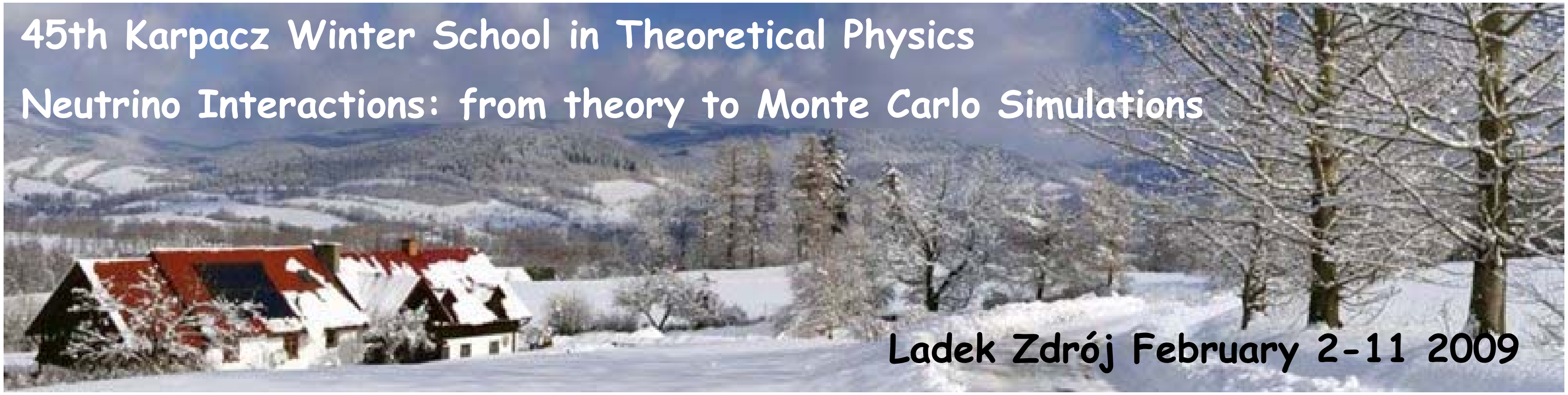
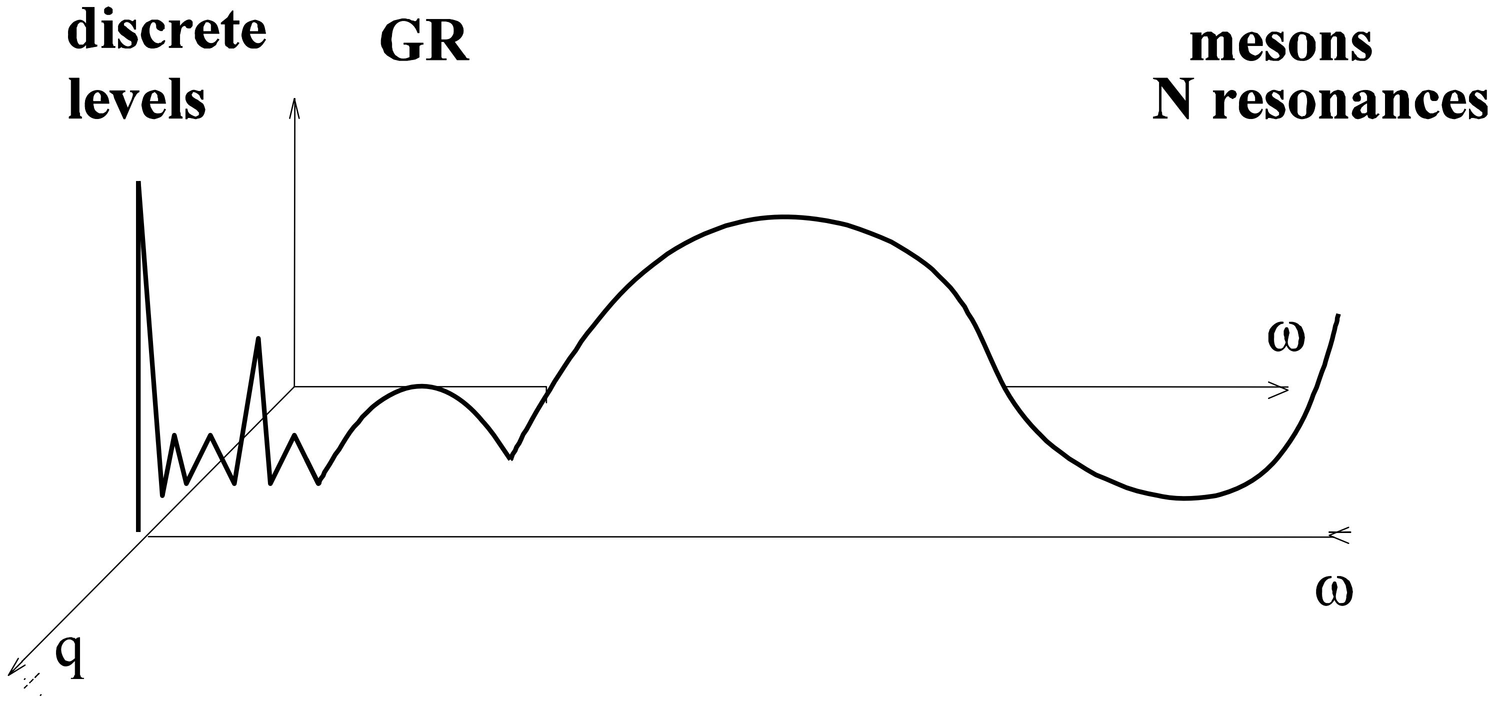


Quasielastic Charged-Current and Neutral-Current ν-Nucleus Scattering in a Relativistic Approach

Carlotta Giusti
Andrea Meucci
Franco Pacati
University and INFN Pavia

nuclear response to the electroweak probe



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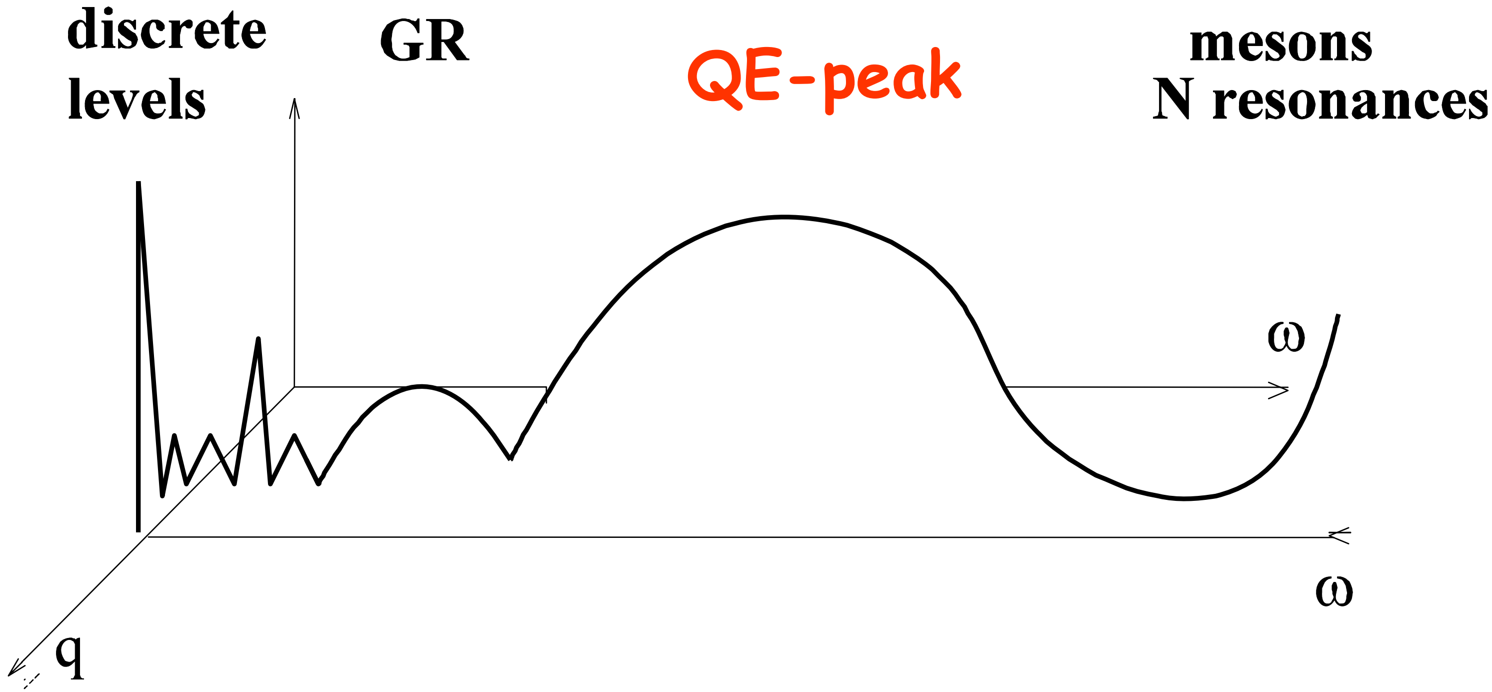

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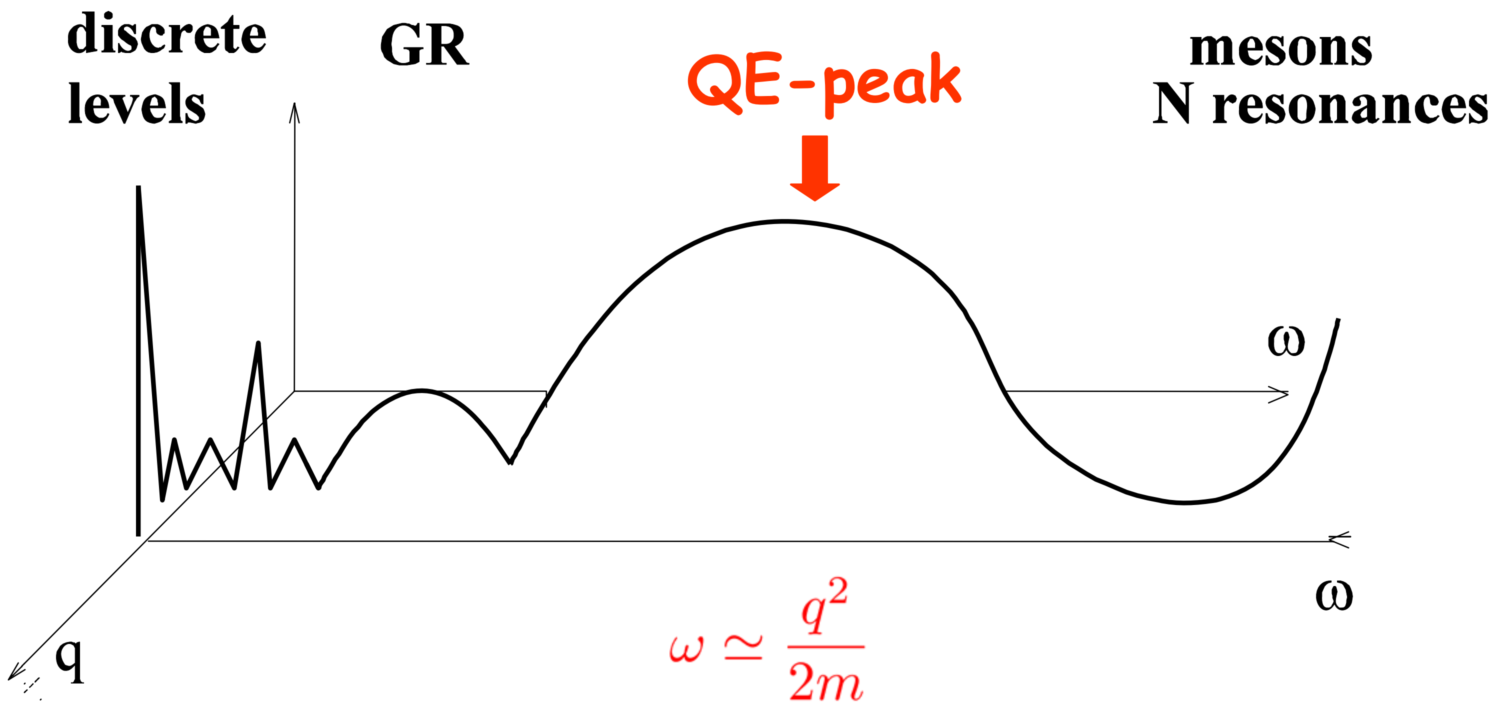

QE-peak dominated by one-nucleon knockout

QE e-nucleus scattering

$$e + A \Longrightarrow e' + N + (A - 1)$$

QE e-nucleus scattering

$$e + A \Longrightarrow e' + N + (A-1)$$

- both e′ and N detected one-nucleon-knockout (e,e′p)

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QE ν-nucleus scattering

$$\nu_l(\bar{\nu}_l) + A \Longrightarrow \nu_l(\bar{\nu}_l) + N + (A-1) \qquad \text{NC}$$

$$\nu_l(\bar{\nu}_l) + A \Longrightarrow l^-(l^+) + N + (A-1) \qquad \text{CC}$$

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- only N detected semi-inclusive NC and CC

QE e-nucleus scattering

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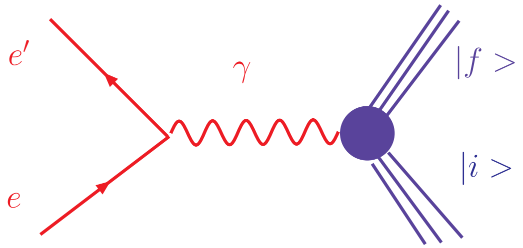
QE ν-nucleus scattering

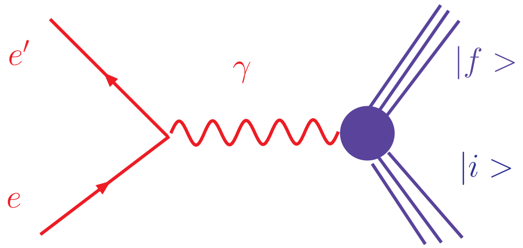
$$\nu_l(\bar{\nu}_l) + A \Longrightarrow \nu_l(\bar{\nu}_l) + N + (A-1)$$ NC

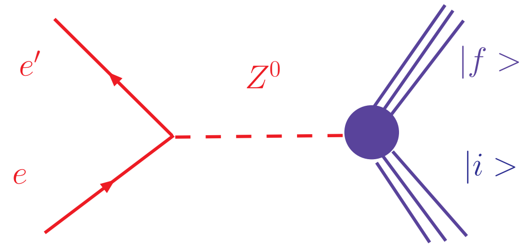
$$\nu_l(\bar{\nu}_l) + A \Longrightarrow l^-(l^+) + N + (A-1)$$ CC

