Analyzing SRC through the Nonlocal Dispersive Optical Model

Mack C. Atkinson

Washington University in St. Louis

2nd Workshop on SRC and EMC Research (2019)

Analyzing SRC through the Nonlocal Dispersive Optical Model

Willem Dickhoff
Bob Charity
Henk Blok
Louk Lapikás
Hossein Mahzoon
Cole Pruitt
Lee Sobotka

Mack C. Atkinson

Washington University in St. Louis

2nd Workshop on SRC and EMC Research (2019)

Introduction and Outline

- Want to know how nucleons arrange themselves in nuclei, in particular momentum distributions

Introduction and Outline

- Want to know how nucleons arrange themselves in nuclei, in particular momentum distributions
- Scattering experiments are used to look inside the nucleus

Introduction and Outline

- Want to know how nucleons arrange themselves in nuclei, in particular momentum distributions
- Scattering experiments are used to look inside the nucleus
- Goal is to connect scattering experiments with nuclear structure

Introduction and Outline

- Want to know how nucleons arrange themselves in nuclei, in particular momentum distributions
- Scattering experiments are used to look inside the nucleus
- Goal is to connect scattering experiments with nuclear structure
    1. Green's function formalism

Introduction and Outline

- Want to know how nucleons arrange themselves in nuclei, in particular momentum distributions
- Scattering experiments are used to look inside the nucleus
- Goal is to connect scattering experiments with nuclear structure
  1. Green's function formalism
  2. The dispersive optical model

Introduction and Outline

- Want to know how nucleons arrange themselves in nuclei, in particular momentum distributions
- Scattering experiments are used to look inside the nucleus
- Goal is to connect scattering experiments with nuclear structure
    1. Green's function formalism
    2. The dispersive optical model
    3. Momentum distributions and high-momentum content

Introduction and Outline

- Want to know how nucleons arrange themselves in nuclei, in particular momentum distributions
- Scattering experiments are used to look inside the nucleus
- Goal is to connect scattering experiments with nuclear structure
    1. Green's function formalism
    2. The dispersive optical model
    3. Momentum distributions and high-momentum content
    4. Asymmetry dependence of high-momentum content

Introduction and Outline

- Want to know how nucleons arrange themselves in nuclei, in particular momentum distributions
- Scattering experiments are used to look inside the nucleus
- Goal is to connect scattering experiments with nuclear structure
    1. Green's function formalism
    2. The dispersive optical model
    3. Momentum distributions and high-momentum content
    4. Asymmetry dependence of high-momentum content
    5. The role of high-momentum content in exclusive $(e, e'p)$ reactions

Single-Particle Propagator and the Dyson Equation

$$G_{\ell j}(r,r';E) = \sum_m \frac{\langle\Psi_0^A|\, a_{r\ell j}\, |\Psi_m^{A+1}\rangle \langle\Psi_m^{A+1}|\, a^\dagger_{r'\ell j}\, |\Psi_0^A\rangle}{E-(E_m^{A+1}-E_0^A)+i\eta} + \sum_n \frac{\langle\Psi_0^A|\, a^\dagger_{r'\ell j}\, |\Psi_n^{A-1}\rangle \langle\Psi_n^{A-1}|\, a_{r\ell j}\, |\Psi_0^A\rangle}{E-(E_0^A-E_n^{A-1})-i\eta}$$

Single-Particle Propagator and the Dyson Equation

$$G_{\ell j}(r,r';E) = \sum_m \frac{\langle \Psi_0^A | a_{r\ell j} | \Psi_m^{A+1} \rangle \langle \Psi_m^{A+1} | a^\dagger_{r'\ell j} | \Psi_0^A \rangle}{E - (E_m^{A+1} - E_0^A) + i\eta} + \sum_n \frac{\langle \Psi_0^A | a^\dagger_{r'\ell j} | \Psi_n^{A-1} \rangle \langle \Psi_n^{A-1} | a_{r\ell j} | \Psi_0^A \rangle}{E - (E_0^A - E_n^{A-1}) - i\eta}$$

