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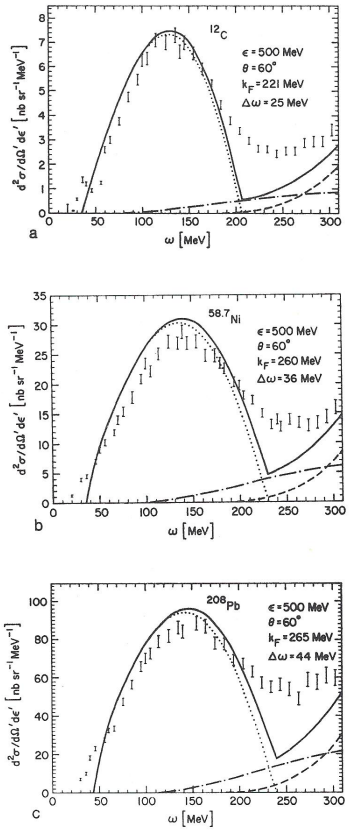
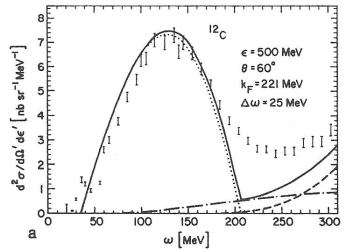
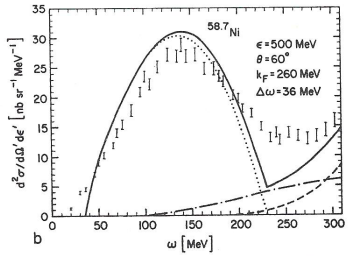
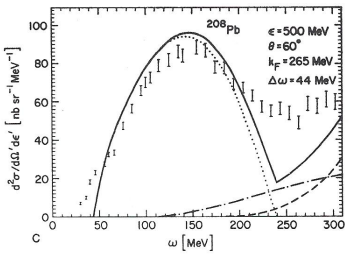


FIG. 10. Calculated cross sections for (a) ^{12}C, (b) $^{58.7}$Ni, and (c) ^{208}Pb, conditions as in Fig. 2, data from Ref. [8]. The dotted curve is the quasielastic contribution, the dash–dot curve the MEC contribution, the dashed curve the pion production contribution, and the solid curve the total.







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Note the relative increase of the 2p-2h MEC contributions with respect to the QE

Second-kind scaling violations

By expressing the quasielastic, MEC, and pion production contributions in terms of dimensionless variables (as done for the MEC in Section 2), it is found that the one-body QE and pion production contributions scale roughly as A/k_F^2, while the MEC scales as Ak_F^2. Careful comparison of Figs. 10a–c shows that the size of the MEC contribution relative to the QE peak increases considerably going from ^{12}C, where $k_F = 221$ MeV, to $^{58.7}$Ni, where $k_F = 260$ MeV, but that there is very little increase in relative size when going from $^{58.7}$Ni to ^{208}Pb, where $k_F = 265$ MeV. Thus, for lighter nuclei, where k_F is changing more rapidly with increasing A, the size of the MEC relative to the QE peak changes noticeably as A becomes larger. As A increases toward heavier nuclei, the nuclear density saturates, causing k_F to slowly approach the nuclear matter value of $k_F = 270$ MeV. This implies that for heavier nuclei all contributions will scale approximately as A. Therefore, while the relative MEC contribution will be largest for heavy nuclei, it changes most rapidly when comparing cross sections for light nuclei.

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Work from a decade ago:

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- Vector current (for electron scattering)
- Pion-in-flight, contact and Delta contributions
- Fully relativistic treatment of 2p-2h RFG
- Gauge invariant (order-by-order in perturbation expansion)
- Direct and exchange contributions