- only N detected semi-inclusive NC and CC
- only final lepton detected inclusive CC



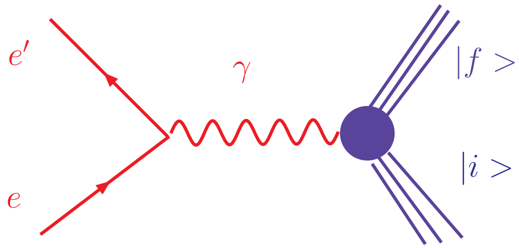
electron scattering

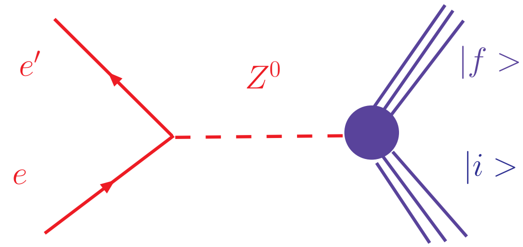




PVES

electron scattering





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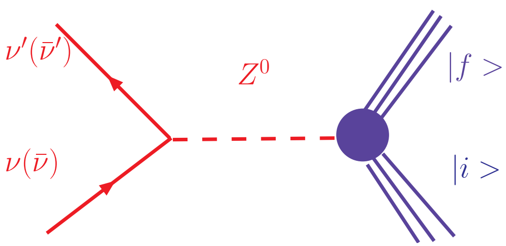
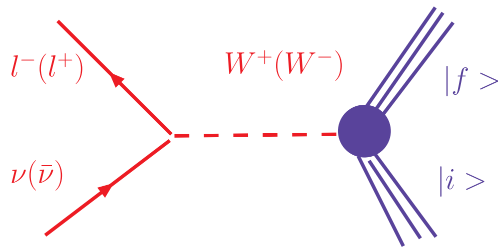
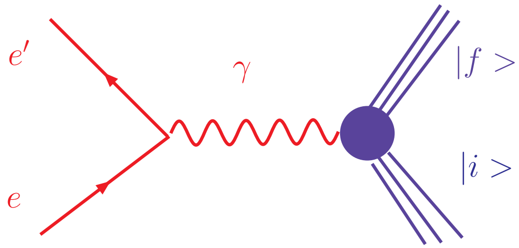


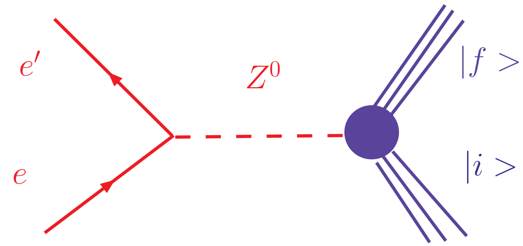
NC



CC

neutrino scattering





PVES

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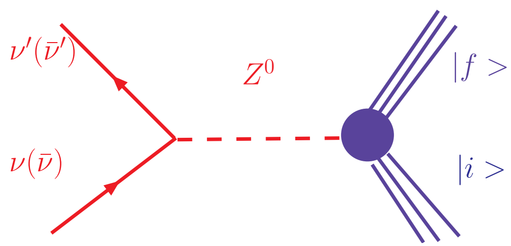

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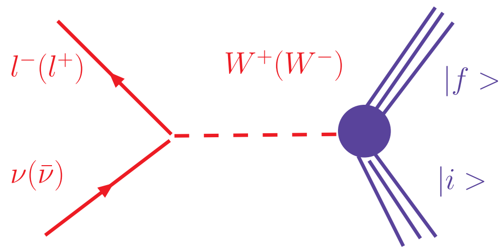
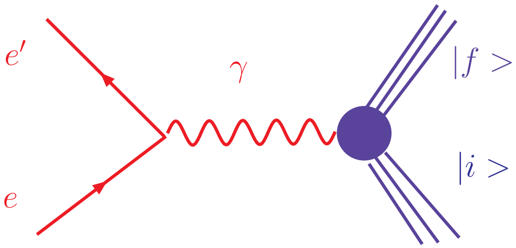
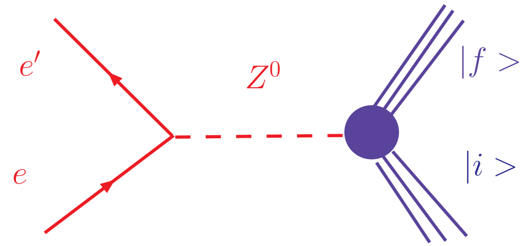


CC

neutrino scattering

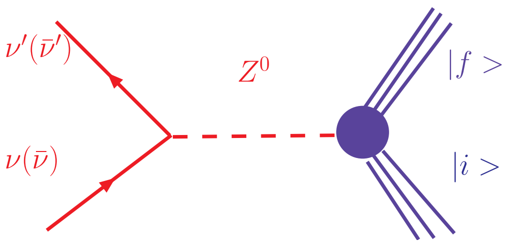
$$\sigma = K L^{\mu\nu} W_{\mu\nu}$$



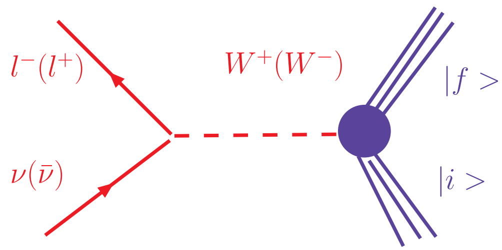


PVES

electron scattering



NC

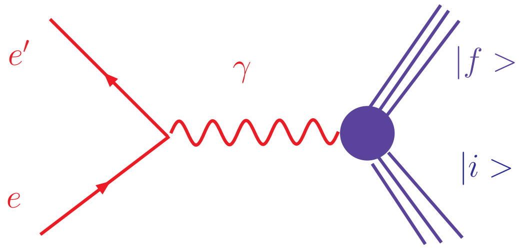


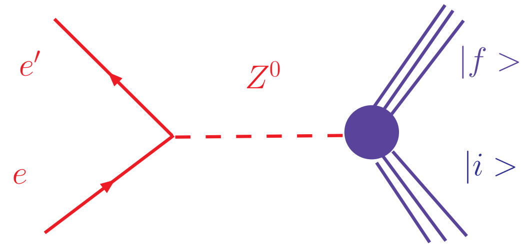
CC

neutrino scattering

$$\sigma = K L^{\mu\nu} \; W_{\mu\nu}$$

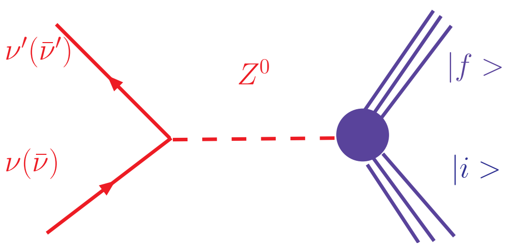
kin factor



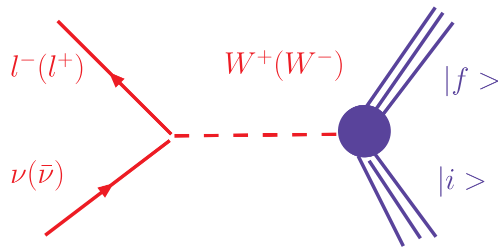


PVES

electron scattering



NC

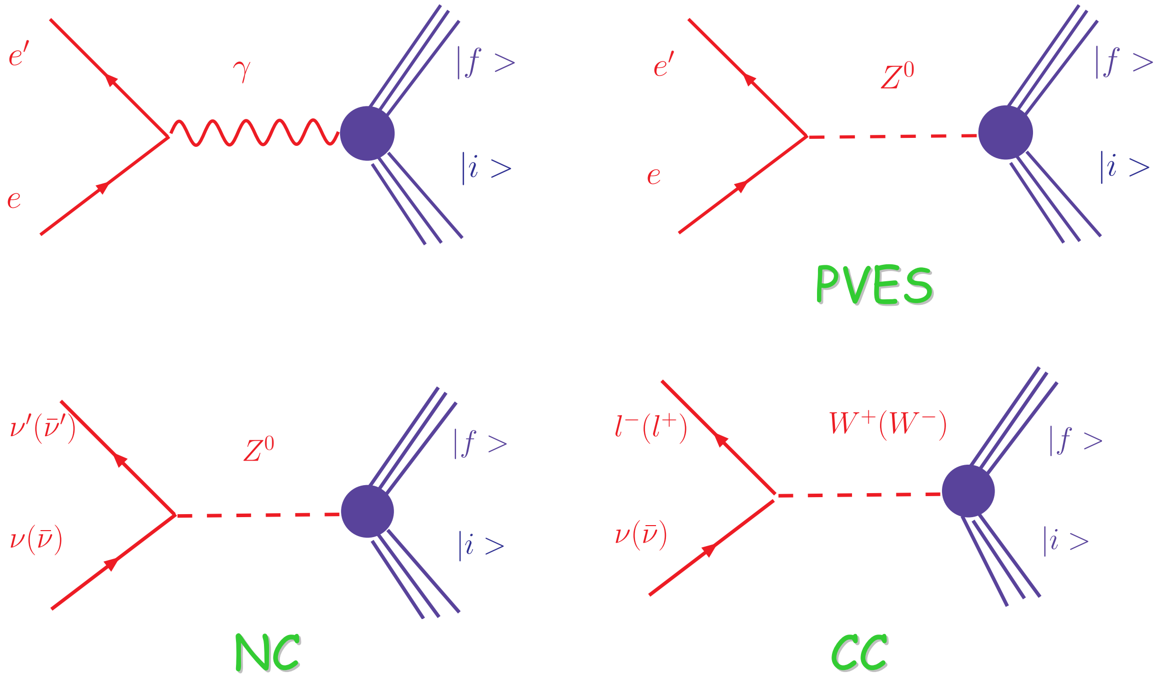


CC

neutrino scattering

$$\sigma = K L^{\mu\nu} \; W_{\mu\nu}$$

lepton tensor contains lepton kinematics



electron scattering

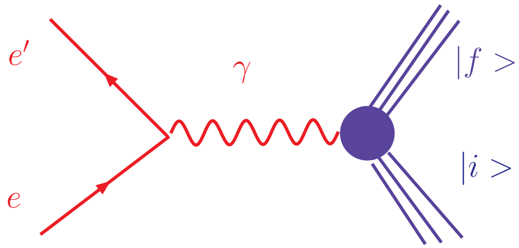
neutrino scattering

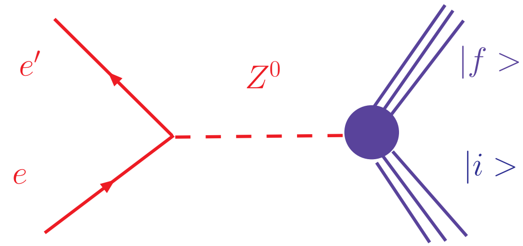
$$\sigma = K L^{\mu\nu} \, W_{\mu\nu}$$

hadron tensor

$$W^{\mu\nu} = \overline{\sum_{\mathrm{i,f}}} J^{\mu}(\boldsymbol{q}) \, J^{\nu *}(\boldsymbol{q}) \, \delta(E_{\mathrm{i}} + \omega - E_{\mathrm{f}})$$

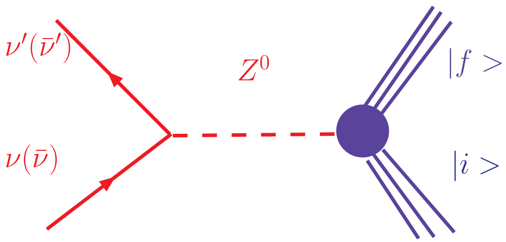
$$J^{\mu}(\boldsymbol{q}) = \int \mathrm{e}^{\mathrm{i}\boldsymbol{q}\cdot\boldsymbol{r}} \langle f \mid \hat{J}^{\mu}(\boldsymbol{r}) \mid i \rangle \mathrm{d}\boldsymbol{r}$$



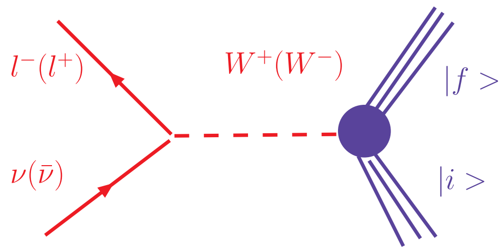


PVES

electron scattering



NC



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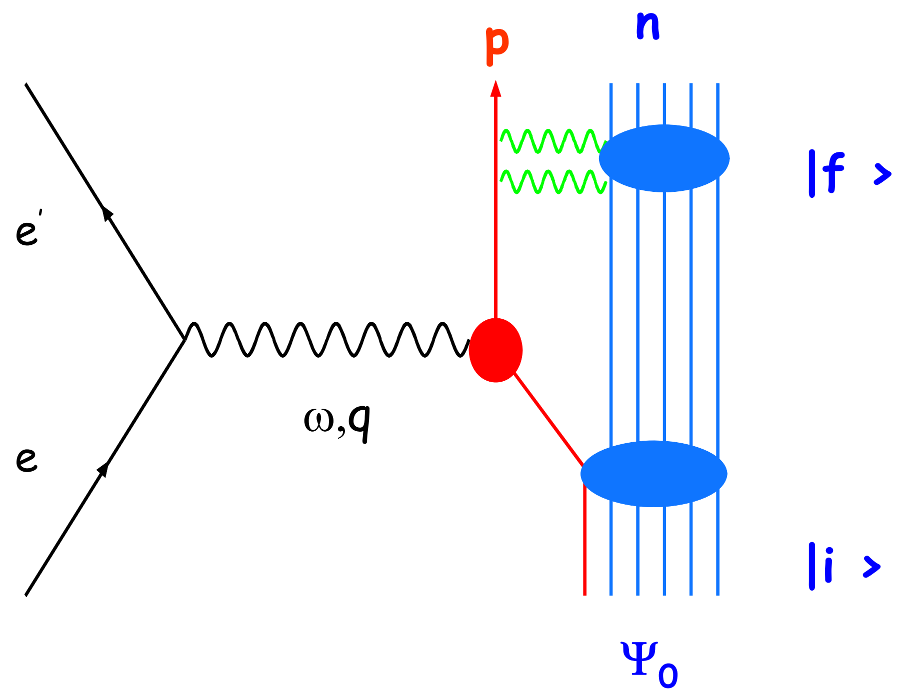
Direct knockout DWIA (e,e′p)