- Poles correspond to excitation energies of $(A+1)$ or $(A-1)$ nucleus

Single-Particle Propagator and the Dyson Equation

$$G_{\ell j}(r,r';E) = \sum_m \frac{\langle \Psi_0^A | a_{r\ell j} | \Psi_m^{A+1} \rangle \langle \Psi_m^{A+1} | a^\dagger_{r'\ell j} | \Psi_0^A \rangle}{E - (E_m^{A+1} - E_0^A) + i\eta} + \sum_n \frac{\langle \Psi_0^A | a^\dagger_{r'\ell j} | \Psi_n^{A-1} \rangle \langle \Psi_n^{A-1} | a_{r\ell j} | \Psi_0^A \rangle}{E - (E_0^A - E_n^{A-1}) - i\eta}$$

- Poles correspond to excitation energies of $(A+1)$ or $(A-1)$ nucleus
- Numerator like a transition probability to given excitation

Single-Particle Propagator and the Dyson Equation

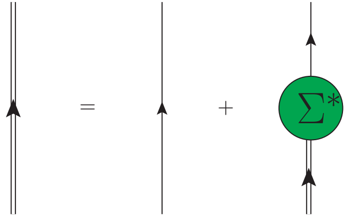
$$G_{\ell j}(r, r'; E) = \sum_m \frac{\langle \Psi_0^A | a_{r\ell j} | \Psi_m^{A+1} \rangle \langle \Psi_m^{A+1} | a_{r'\ell j}^\dagger | \Psi_0^A \rangle}{E - (E_m^{A+1} - E_0^A) + i\eta} + \sum_n \frac{\langle \Psi_0^A | a_{r'\ell j}^\dagger | \Psi_n^{A-1} \rangle \langle \Psi_n^{A-1} | a_{r\ell j} | \Psi_0^A \rangle}{E - (E_0^A - E_n^{A-1}) - i\eta}$$

- Poles correspond to excitation energies of $(A+1)$ or $(A-1)$ nucleus
- Numerator like a transition probability to given excitation
- Close connection with experimental observables

Single-Particle Propagator and the Dyson Equation

$$G_{\ell j}(r, r'; E) = \sum_m \frac{\langle \Psi_0^A | a_{r\ell j} | \Psi_m^{A+1} \rangle \langle \Psi_m^{A+1} | a^\dagger_{r'\ell j} | \Psi_0^A \rangle}{E - (E_m^{A+1} - E_0^A) + i\eta} + \sum_n \frac{\langle \Psi_0^A | a^\dagger_{r'\ell j} | \Psi_n^{A-1} \rangle \langle \Psi_n^{A-1} | a_{r\ell j} | \Psi_0^A \rangle}{E - (E_0^A - E_n^{A-1}) - i\eta}$$

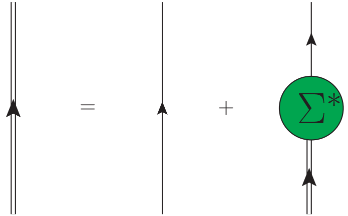
- Poles correspond to excitation energies of $(A+1)$ or $(A-1)$ nucleus
- Numerator like a transition probability to given excitation
- Close connection with experimental observables
- Perturbation expansion of G leads to the Dyson equation



Single-Particle Propagator and the Dyson Equation

$$G_{\ell j}(r, r'; E) = \sum_m \frac{\langle \Psi_0^A | a_{r\ell j} | \Psi_m^{A+1} \rangle \langle \Psi_m^{A+1} | a_{r'\ell j}^\dagger | \Psi_0^A \rangle}{E - (E_m^{A+1} - E_0^A) + i\eta} + \sum_n \frac{\langle \Psi_0^A | a_{r'\ell j}^\dagger | \Psi_n^{A-1} \rangle \langle \Psi_n^{A-1} | a_{r\ell j} | \Psi_0^A \rangle}{E - (E_0^A - E_n^{A-1}) - i\eta}$$

- Poles correspond to excitation energies of $(A+1)$ or $(A-1)$ nucleus
- Numerator like a transition probability to given excitation
- Close connection with experimental observables
- Perturbation expansion of G leads to the Dyson equation
- If the irreducible self-energy (Σ^*) is known, then so is G



The Dispersive Optical Model (DOM)

- Irreducible self-energy at positive energies corresponds to an optical potential

The Dispersive Optical Model (DOM)

- Irreducible self-energy at positive energies corresponds to an optical potential
- Use same functional form as standard optical potentials to parametrize self-energy

The Dispersive Optical Model (DOM)