- Hadronic vertex functions (short-range physics)
- Peccei chiral Lagrangian

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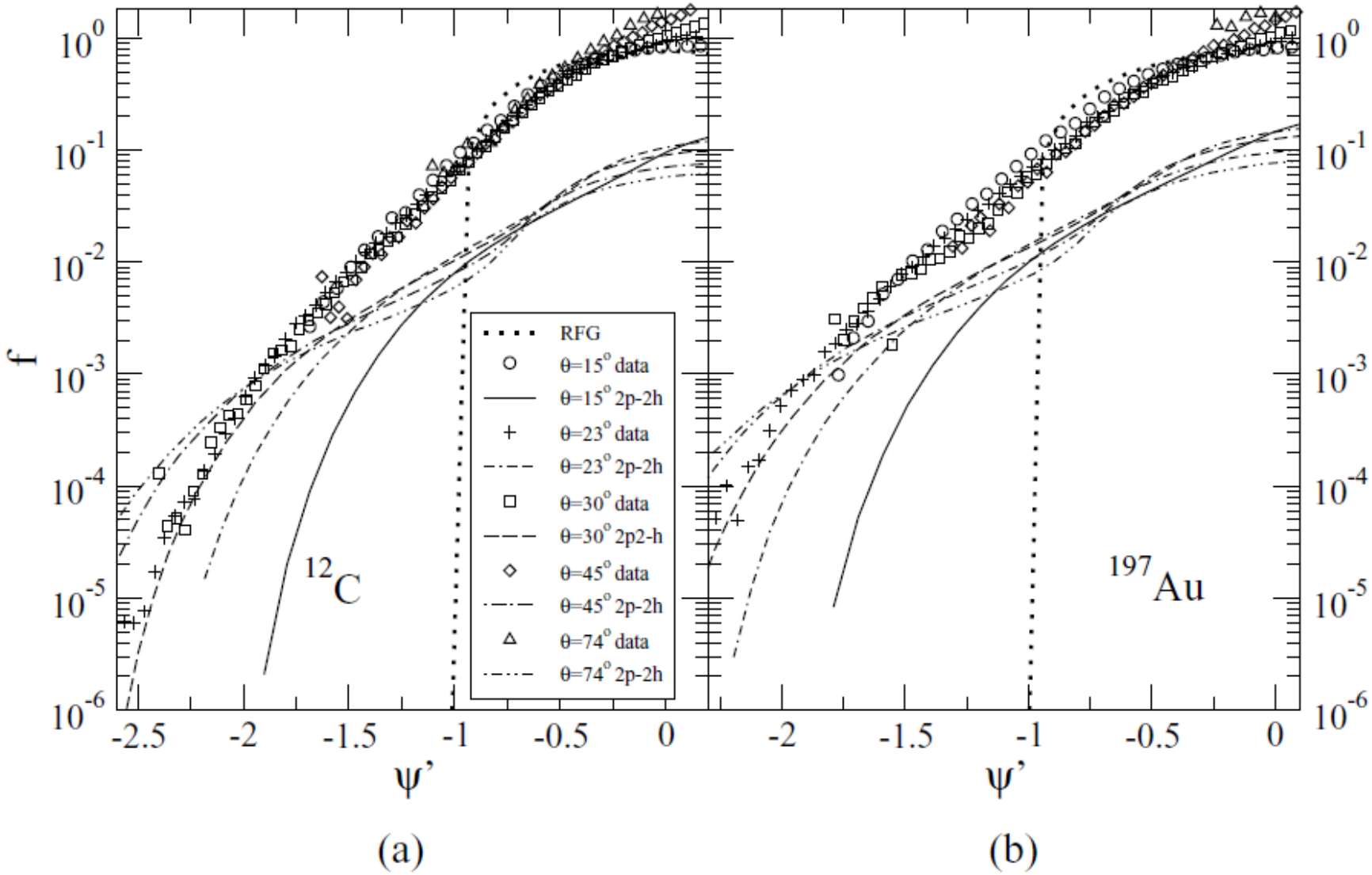
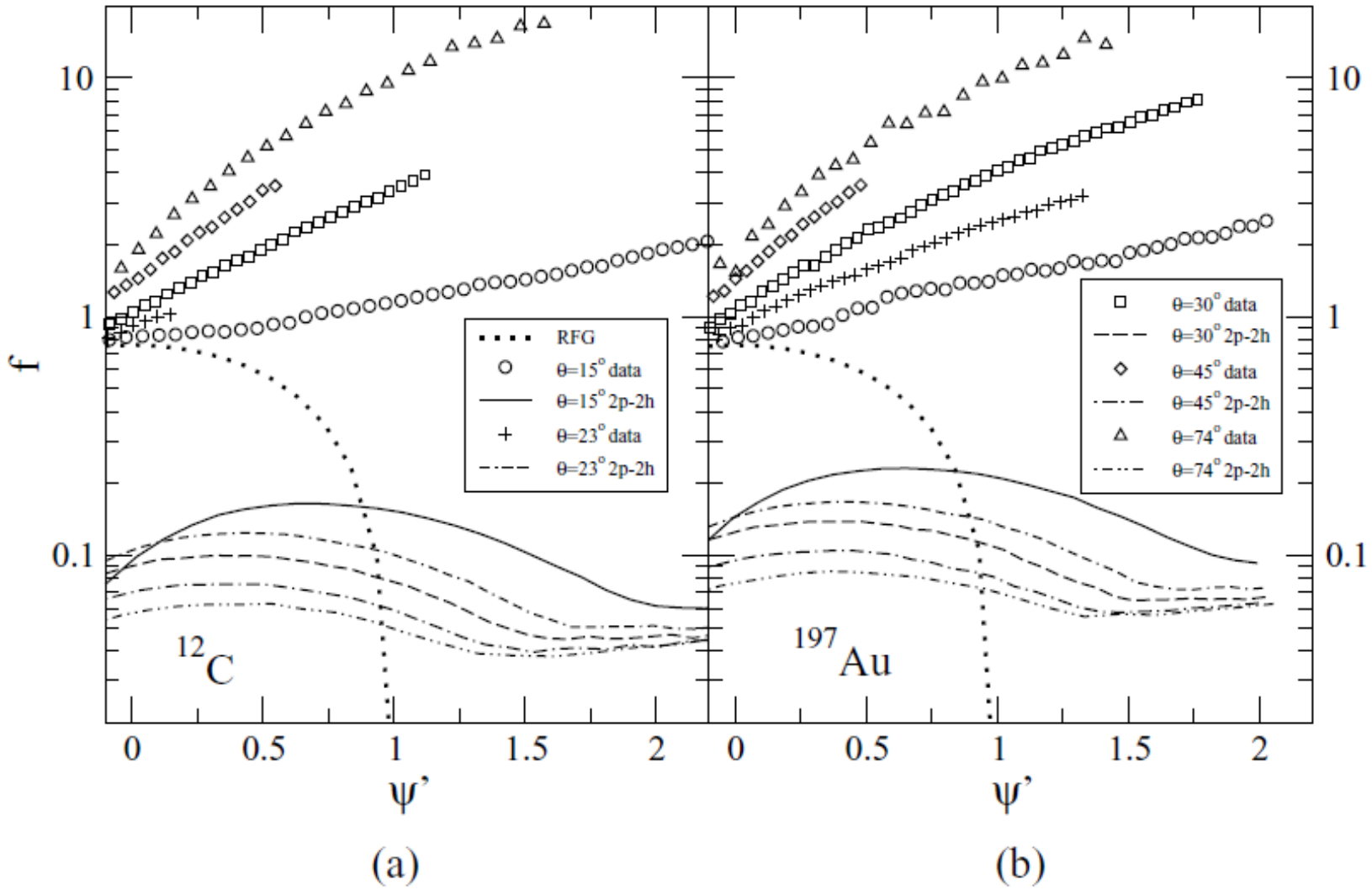
… plus many studies from the past decade
to be discussed by others at this workshop