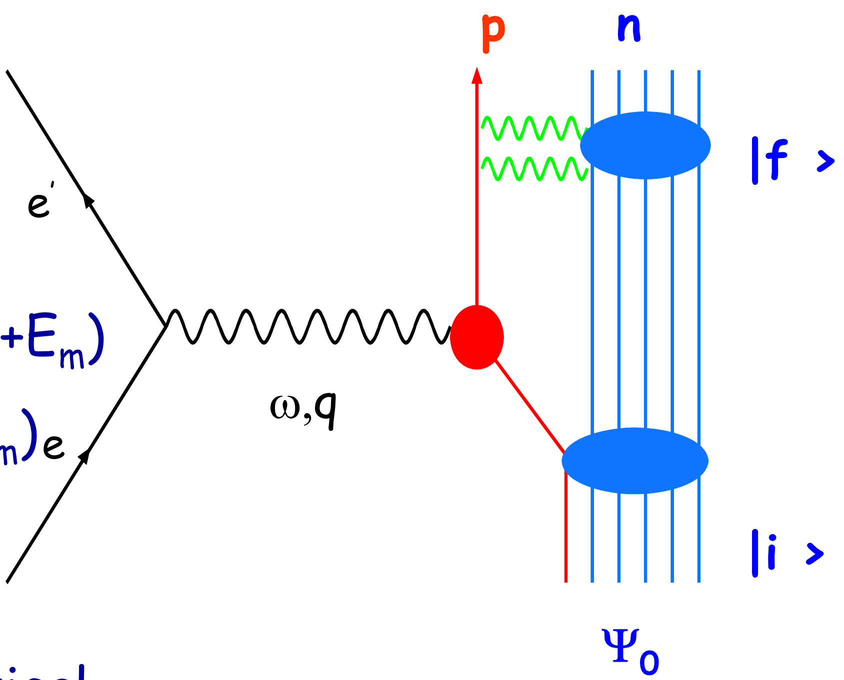
- exclusive reaction: n
- DKO mechanism: the probe interacts through a one-body current with one nucleon which is then emitted the remaining nucleons are spectators



$$\langle f \mid J^\mu(\boldsymbol{q}) \mid i\rangle \Rightarrow \lambda_n^{1/2}\ \langle \chi_{\boldsymbol{p}}^{(-)} \mid j^\mu(\boldsymbol{q}) \mid \phi_n\rangle$$

Direct knockout DWIA (e,e′p)

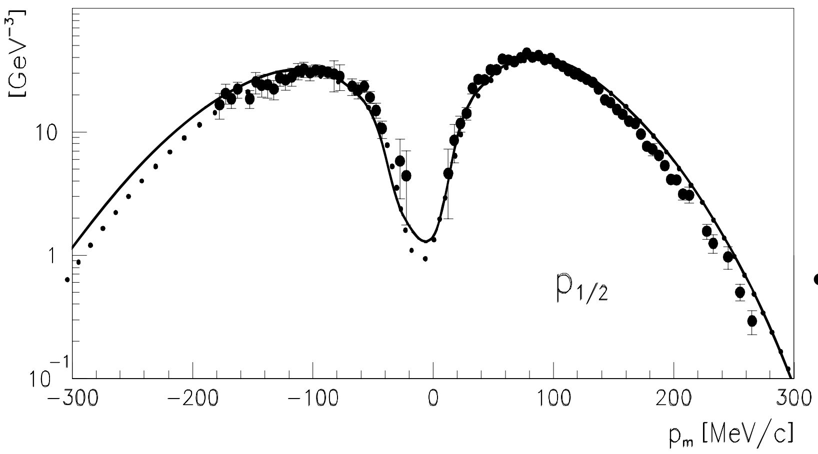
$$\boxed{\lambda_n^{1/2}\ \langle \chi_{\boldsymbol{p}}^{(-)} \mid j^{\mu}(\boldsymbol{q}) \mid \phi_n \rangle}$$



- j^{μ} one-body nuclear current
- $\chi^{(-)}$ = < n|f > s.p. scattering w.f. $H^{+}(\omega+E_m)$
- ϕ_n = $\langle n|\Psi_0\rangle$ one-nucleon overlap $H(-E_m)$
- λ_n spectroscopic factor
- $\chi^{(-)}$ and ϕ consistently derived as eigenfunctions of a Feshbach-type optical model Hamiltonian
- phenomenological ingredients used in the calculations for $\chi^{(-)}$ and ϕ

RDWIA: (e,e'p) comparison to data

$^{16}O(e,e'p)$



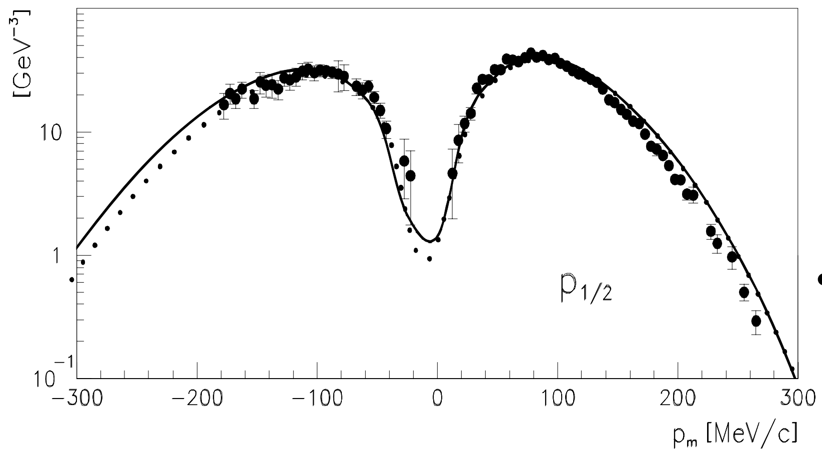
NIKHEF parallel kin e=520 MeV T_p = 90 MeV

rel RDWIA

nonrel DWIA

RDWIA: (e,e′p) comparison to data

$^{16}O(e,e'p)$

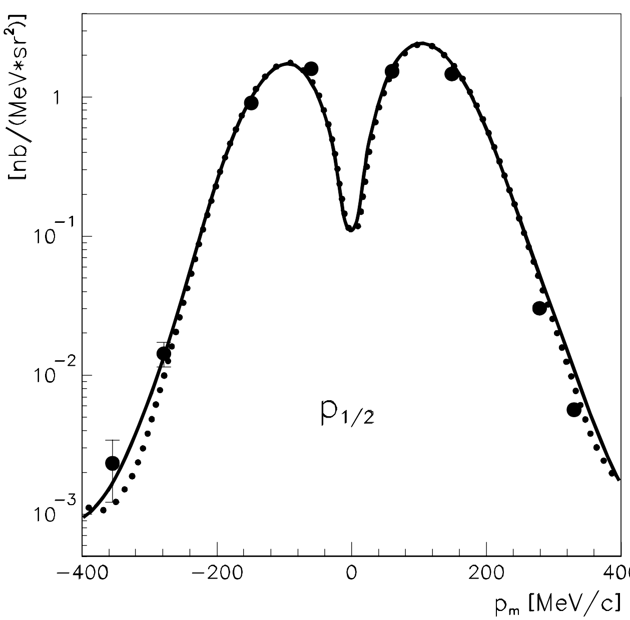


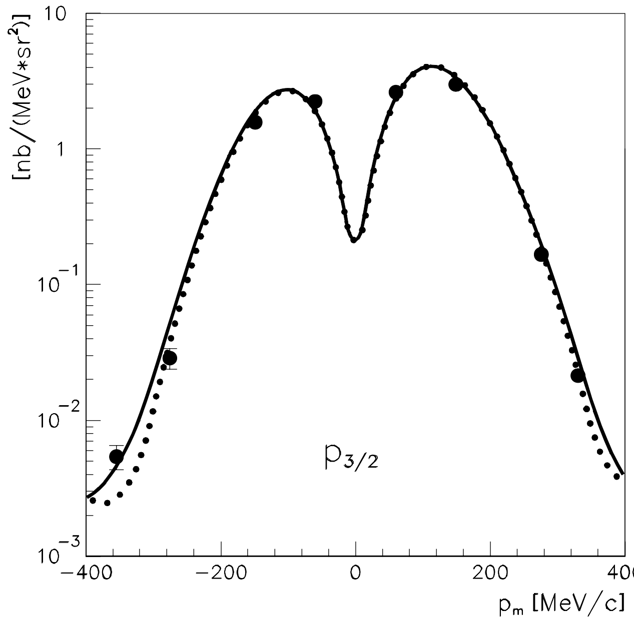
NIKHEF parallel kin e=520 MeV T_p = 90 MeV

—— rel RDWIA

• • • • • • nonrel DWIA

JLab (ω,q) const kin e=2445 MeV ω =439 MeV T_p= 435 MeV





—— RDWIA diff opt.pot.

• • • • • •

RDWIA: (e,e′p) comparison to data

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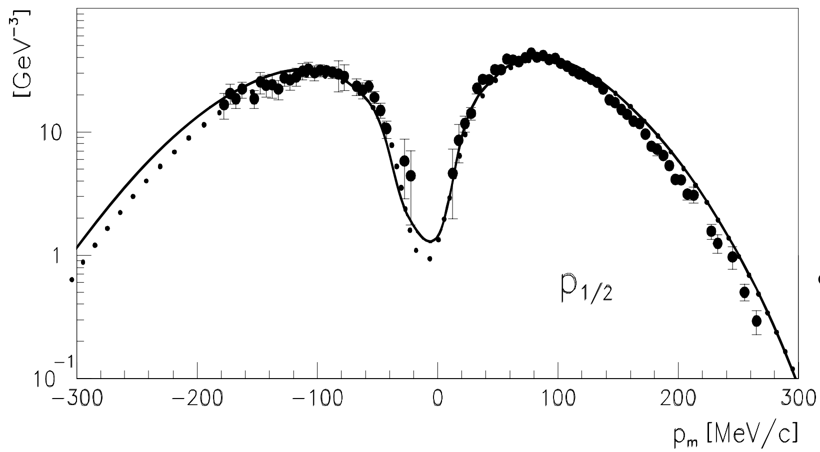
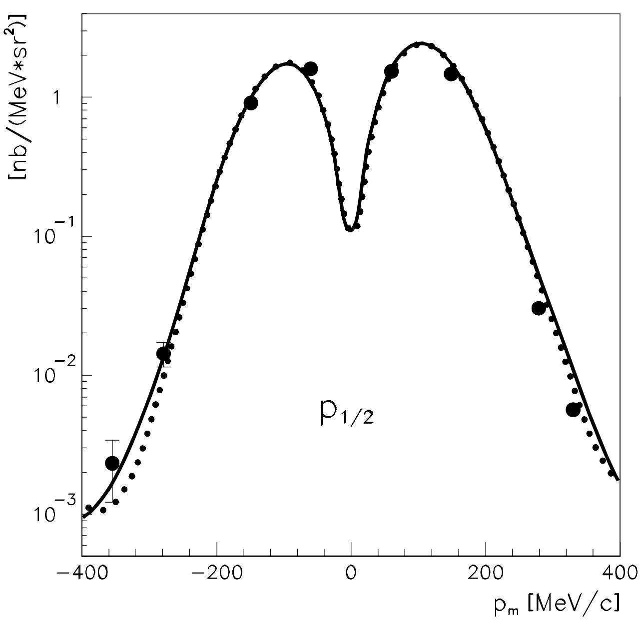


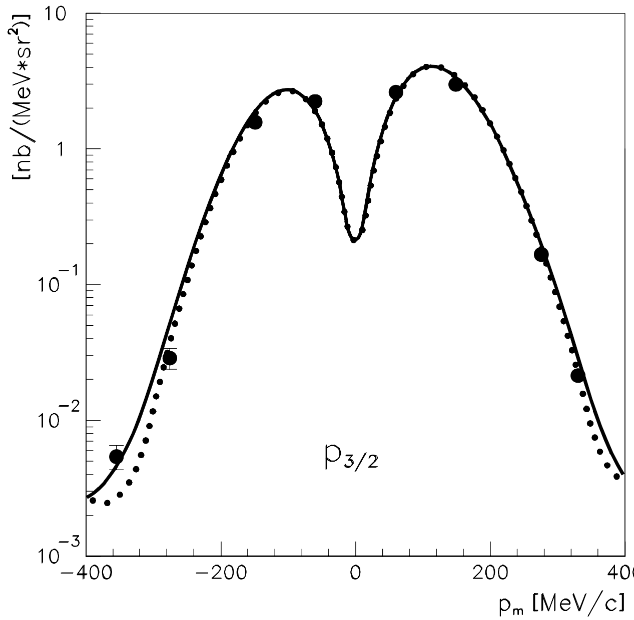
NIKHEF parallel kin e=520 MeV T_p = 90 MeV

rel RDWIA $\lambda_n = 0.7$

nonrel DWIA $\lambda_n = 0.65$

JLab (ω,q) const kin e=2445 MeV ω =439 MeV T_p= 435 MeV





RDWIA diff opt.pot.

$\lambda_n = 0.7$

RDWIA: (e,e′p) comparison to data

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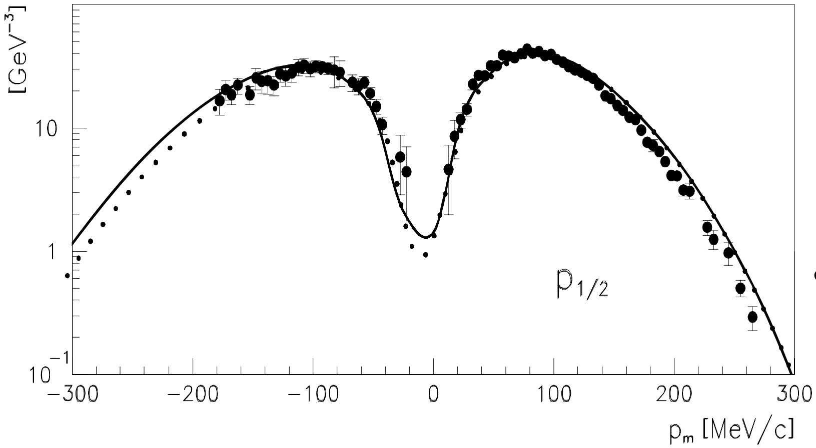