- Irreducible self-energy at positive energies corresponds to an optical potential
- Use same functional form as standard optical potentials to parametrize self-energy
- $\Sigma^*(\boldsymbol{r}, \boldsymbol{r'}; E)$ is explicitly **nonlocal**

The Dispersive Optical Model (DOM)

- Irreducible self-energy at positive energies corresponds to an optical potential
- Use same functional form as standard optical potentials to parametrize self-energy
- $\Sigma^*(\boldsymbol{r}, \boldsymbol{r'}; E)$ is explicitly **nonlocal**
- Dispersion relation connects to negative energies

The Dispersive Optical Model (DOM)

- Irreducible self-energy at positive energies corresponds to an optical potential
- Use same functional form as standard optical potentials to parametrize self-energy
- $\Sigma^*(\boldsymbol{r}, \boldsymbol{r'}; E)$ is explicitly **nonlocal**
- Dispersion relation connects to negative energies

Dispersive Correction

$$Re\Sigma_{\ell j}(r, r'; E) = Re\Sigma_{\ell j}(r, r'; \epsilon_F) - \frac{1}{\pi}(\epsilon_F - E)\mathcal{P}\int_{\epsilon_T^+}^{\infty} dE' Im\Sigma_{\ell j}(r, r'; E')[\frac{1}{E - E'} - \frac{1}{\epsilon_F - E'}]$$
$$+\frac{1}{\pi}(\epsilon_F - E)\mathcal{P}\int_{-\infty}^{\epsilon_T^-} dE' Im\Sigma_{\ell j}(r, r'; E')[\frac{1}{E - E'} - \frac{1}{\epsilon_F - E'}]$$

The Dispersive Optical Model (DOM)

- Irreducible self-energy at positive energies corresponds to an optical potential
- Use same functional form as standard optical potentials to parametrize self-energy
- $\Sigma^*(\boldsymbol{r}, \boldsymbol{r'}; E)$ is explicitly **nonlocal**
- Dispersion relation connects to negative energies

Dispersive Correction

$$Re\Sigma_{\ell j}(r, r'; E) = Re\Sigma_{\ell j}(r, r'; \epsilon_F) - \frac{1}{\pi}(\epsilon_F - E)\mathcal{P}\int_{\epsilon_T^+}^{\infty} dE' Im\Sigma_{\ell j}(r, r'; E')[\frac{1}{E - E'} - \frac{1}{\epsilon_F - E'}]$$
$$+\frac{1}{\pi}(\epsilon_F - E)\mathcal{P}\int_{-\infty}^{\epsilon_T^-} dE' Im\Sigma_{\ell j}(r, r'; E')[\frac{1}{E - E'} - \frac{1}{\epsilon_F - E'}]$$

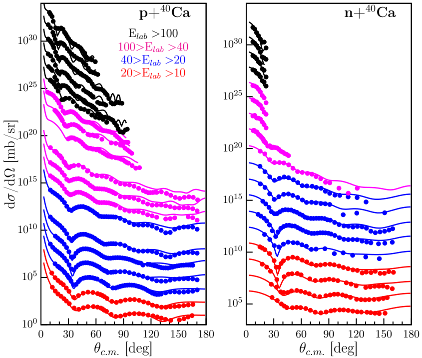
- This constraint ensures bound and scattering quantities are simultaneously described

Fitting the Self-energy (^{40}Ca)

- Parameters of self-energy varied to minimize χ^2

Fitting the Self-energy (^{40}Ca)

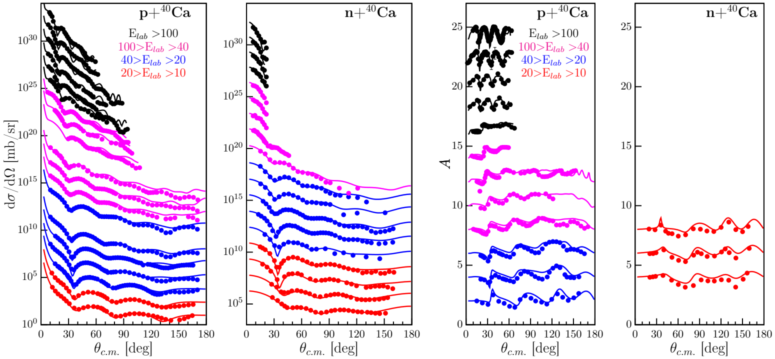
- Parameters of self-energy varied to minimize χ^2