f
ψ'
RFG
θ=15° data
θ=15° 2p-2h
θ=23° data
θ=23° 2p-2h
θ=30° data
θ=30° 2p2-h
θ=45° data
θ=45° 2p-2h
θ=74° data
θ=74° 2p-2h
12C
197Au
(a)
(b)


f
10
1
0.1
RFG
θ=15° data
θ=15° 2p-2h
θ=23° data
θ=23° 2p-2h
θ=30° data
θ=30° 2p-2h
θ=45° data
θ=45° 2p-2h
θ=74° data
θ=74° 2p-2h
12C
197Au
0
0.5
1
1.5
2
ψ'
(a)
(b)

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Suggestions for near-future studies:

Benchmark 2p-2h MEC modeling of vector contributions for ee'

Agree on the basic ingredients, for instance

- Fully relativistic (pion-in-flight, contact, Delta)
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- Specific Lagrangian; specific hadronic form factors
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Provide individual contributions

^{12}C

k_F = 228 MeV/c

E_{shift} = 25 MeV (x2)

q = 0.5, 1.0, 1.5, 2.0 GeV/c

over full range of ω

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Make a matrix of who has done what, *i.e.,* who has performed the fully relativistic modeling above, and who has made approximations (no exchange terms, simplified phase space, and so on… some approximations may be good, others not)

Suggestions (cont'd):

Investigate MEC **first-kind** scaling behavior

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Do all of the above for the axial-vector contributions for CCν

Some issues:

MEC: 1p-1h together with 2p-2h?

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MEC together with corresponding long-range correlations

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Relevance of using these models in semi-inclusive
reactions (see O. Moreno *et al., Phys. Rev.* **D90** (2014) 013014)

In contrast to inclusive scattering, for semi-inclusive reactions there are many more response function (18 in fact), some of which are known not to be negligible for some kinematics, but critically depend on the presence of FSI, meaning that factorization is clearly invalid


. . . thank you