NIKHEF parallel kin e=520 MeV T_p = 90 MeV

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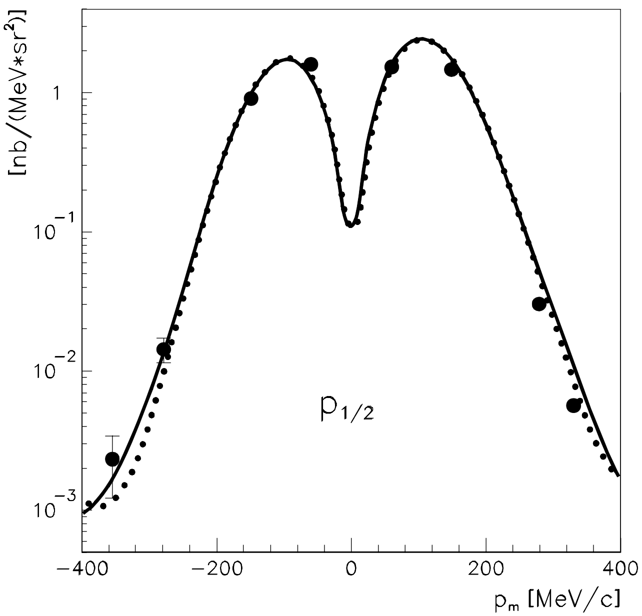
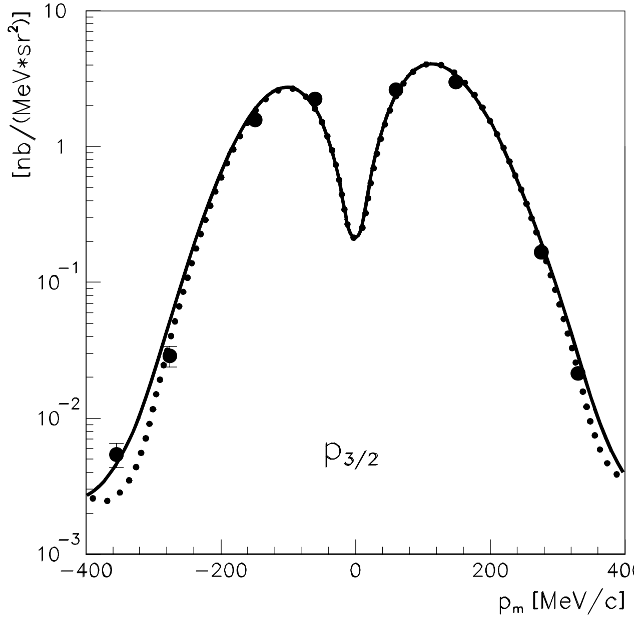


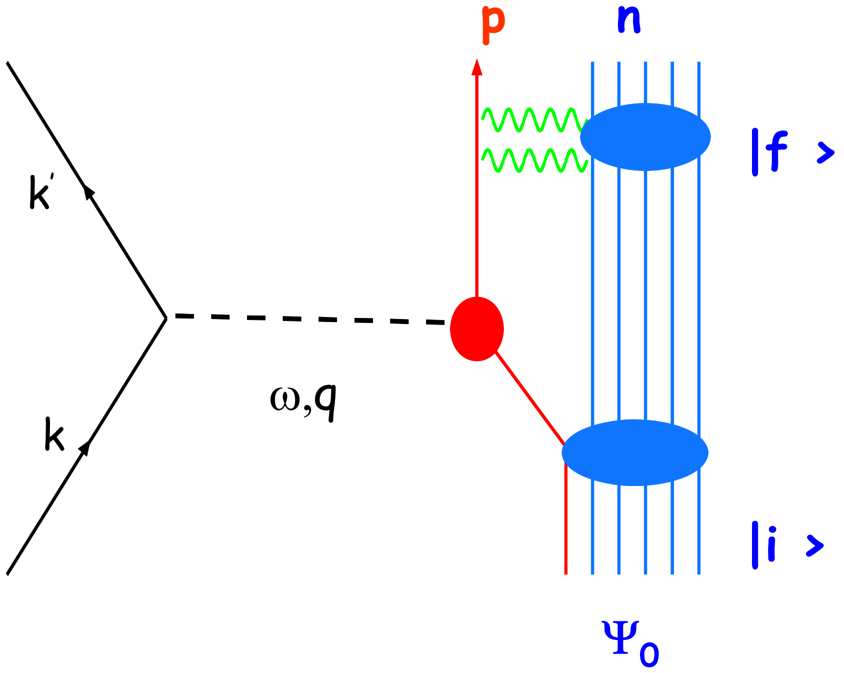


RDWIA diff opt.pot.

λ_n = 0.7

RDWIA: NC and CC ν -nucleus scattering

$$\lambda_n^{1/2} \langle \chi_{\boldsymbol{p}}^{(-)} \mid j^{\mu}(\boldsymbol{q}) \mid \phi_n \rangle$$



- transition amplitudes calculated with the same model used for (e,e'p)
- the same phenomenological ingredients are used for $\chi^{(-)}$ and ϕ
- j^{μ} one-body nuclear weak current

One-body nuclear weak current

$$j^{\mu} = F_1^{\mathrm{V}}(Q^2)\gamma^{\mu} + i\frac{\kappa}{2M}F_2^{\mathrm{V}}(Q^2)\sigma^{\mu\nu}q_{\nu} - G_{\mathrm{A}}(Q^2)\gamma^{\mu}\gamma^5$$

NC

K anomalous part of the magnetic moment

One-body nuclear weak current

$$j^\mu = \left[F_1^{\mathrm{V}}(Q^2)\gamma^\mu + i\frac{\kappa}{2M}F_2^{\mathrm{V}}(Q^2)\sigma^{\mu\nu}q_\nu - G_{\mathrm{A}}(Q^2)\gamma^\mu\gamma^5 + F_{\mathrm{P}}(Q^2)q^\mu\gamma^5\right]\tau^\pm$$

CC

$$F_{\mathrm{P}} = \frac{2MG_{\mathrm{A}}}{m_\pi^2 + Q^2}$$

induced pseudoscalar form factor

One-body nuclear weak current

$$j^\mu = \left[F_1^V(Q^2)\gamma^\mu + i\frac{\kappa}{2M}F_2^V(Q^2)\sigma^{\mu\nu}q_\nu - G_A(Q^2)\gamma^\mu\gamma^5 + F_P(Q^2)q^\mu\gamma^5\right]\tau^\pm$$

CC

$$F_P = \frac{2MG_A}{m_\pi^2 + Q^2}$$

induced pseudoscalar form factor

The axial form factor

$$G_A^{CC} = 1.26\left(1 + \frac{Q^2}{M_A^2}\right)^{-2}$$

CC

$$G_A^{p(n)NC} = \frac{1}{2}\left[+(-)G_A^{CC} - G_A^s\right]$$

NC

$$M_A = (1.026 \pm 0.021)\mathrm{GeV}$$

One-body nuclear weak current

$$j^\mu = \left[F_1^{\rm V}(Q^2)\gamma^\mu + i\frac{\kappa}{2M}F_2^{\rm V}(Q^2)\sigma^{\mu\nu}q_\nu - G_{\rm A}(Q^2)\gamma^\mu\gamma^5 + F_{\rm P}(Q^2)q^\mu\gamma^5\right]\tau^\pm$$

CC

$$F_{\rm P} = \frac{2MG_{\rm A}}{m_\pi^2 + Q^2}$$

induced pseudoscalar form factor

The axial form factor

$$G_{\rm A}^{\rm CC} = 1.26\left(1 + \frac{Q^2}{M_{\rm A}^2}\right)^{-2}$$

CC

$$G_{\rm A}^{p(n){\rm NC}} = \frac{1}{2}\left[+(-)G_{\rm A}^{\rm CC} - G_{\rm A}^{\rm s}\right]$$

NC

$$M_{\rm A} = (1.026 \pm 0.021){\rm GeV}$$

possible strange-quark contribution

One-body nuclear weak current

$$j^\mu = \left[F_1^{\rm V}(Q^2)\gamma^\mu + i\frac{\kappa}{2M}F_2^{\rm V}(Q^2)\sigma^{\mu\nu}q_\nu - G_{\rm A}(Q^2)\gamma^\mu\gamma^5 + F_{\rm P}(Q^2)q^\mu\gamma^5\right]\tau^\pm$$

The weak isovector Dirac and Pauli FF are related to the Dirac and Pauli elm FF by the CVC hypothesis

$$F_i^{\rm V\ CC} = F_i^{\rm p} - F_i^{\rm n}$$

CC

$$F_i^{\rm Vp(n)\ NC} = \left(\frac{1}{2} - 2\sin^2\theta_{\rm W}\right)F_i^{\rm p(n)} - \frac{1}{2}F_i^{\rm n(p)} - \frac{1}{2}F_i^{\rm s}$$

NC

$$\sin^2\theta_{\rm W} \simeq 0.23143$$

One-body nuclear weak current

$$j^\mu = \left[F_1^{\mathrm{V}}(Q^2)\gamma^\mu + i\frac{\kappa}{2M}F_2^{\mathrm{V}}(Q^2)\sigma^{\mu\nu}q_\nu - G_{\mathrm{A}}(Q^2)\gamma^\mu\gamma^5 + F_{\mathrm{P}}(Q^2)q^\mu\gamma^5\right]\tau^\pm$$

The weak isovector Dirac and Pauli FF are related to the Dirac and Pauli elm FF by the CVC hypothesis

$$F_i^{\mathrm{V\ CC}} = F_i^{\mathrm{p}} - F_i^{\mathrm{n}}$$

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CC

NC

$$\sin^2\theta_{\mathrm{W}} \simeq 0.23143$$

strange FF

ν -nucleus scattering

- only the outgoing nucleon is detected: semi inclusive process
- cross section integrated over the energy and angle of the outgoing lepton
- integration over the angle of the outgoing nucleon
- final nuclear state is not determined : sum over n

ν -nucleus scattering

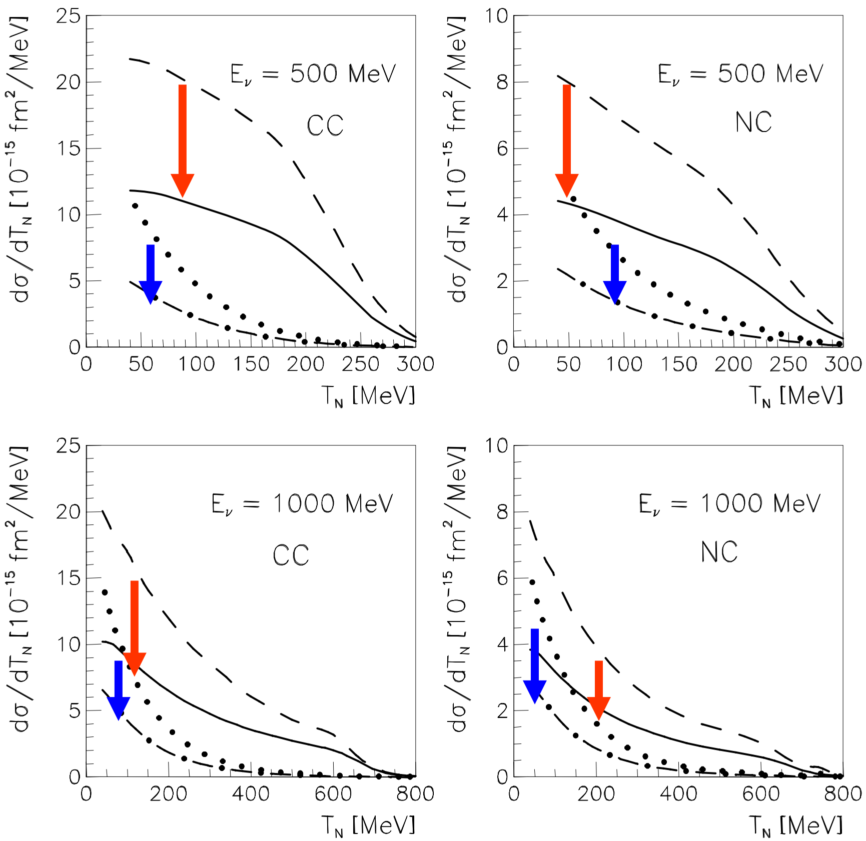
- only the outgoing nucleon is detected: semi inclusive process
- cross section integrated over the energy and angle of the outgoing lepton
- integration over the angle of the outgoing nucleon
- final nuclear state is not determined : sum over n

$$W^{\mu\nu}(\omega, q) = \sum_n \langle n; \chi^{(-)}_{\boldsymbol{p}_{\rm N}} \mid J^{\mu}(\boldsymbol{q}) \mid \Psi_0 \rangle \langle \Psi_0 \mid J^{\nu\dagger}(\boldsymbol{q}) \mid n; \chi^{(-)}_{\boldsymbol{p}_{\rm N}} \rangle \; \delta(E_0 + \omega - E_{\rm f})$$

calculations

- pure Shell Model description: ϕ_n one-hole states in the target with an unitary spectral strength
- $\sum_n$ over all occupied states in the SM: all the nucleons are included but correlations are neglected
- the cross section for the ν-nucleus scattering where one nucleon is detected is obtained from the sum of all the integrated one-nucleon knockout channels
- FSI are described by a complex optical potential with an imaginary absorptive part

CC **NC**



$^{12}\mathrm{C}(\nu_\mu, \mu^- p)$ RPWIA

RDWIA

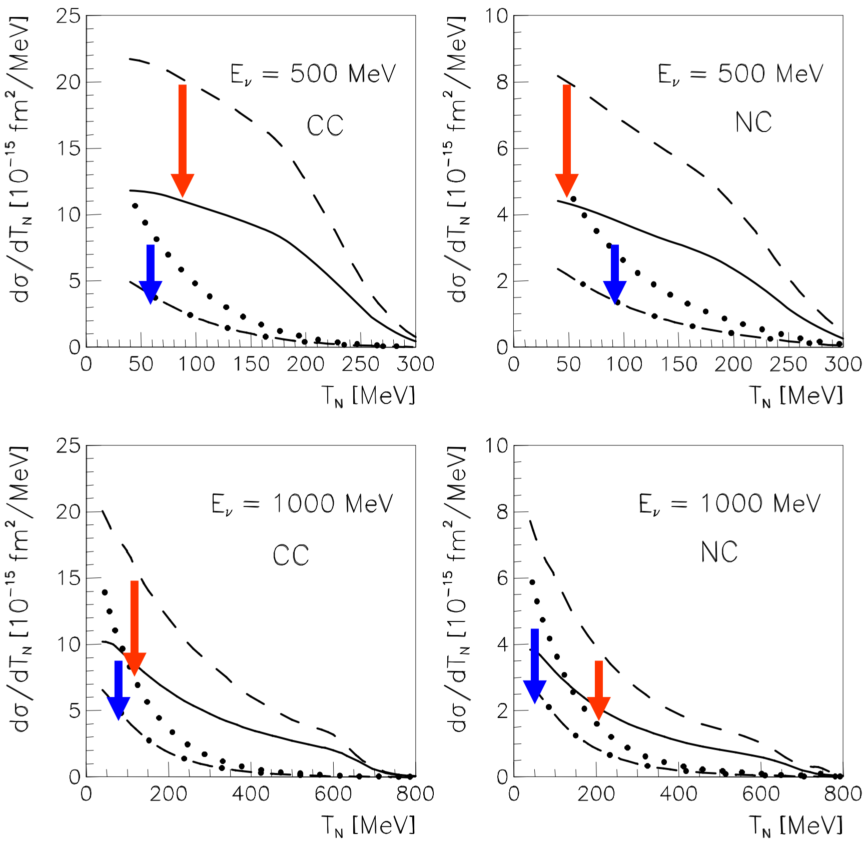
$^{12}\mathrm{C}(\nu, \nu' p)$ FSI

$^{12}\mathrm{C}(\bar{\nu}_\mu, \mu^+ n)$ RPWIA

RDWIA

$^{12}\mathrm{C}(\bar{\nu}, \bar{\nu}' p)$ FSI

CC NC



FSI

the imaginary part of the optical potential gives an absorption that reduces the calculated cross sections