Data: J.M. Mueller et al. *Phys. Rev. C*, **83** 064605, 2011

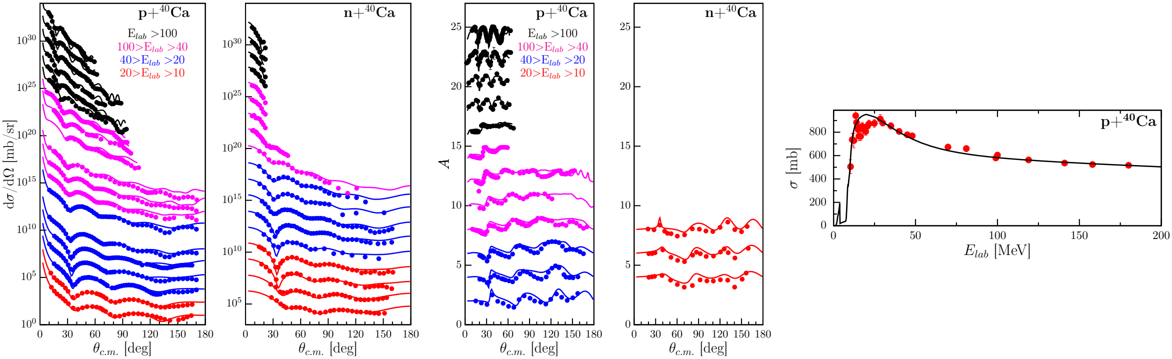
Fitting the Self-energy (^{40}Ca)

- Parameters of self-energy varied to minimize χ^2



Data: J.M. Mueller et al. *Phys. Rev. C*, **83** 064605, 2011

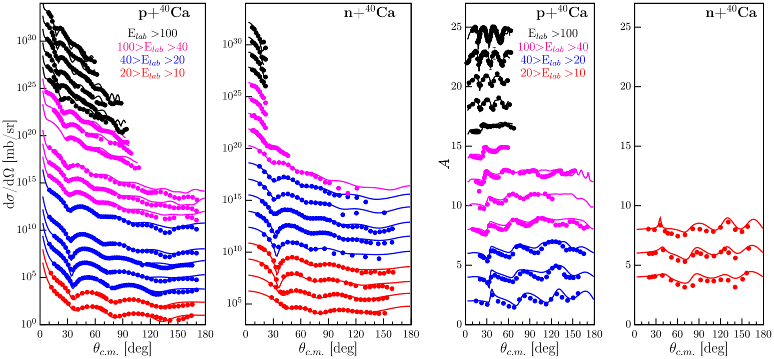
- Parameters of self-energy varied to minimize χ^2

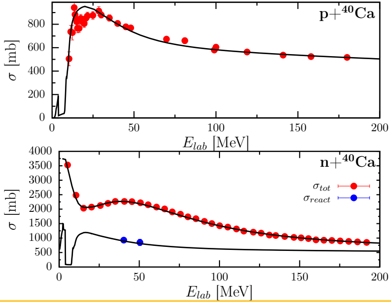


Data: J.M. Mueller et al. *Phys. Rev. C*, **83** 064605, 2011

Fitting the Self-energy (^{40}Ca)

- Parameters of self-energy varied to minimize χ^2

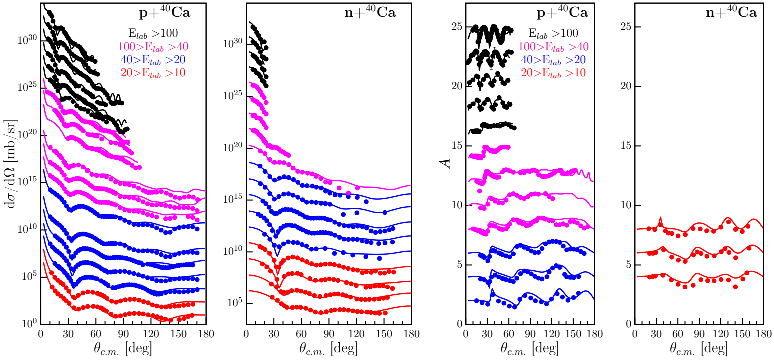


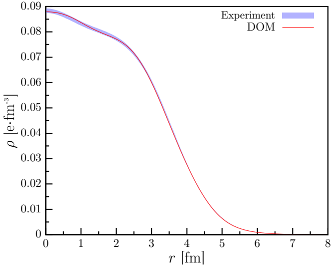


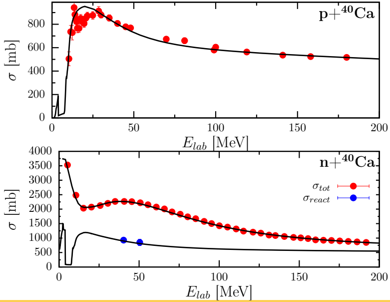
Data: J.M. Mueller et al. *Phys. Rev. C*, **83** 064605, 2011

Fitting the Self-energy (^{40}Ca)

- Parameters of self-energy varied to minimize χ^2
- Reproducing the data means self-energy is found



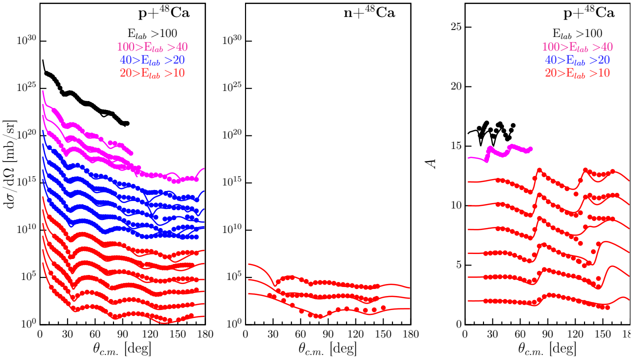


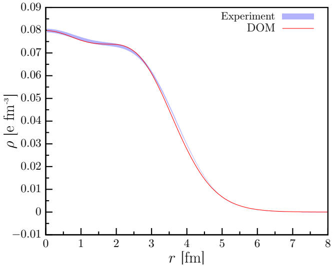


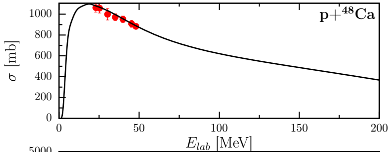
Data: J.M. Mueller et al. *Phys. Rev. C*, **83** 064605, 2011

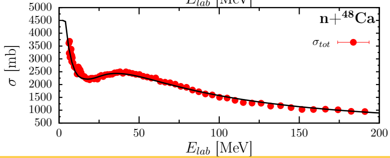
Fitting the Self-energy (^{48}Ca)

- Parameters of self-energy varied to minimize χ^2
- Reproducing the data means self-energy is found



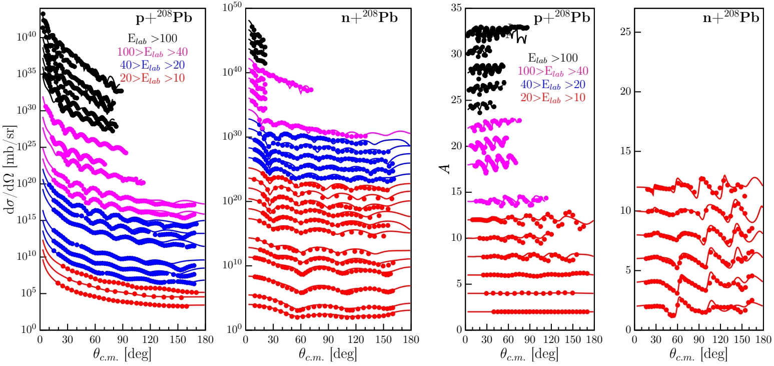


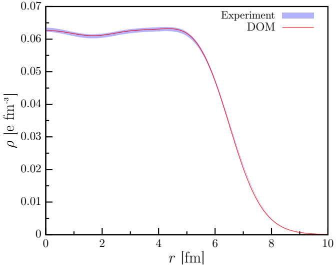


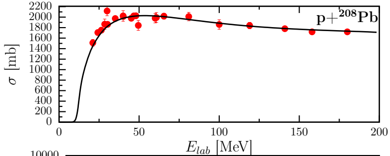


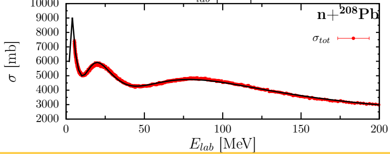
Data: J.M. Mueller et al. *Phys. Rev. C*, **83** 064605, 2011