$^{12}\mathrm{C}(\nu_\mu, \mu^- p)$ RPWIA RDWIA $^{12}\mathrm{C}(\nu, \nu' p)$ FSI

$^{12}\mathrm{C}(\bar{\nu}_\mu, \mu^+ n)$ RPWIA RDWIA $^{12}\mathrm{C}(\bar{\nu}, \bar{\nu}' p)$ FSI

FSI for the inclusive scattering : Green's Function Approach

FSI for the inclusive scattering : Green's Function Approach

(e,e') nonrelativistic

F. Capuzzi, C. Giusti, F.D. Pacati, Nucl. Phys. A 524 (1991) 281

F. Capuzzi, C. Giusti, F.D. Pacati, D.N. Kadrev Ann. Phys. 317 (2005) 492 (AS CORR)

(e,e') relativistic

A. Meucci, F. Capuzzi, C. Giusti, F.D. Pacati, PRC (2003) 67 054601

A. Meucci, C. Giusti, F.D. Pacati Nucl. Phys. A 756 (2005) 359 (PVES)

CC relativistic

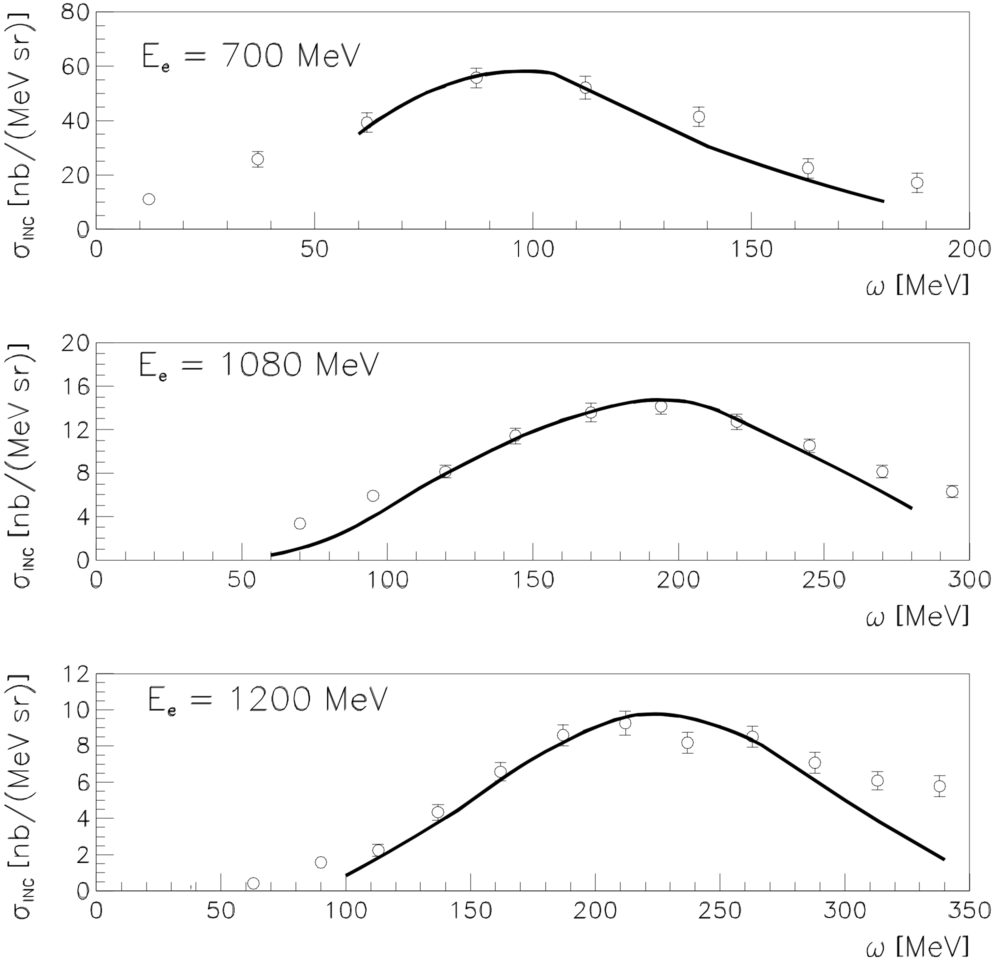
A. Meucci, C. Giusti, F.D. Pacati Nucl. Phys. A739 (2004) 277

FSI for the inclusive scattering : Green's Function Approach

- the components of the inclusive response are expressed in terms of the Green's operators
- under suitable approximations can be written in terms of the s.p. optical model Green's function
- the explicit calculation of the s.p. Green's function can be avoided by its spectral representation which is based on a biorthogonal expansion in terms of a non Herm opt. pot. H and H^{+}
- matrix elements similar to RDWIA
- scattering states eigenfunctions of H and H^{+} (absorption and gain of flux): the imaginary part redistributes the flux and the total flux is conserved
- consistent treatment of FSI in the exclusive and in the inclusive scattering

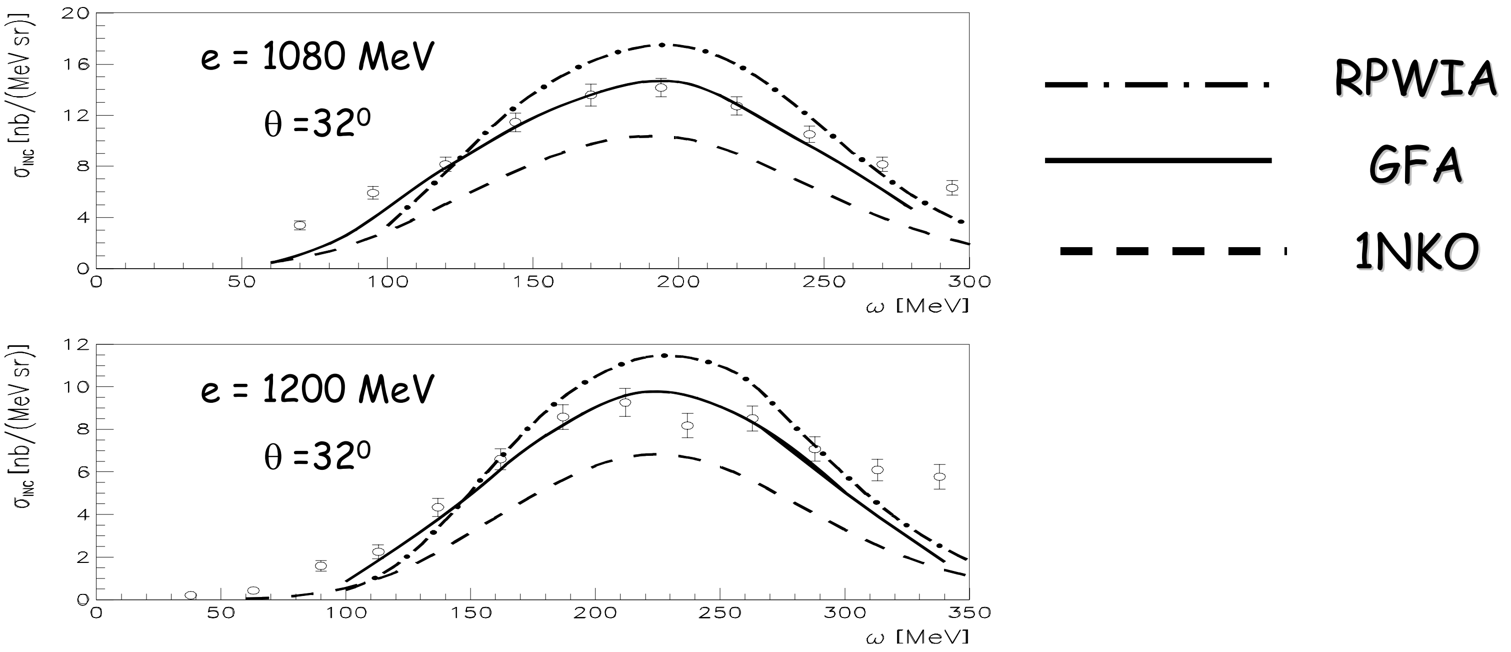
$^{16}O(e,e')$

Green's function approach GFA



data from Frascati NPA 602 405 (1996)

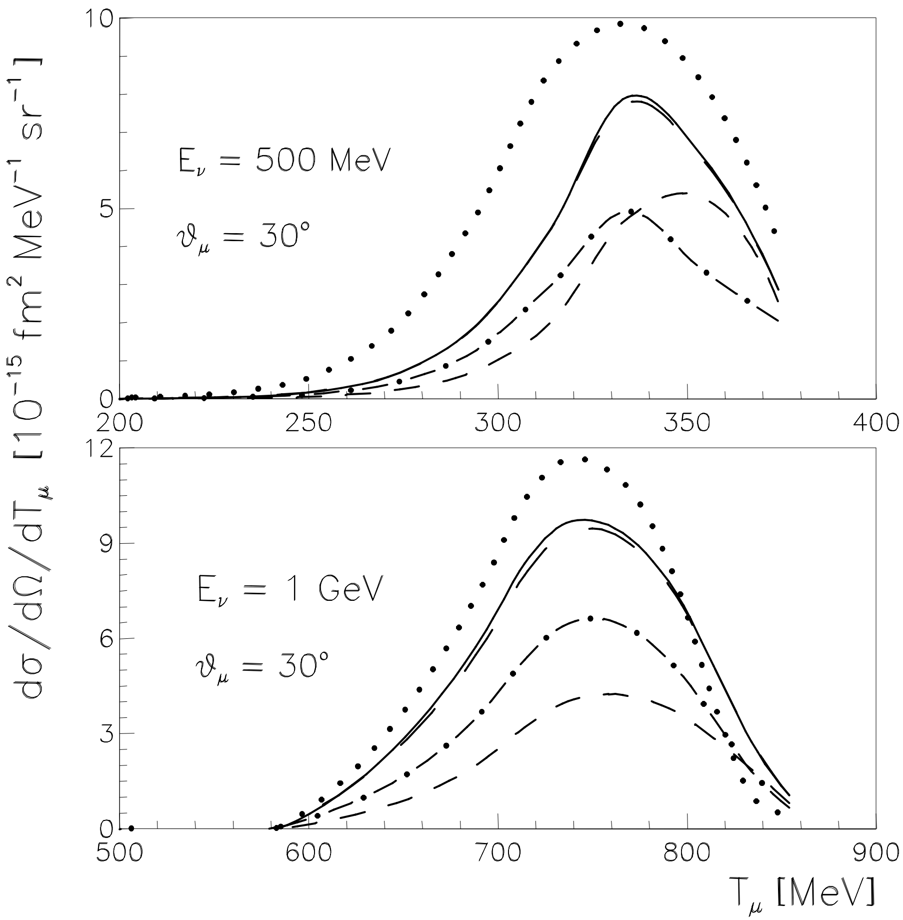
$^{16}O(e,e')$



FSI

data from Frascati NPA 602 405 (1996)