- Parameters of self-energy varied to minimize χ^2
- Reproducing the data means self-energy is found





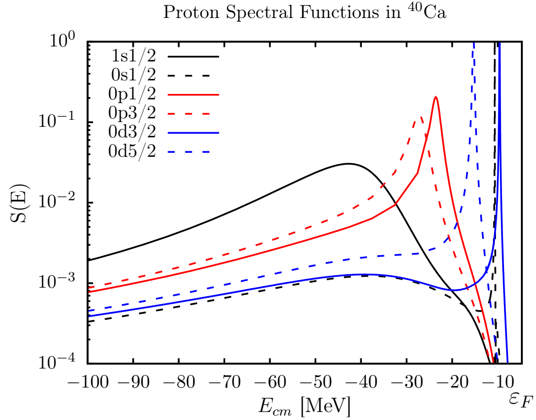




Data: J.M. Mueller et al. *Phys. Rev. C*, **83** 064605, 2011

The Spectral Function and Sum Rules

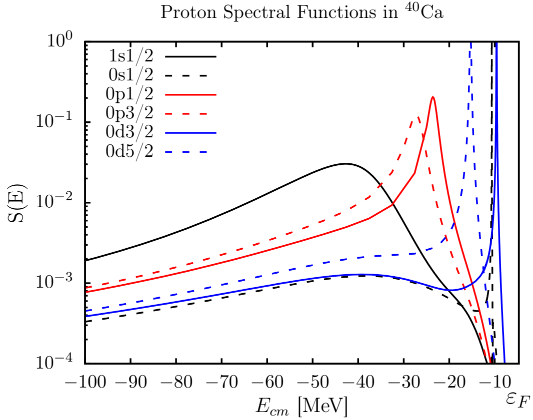
$$S^h(\alpha,\beta;E) = \frac{1}{\pi} Im\{G(\alpha,\beta;E)\} \qquad S^h(E) = \sum_{\alpha} S(\alpha,\alpha;E)$$



The Spectral Function and Sum Rules

$$S^h(\alpha,\beta;E) = \frac{1}{\pi} Im\{G(\alpha,\beta;E)\} \qquad S^h(E) = \sum_\alpha S(\alpha,\alpha;E)$$

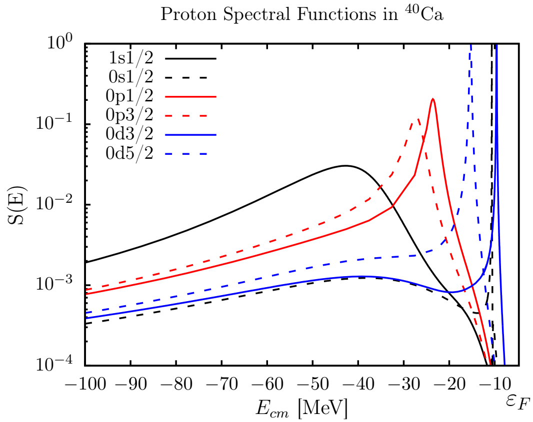
$$\rho_{\alpha,\beta} = \int_{-\infty}^{\varepsilon_F} dE S(\alpha,\beta;E)$$



The Spectral Function and Sum Rules

$$S^h(\alpha,\beta;E) = \frac{1}{\pi} Im\{G(\alpha,\beta;E)\} \qquad S^h(E) = \sum_\alpha S(\alpha,\alpha;E)$$

$$\rho_{\alpha,\beta} = \int_{-\infty}^{\varepsilon_F} dE S(\alpha,\beta;E) \qquad N,Z = \sum_\alpha \rho_{\alpha,\alpha}^{N,Z}$$

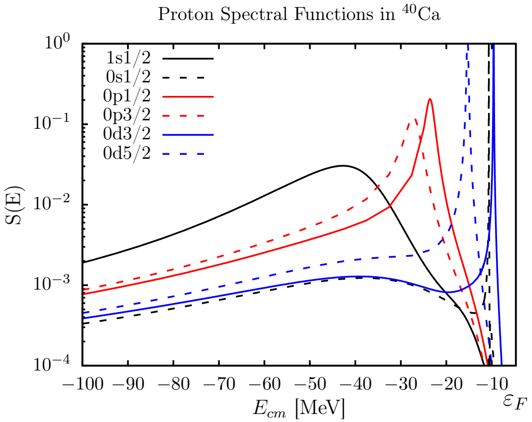


The Spectral Function and Sum Rules

$$S^h(\alpha,\beta;E) = \frac{1}{\pi} Im\{G(\alpha,\beta;E)\} \qquad S^h(E) = \sum_\alpha S(\alpha,\alpha;E)$$