$^{16}O(\nu_\mu, \mu^-)$



FSI

RPWIA

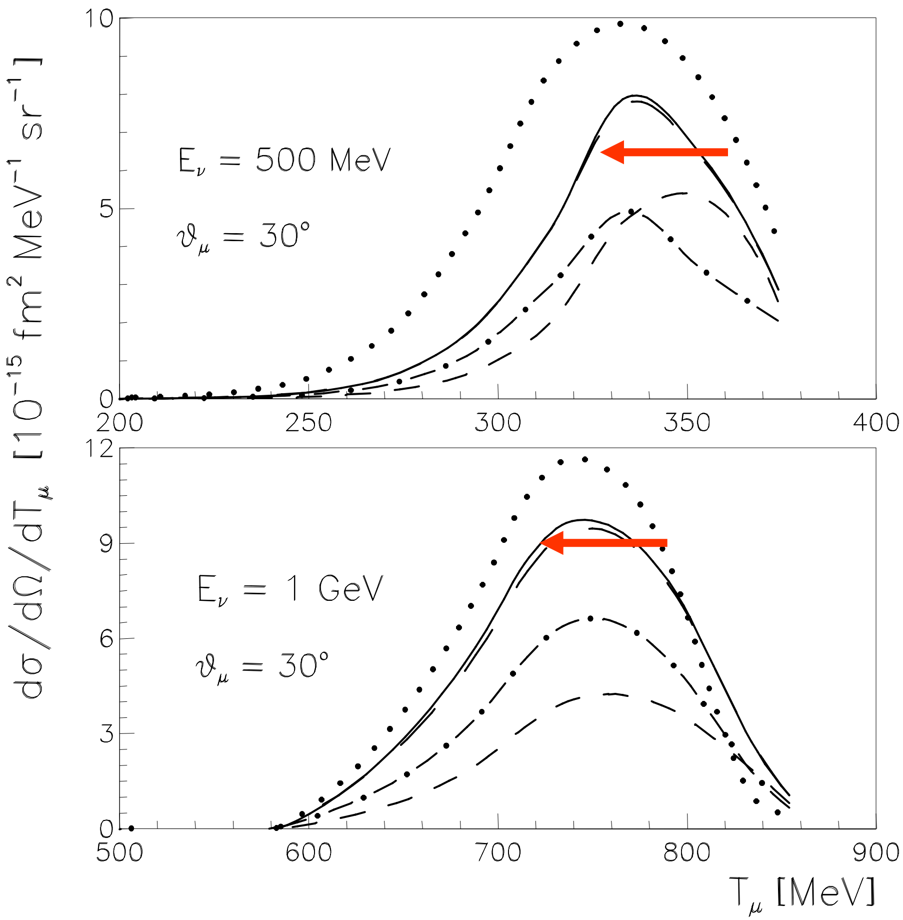
GFA

rROP

1NKO

$^{16}O(\bar{\nu}_\mu, \mu^+)$ GFA

$$^{16}O(\nu_\mu, \mu^-)$$



FSI

RPWIA

GFA

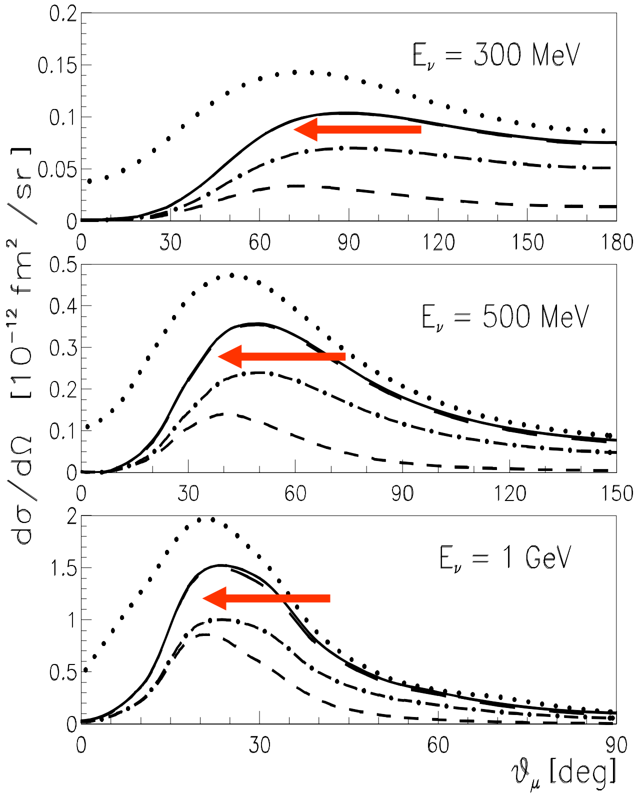
rROP

1NKO

$^{16}O(\bar{\nu}_\mu, \mu^+)$ GFA

$$^{16}O(\nu_\mu,\mu^-)$$

FSI



RPWIA

GFA

rROP

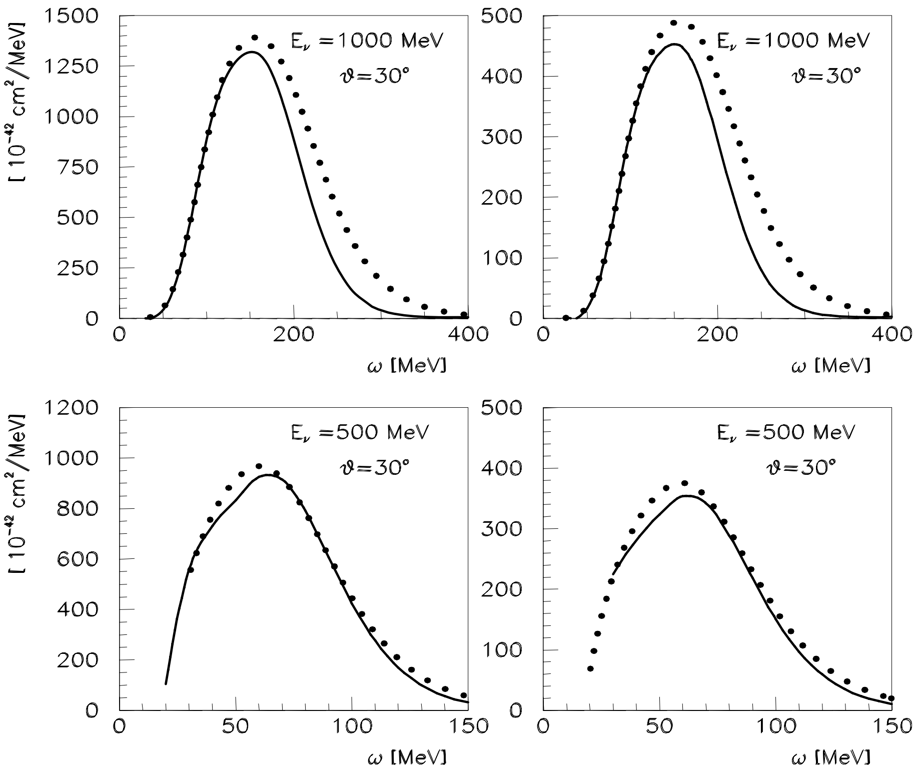
1NKO

$^{16}O(\bar{\nu}_\mu,\mu^+)$ GFA

COMPARISON OF DIFFERENT MODELS

relativistic vs nonrelativistic PWIA

CC ^{16}O NC



E_ν = 1000 MeV

E_ν = 500 MeV

RPWIA (A. Meucci, C. Giusti, F.D. Pacati)

NR PWIA (G. Co')

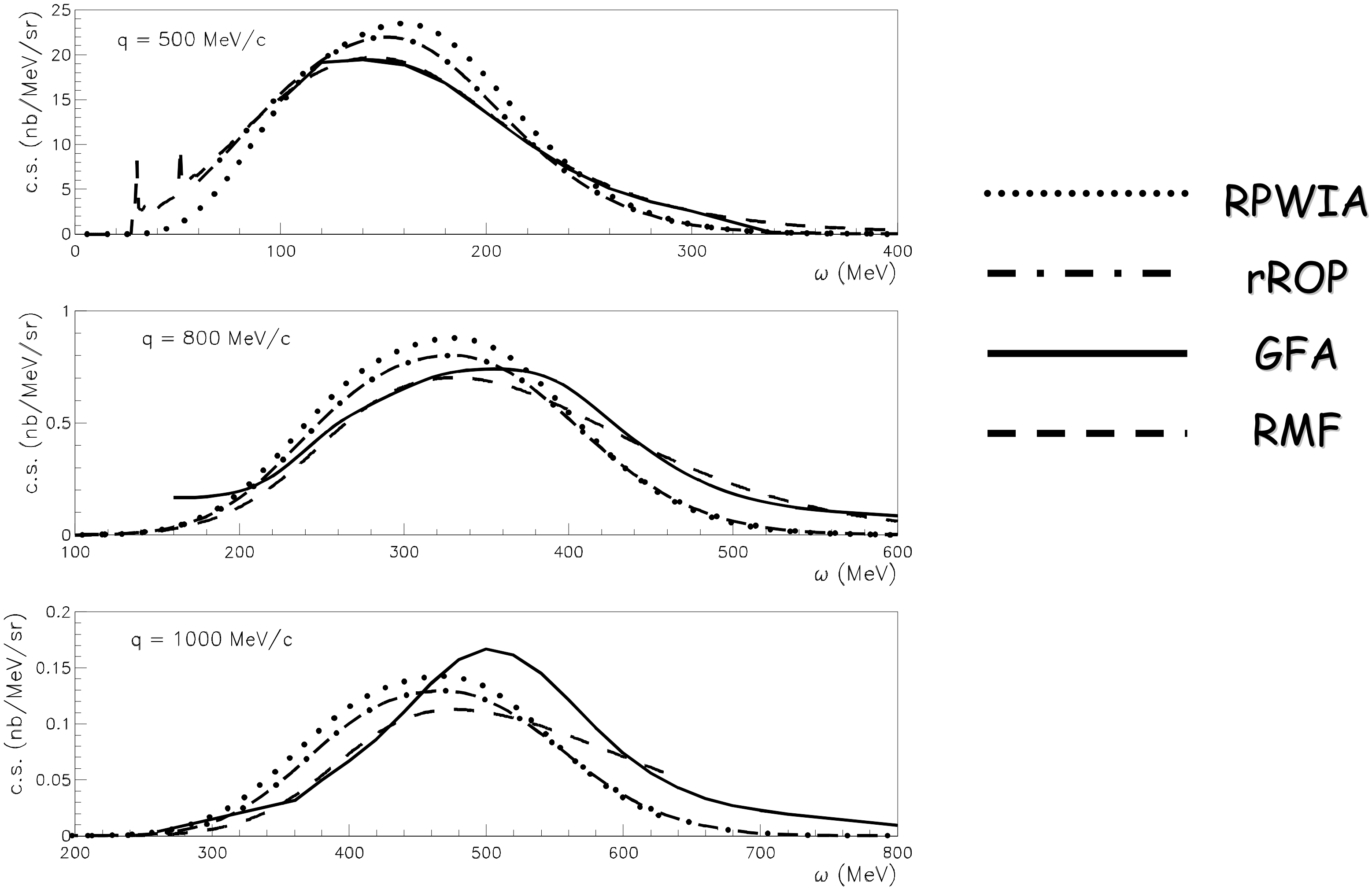
COMPARISON OF RELATIVISTIC MODELS

PAVIA $\Longleftrightarrow$ MADRID-SEVILLA

$^{12}C(e,e')$

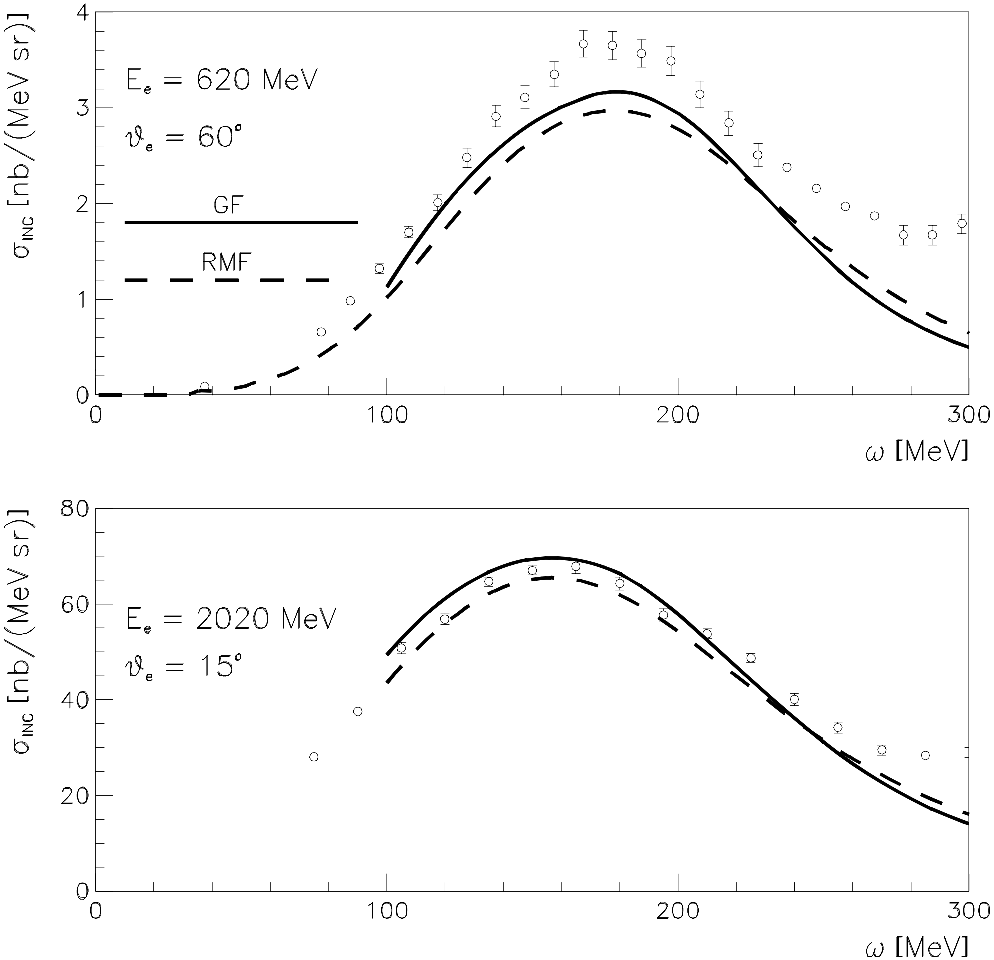
relativistic models

e = 1 GeV



$^{12}C(e,e')$

relativistic models



GFA

RMF

SCALING APPROACH

Need of reliable calculations of ν-nucleus cross sections

Analogies between ν-nucleus and e^--nucleus scattering where a large amount of data is available

Is it possible to extract model independent ν-nucleus cross sections from e^--nucleus experimental cross sections?

Instead of using a specific nuclear model one can exploit the scaling properties of (e,e′) data and

- extract a scaling function from (e,e′) data
- invert the procedure to predict ν-nucleus cross sections

J.E. Amaro, M.B. Barbaro, J.A. Caballero, T.W. Donnelly, A. Molinari and I. Sick
PRC71 (2005) 015501

SCALING APPROACH

The method relies on the scaling properties of the electron scattering data

At sufficiently high q the scaling function $f = \dfrac{d^2\sigma(q,\omega)/d\Omega dk'}{S^{s.n.}(q,\omega)}$

depends only upon one kinematical variable (scaling variable)

(SCALING OF I KIND)

is the same for all nuclei

(SCALING OF II KIND)

I+II SUPERSCALING

Scaling variable (QE) $$\psi_{\mathrm{QE}} = \pm\sqrt{1/(2T_F)\left(q\sqrt{1+1/\tau}-\omega-1\right)}$$

+ (-) for ω lower (higher) than the QEP, where ψ=0

Scaling variable (QE) $\psi_{\rm QE} = \pm\sqrt{1/(2T_F)\left(q\sqrt{1+1/\tau} - \omega - 1\right)}$

+ (-) for ω lower (higher) than the QEP, where ψ=0

- Reasonable scaling of I kind at the left of QEP
- Excellent scaling of II kind in the same region
- Breaking of scaling particularly of I kind at the right of QEP (effects beyond IA)
- The L contribution superscales

Scaling variable (QE) $$\psi_{\rm QE} = \pm\sqrt{1/(2T_F)\left(q\sqrt{1+1/\tau}-\omega-1\right)}$$

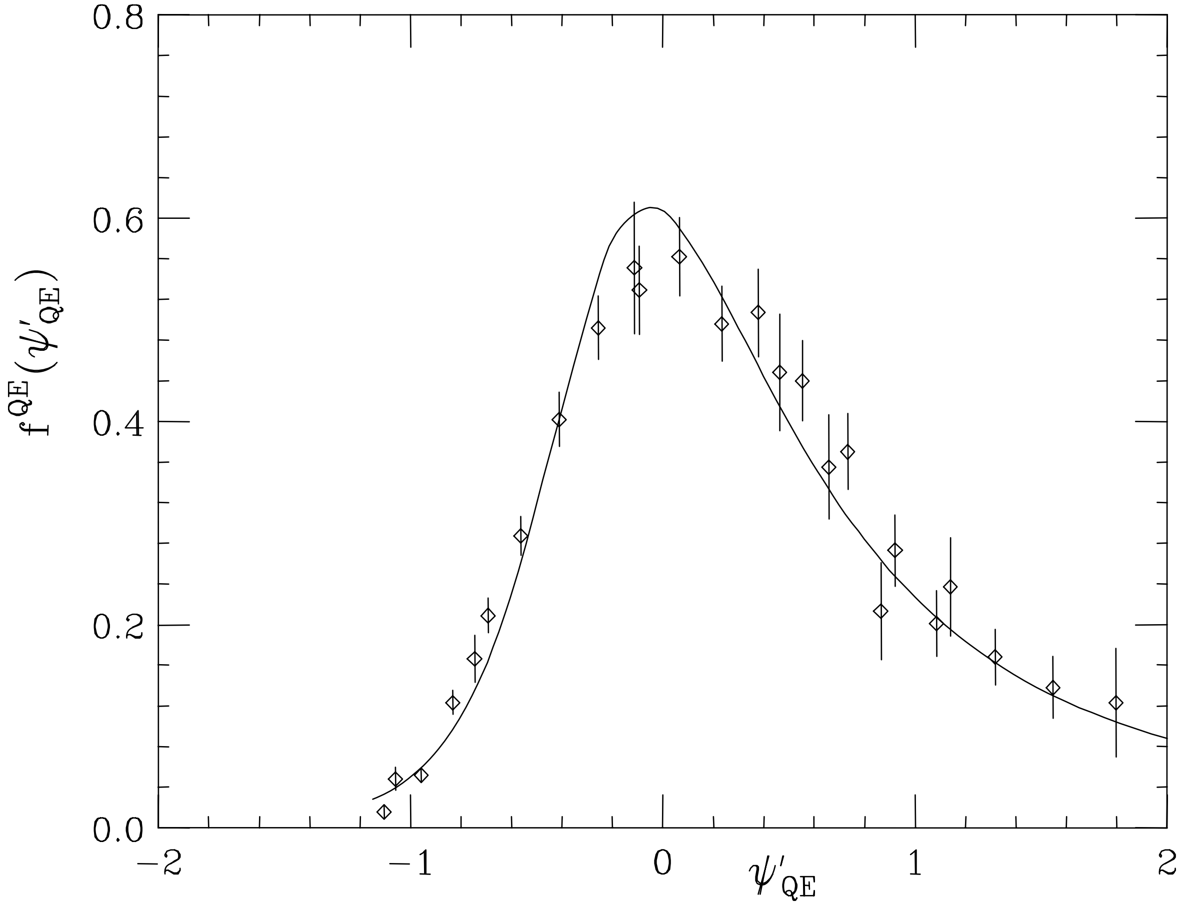
+ (-) for ω lower (higher) than the QEP, where ψ=0

- Reasonable scaling of I kind at the left of QEP
- Excellent scaling of II kind in the same region
- Breaking of scaling particularly of I kind at the right of QEP (effects beyond IA)
- The L contribution superscales

↓

f^{QE} can be extracted from the data and used to calculate ν–nucleus CC cross section

Experimental QE superscaling function



M.B. Barbaro, J.E. Amaro, J.A. Caballero, T.W. Donnelly, A. Molinari, and I. Sick, Nucl. Phys Proc. Suppl 155 (2006) 257

SCALING APPROACH

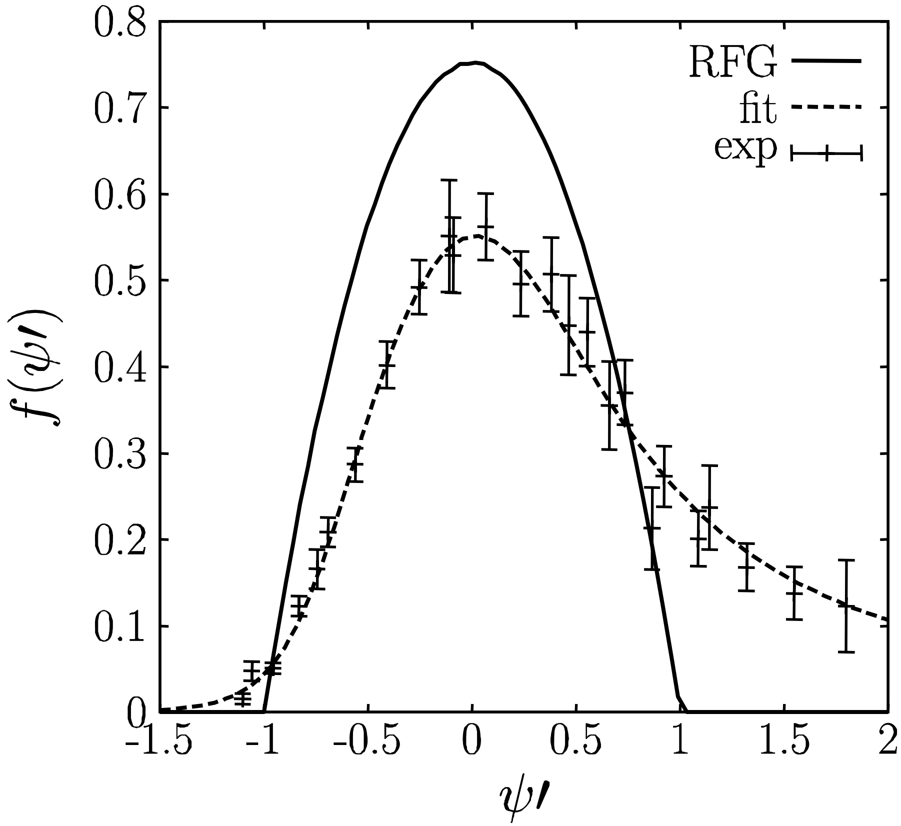
The properties of the experimental scaling function should be accounted for by microscopic calculations

The asymmetric shape of f^{QE} should be explained

The scaling properties of different models can be verified

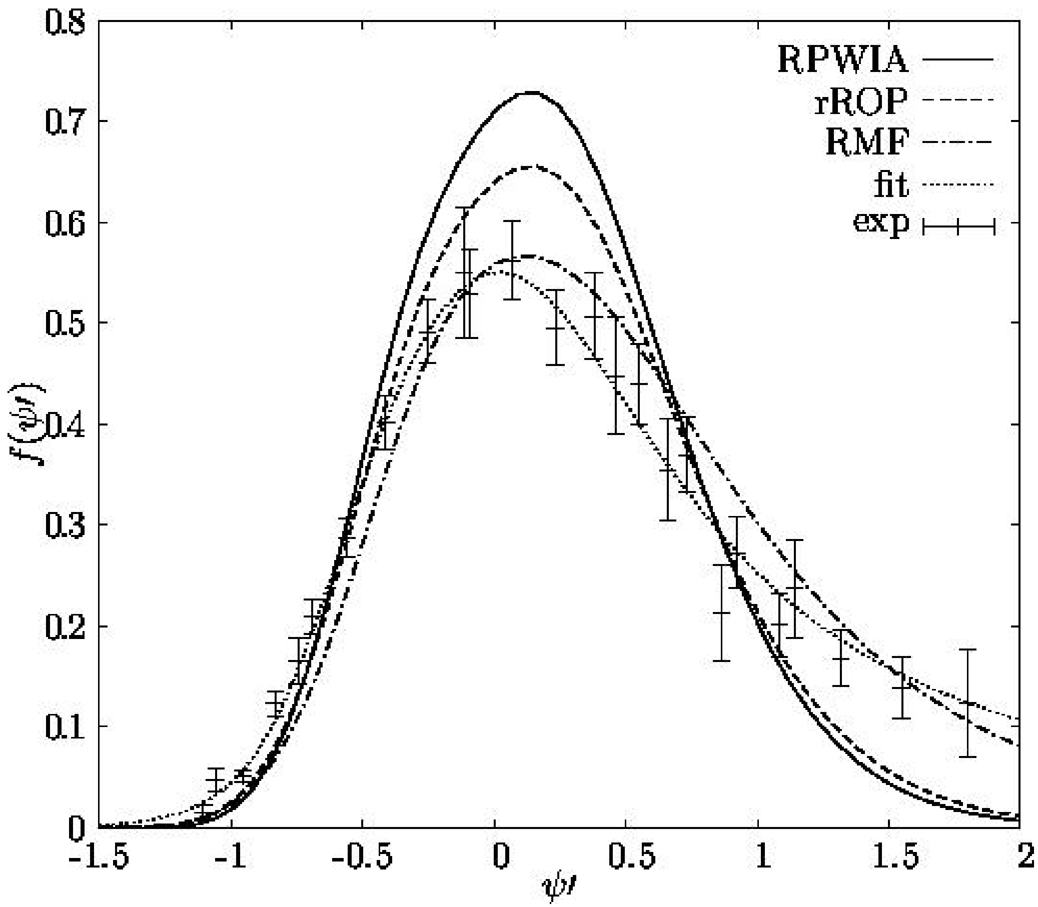
The associated scaling functions are compared with the experimental f^{QE}

Experimental QE superscaling function - RFG



Relativistic Fermi Gas

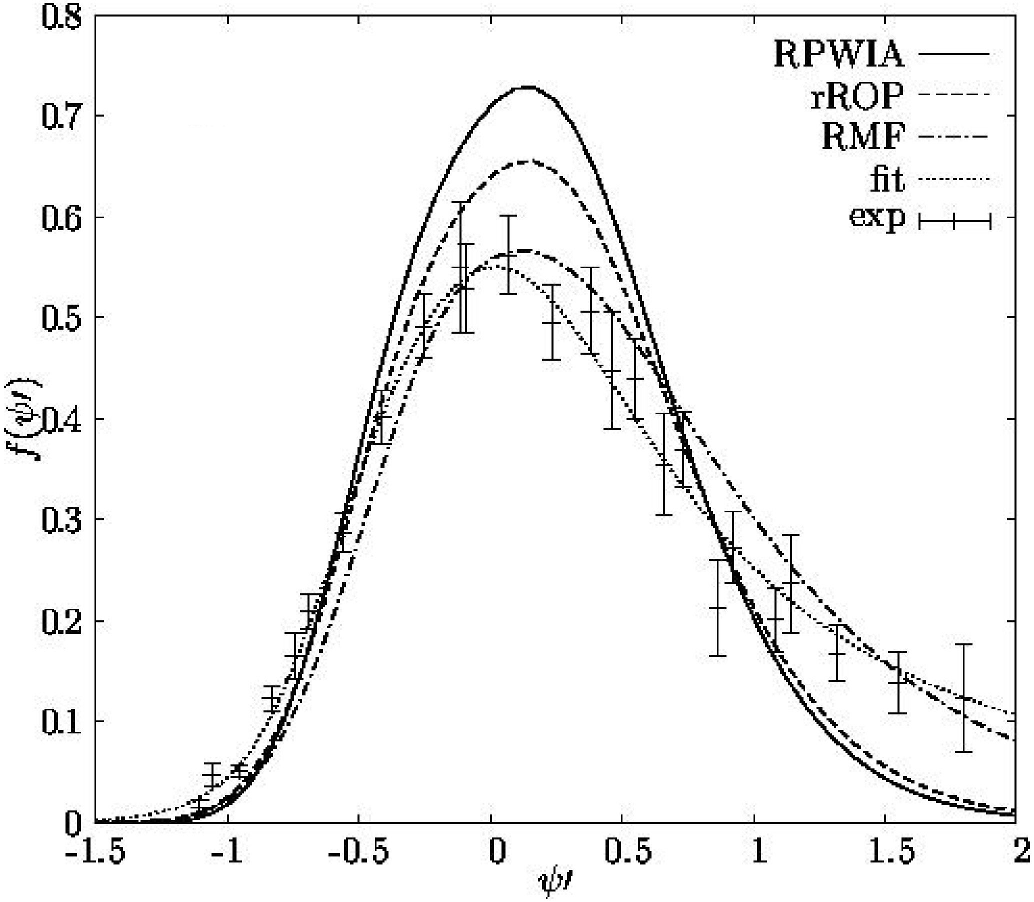
Experimental QE superscaling function: RPWIA, rROP, RMF



RPWIA
rROP
RMF
fit

J.A. Caballero J.E. Amaro, M.B. Barbaro, T.W. Donnelly, C. Maieron, and J.M. Udias PRL 95 (2005) 252502