$$\rho_{\alpha,\beta} = \int_{-\infty}^{\varepsilon_F} dE S(\alpha,\beta;E) \qquad N,Z = \sum_\alpha \rho_{\alpha,\alpha}^{N,Z}$$

$$E_0^A = \frac{1}{2}\sum_{\alpha\beta}\left[T_{\beta\alpha}\rho_{\alpha\beta} + \delta_{\alpha\beta}\int_{-\infty}^{\epsilon_f^-} dE E S_h(\alpha;E)\right]$$



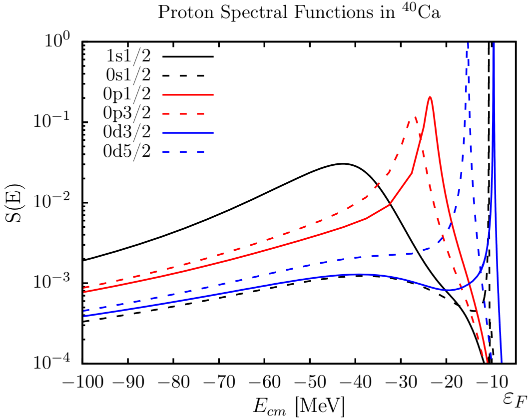
The Spectral Function and Sum Rules

$$S^h(\alpha,\beta;E) = \frac{1}{\pi} Im\{G(\alpha,\beta;E)\} \qquad S^h(E) = \sum_\alpha S(\alpha,\alpha;E)$$

$$\rho_{\alpha,\beta} = \int_{-\infty}^{\varepsilon_F} dES(\alpha,\beta;E) \qquad N,Z = \sum_\alpha \rho_{\alpha,\alpha}^{N,Z}$$

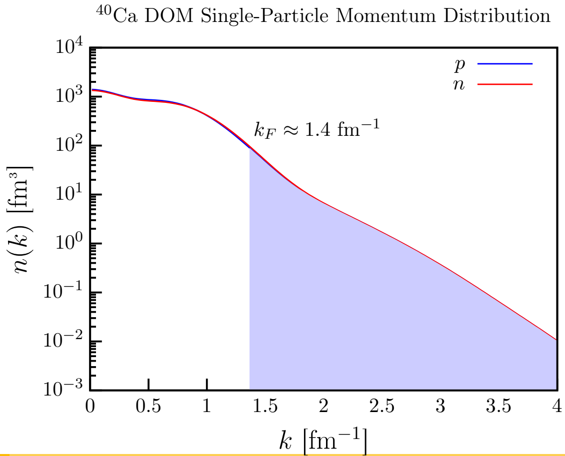
$$E_0^A = \frac{1}{2}\sum_{\alpha\beta}\left[T_{\beta\alpha}\rho_{\alpha\beta} + \delta_{\alpha\beta}\int_{-\infty}^{\epsilon_f^-} dEES_h(\alpha;E)\right]$$

	N	Z	DOM E_0^A/A	Exp. E_0^A/A
^{40}Ca	19.9	19.8	-8.49	-8.55
^{48}Ca	27.9	19.9	-8.7	-8.66
^{208}Pb	125.8	81.7	-7.83	-7.87



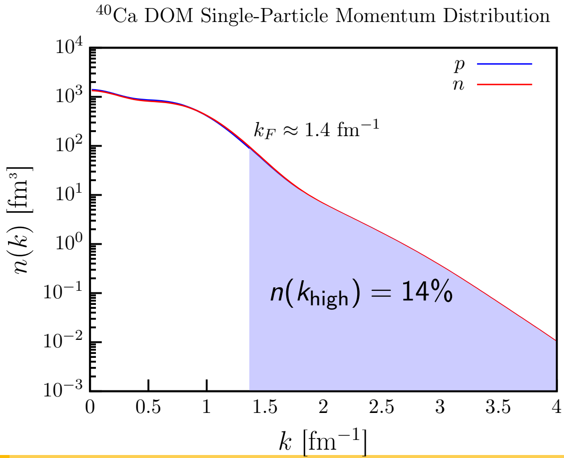
Momentum Distributions

$$n(\boldsymbol{k}) = \int d^3r \int d^3r' e^{i\boldsymbol{k}\cdot(\boldsymbol{r}-\boldsymbol{r}')}\rho(\boldsymbol{r},\boldsymbol{r}')$$