Experimental QE superscaling function: RPWIA, rROP, RMF



RPWIA

rROP

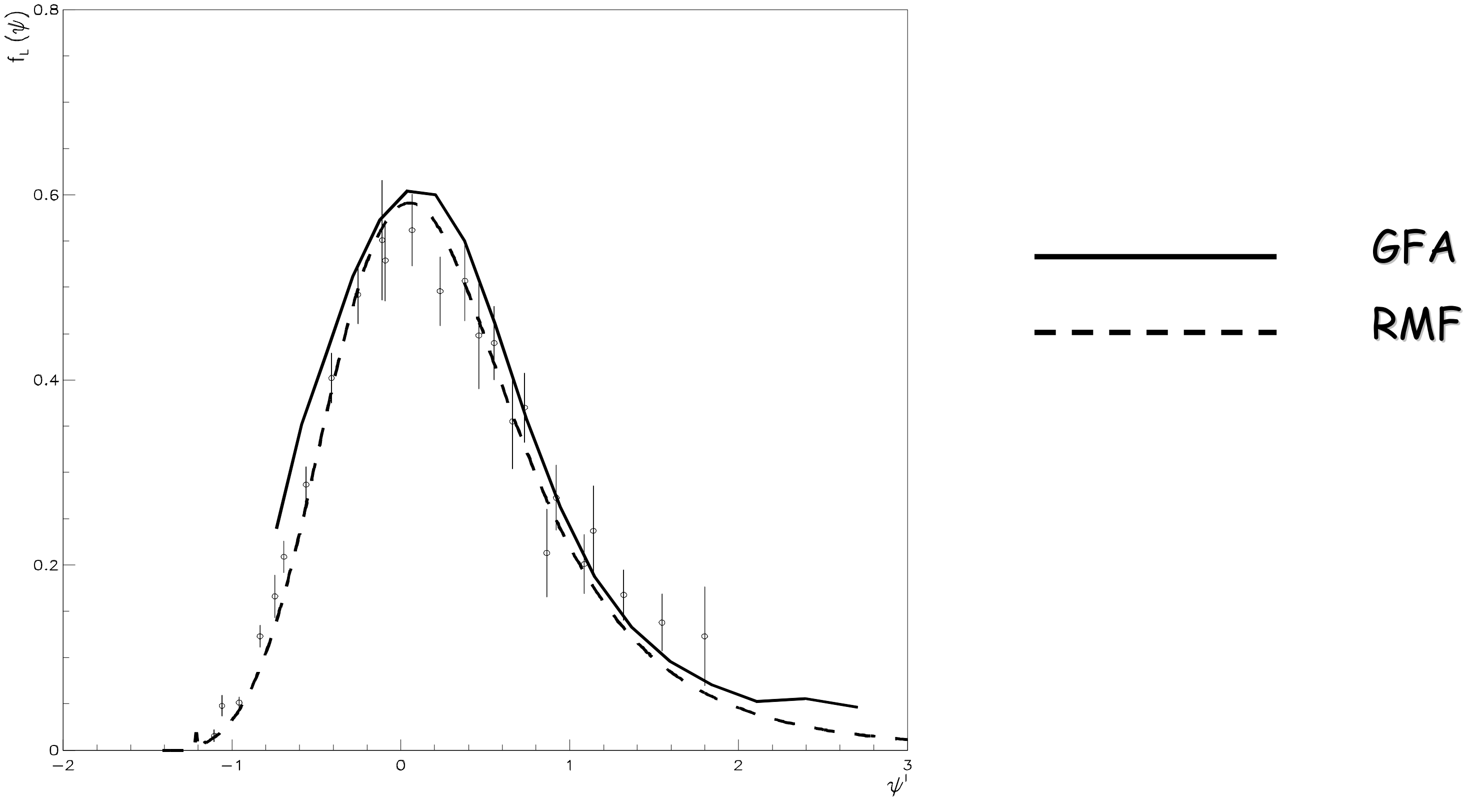
RMF

fit

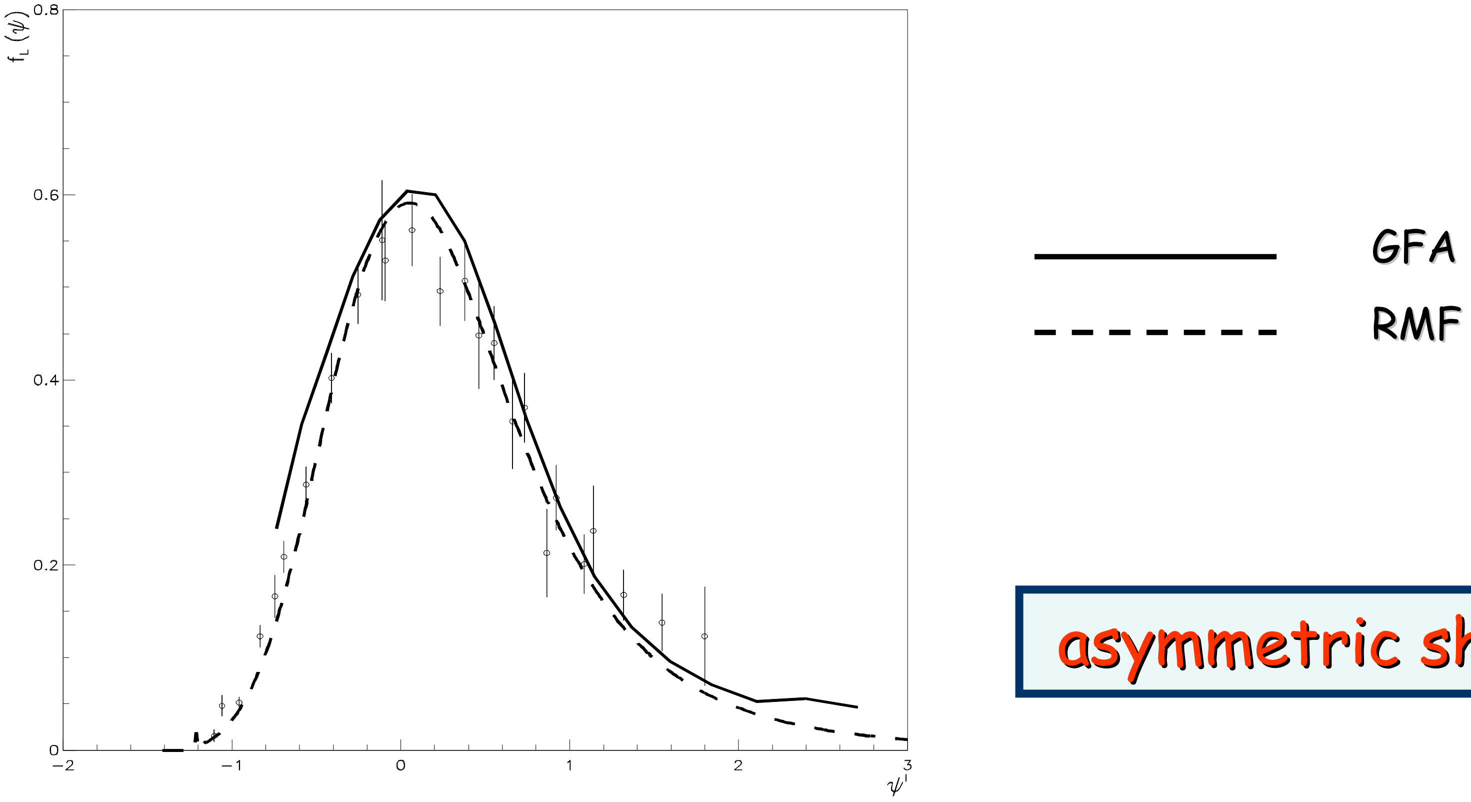
only RMF gives an asymmetric shape

J.A. Caballero J.E. Amaro, M.B. Barbaro, T.W. Donnelly, C. Maieron, and J.M. Udias PRL 95 (2005) 252502

scaling function: comparison GFA - RMF



scaling function: comparison GFA - RMF



asymmetric shape

CONCLUSIONS

- ν- nucleus cross sections calculated in the QE region
- nuclear effects treated extending to ν- nucleus scattering relativistic models developed for QE electron-nucleus scattering and tested in comparison with electron-scattering data
- consistent models for exclusive, semi-inclusive, inclusive processes with CC and NC
- numerical predictions can be given for different nuclei and kinematics
- comparison of the numerical results of different models helpful to reduce theoretical uncertainties on nuclear effects

Relativistic DWIA

- ϕ_n Dirac-Hartree solution of a relativistic Lagrangian containing scalar and vector potentials, obtained in the context of the relativistic MF theory and reproduce s.p. properties of several nuclei
- χ obtained following the Pauli reduction scheme

$$\chi^{(-)}_{\boldsymbol{p}_{\mathrm{N}}} = \left(\begin{array}{c} \Psi_{\mathrm{f}+} \\ \dfrac{1}{M+E+S^{\dagger}(E)-V^{\dagger}(E)} \boldsymbol{\sigma} \cdot \boldsymbol{p} \Psi_{\mathrm{f}+} \end{array} \right)$$

$$\Psi_{\mathrm{f}+} = \sqrt{D^{\dagger}(E)}\ \Phi_{\mathrm{f}} \qquad D(E) = 1 + \frac{S(E)-V(E)}{M+E}$$

D Darwin factor

S and V scalar and vector potentials

- complex phenomenological optical potentials fitted to proton scattering data on several nuclei in a wide energy range

FSI for the inclusive scattering : Green's Function Approach

$$W^{\mu\mu}(\omega, q) = \sum_n \left[\mathbf{Re} T_n^{\mu\mu}(E_{\mathbf{f}} - \varepsilon_n, E_{\mathbf{f}} - \varepsilon_n) - \frac{1}{\pi} \mathcal{P} \int_M^\infty \mathbf{d}\mathcal{E} \frac{1}{E_{\mathbf{f}} - \varepsilon_n - \mathcal{E}} \mathbf{Im} T_n^{\mu\mu}(\mathcal{E}, E_{\mathbf{f}} - \varepsilon_n) \right]$$

$$T_n^{\mu\mu}(\mathcal{E}, E) = \lambda_n \langle \varphi_n \mid j^{\mu\dagger}(\boldsymbol{q}) \sqrt{1 - \mathcal{V}'(E)} \mid \tilde{\chi}_{\mathcal{E}}^{(-)}(E) \rangle \langle \chi_{\mathcal{E}}^{(-)}(E) \mid \sqrt{1 - \mathcal{V}'(E)} j^{\mu}(\boldsymbol{q}) \mid \varphi_n \rangle$$

interference between different channels

FSI for the inclusive scattering : Green's Function Approach

$$W^{\mu\mu}(\omega,q) = \sum_n \left[\mathbf{Re} T_n^{\mu\mu}(E_{\mathbf{f}} - \varepsilon_n, E_{\mathbf{f}} - \varepsilon_n) - \frac{1}{\pi}\mathcal{P}\int_M^\infty \mathbf{d}\mathcal{E}\, \frac{1}{E_{\mathbf{f}} - \varepsilon_n - \mathcal{E}} \mathbf{Im} T_n^{\mu\mu}(\mathcal{E}, E_{\mathbf{f}} - \varepsilon_n) \right]$$

$$T_n^{\mu\mu}(\mathcal{E}, E) = \lambda_n \langle \varphi_n \mid j^{\mu\dagger}(\boldsymbol{q}) \sqrt{1 - \mathcal{V}'(E)} \mid \tilde{\chi}_{\mathcal{E}}^{(-)}(E) \rangle \langle \chi_{\mathcal{E}}^{(-)}(E) \mid \sqrt{1 - \mathcal{V}'(E)} j^{\mu}(\boldsymbol{q}) \mid \varphi_n \rangle$$

eigenfunctions of H and H⁺

FSI for the inclusive scattering : Green's Function Approach

$$W^{\mu\mu}(\omega,q) = \sum_n \left[\mathbf{Re} T_n^{\mu\mu}(E_{\mathbf{f}}-\varepsilon_n, E_{\mathbf{f}}-\varepsilon_n) - \frac{1}{\pi}\mathcal{P}\int_M^\infty \mathbf{d}\mathcal{E} \frac{1}{E_{\mathbf{f}}-\varepsilon_n-\mathcal{E}} \mathbf{Im} T_n^{\mu\mu}(\mathcal{E}, E_{\mathbf{f}}-\varepsilon_n) \right]$$

$$T_n^{\mu\mu}(\mathcal{E},E) = \lambda_n \underbrace{\langle\varphi_n \mid j^{\mu\dagger}(\boldsymbol{q})\sqrt{1-\mathcal{V}'(E)} \mid \tilde{\chi}_{\mathcal{E}}^{(-)}(E)\rangle}_{\text{gain of flux}} \underbrace{\langle\chi_{\mathcal{E}}^{(-)}(E) \mid \sqrt{1-\mathcal{V}'(E)}\, j^{\mu}(\boldsymbol{q}) \mid \varphi_n\rangle}_{\text{loss of flux}}$$

Flux redistributed and conserved

The imaginary part of the optical potential is responsible for the redistribution of the flux among the different channels

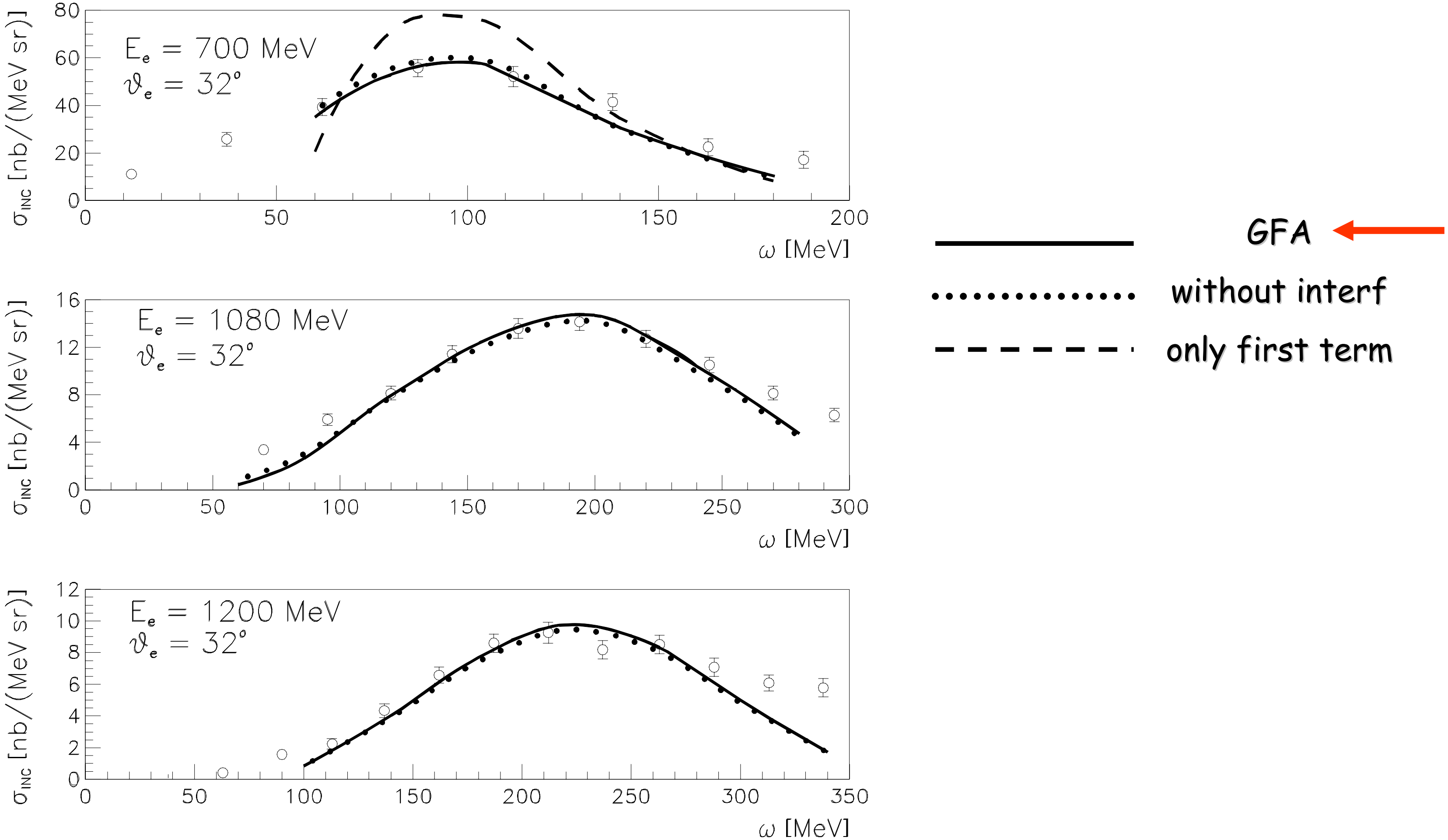
FSI for the inclusive scattering : Green's Function Approach

$$W^{\mu\mu}(\omega,q) = \sum_n \left[\mathbf{Re}\, T_n^{\mu\mu}(E_{\mathbf{f}} - \varepsilon_n, E_{\mathbf{f}} - \varepsilon_n) - \frac{1}{\pi}\mathcal{P}\int_M^{\infty} \mathbf{d}\mathcal{E}\, \frac{1}{E_{\mathbf{f}} - \varepsilon_n - \mathcal{E}}\, \mathbf{Im}\, T_n^{\mu\mu}(\mathcal{E}, E_{\mathbf{f}} - \varepsilon_n) \right]$$

$$T_n^{\mu\mu}(\mathcal{E},E) = \lambda_n \underbrace{\langle \varphi_n \mid j^{\mu\dagger}(\boldsymbol{q})\sqrt{1-\mathcal{V}'(E)} \mid \tilde{\chi}_{\mathcal{E}}^{(-)}(E)\rangle}_{\text{gain of flux}} \underbrace{\langle \chi_{\mathcal{E}}^{(-)}(E) \mid \sqrt{1-\mathcal{V}'(E)}\, j^{\mu}(\boldsymbol{q}) \mid \varphi_n \rangle}_{\text{loss of flux}}$$

For a real optical potential H=H+ the second term vanishes and the nuclear response is given by the sum of all the integrated one-nucleon knockout processes (without absorption)

$^{16}O(e,e')$



data from Frascati NPA 602 405 (1996)