Momentum Distributions

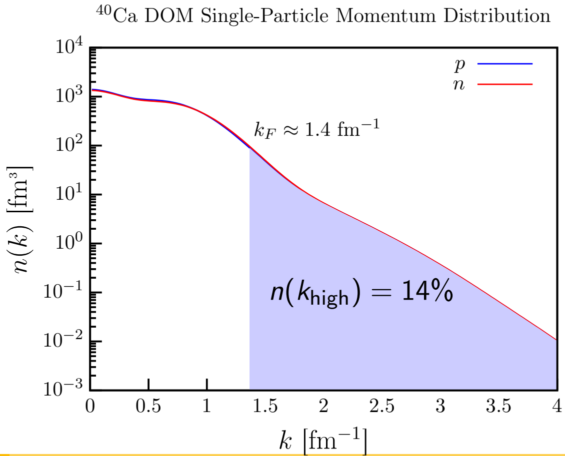
$$n(\boldsymbol{k}) = \int d^3r \int d^3r' e^{i\boldsymbol{k}\cdot(\boldsymbol{r}-\boldsymbol{r}')}\rho(\boldsymbol{r},\boldsymbol{r}')$$



Momentum Distributions

- Short-range correlations (SRC) responsible for this high-momentum content

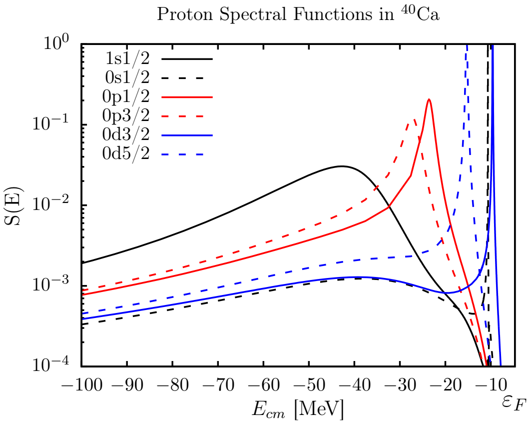
$$n(\boldsymbol{k}) = \int d^3r \int d^3r' e^{i\boldsymbol{k}\cdot(\boldsymbol{r}-\boldsymbol{r}')}\rho(\boldsymbol{r},\boldsymbol{r}')$$

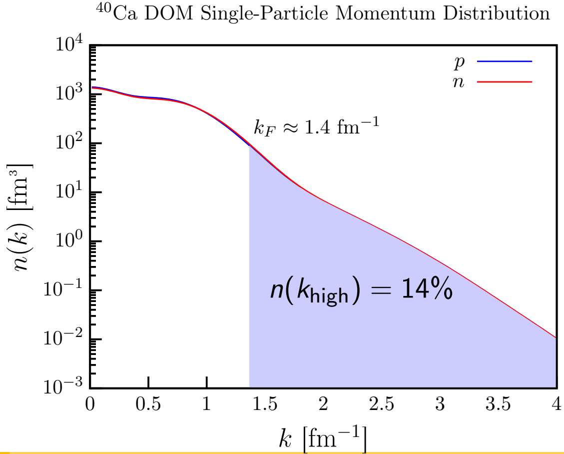


Momentum Distributions

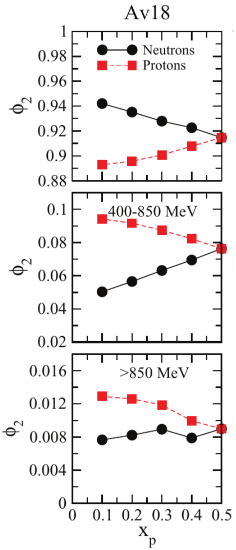
- Short-range correlations (SRC) responsible for this high-momentum content

$$n(\boldsymbol{k}) = \int d^3r \int d^3r' e^{i\boldsymbol{k}\cdot(\boldsymbol{r}-\boldsymbol{r}')}\rho(\boldsymbol{r},\boldsymbol{r}')$$





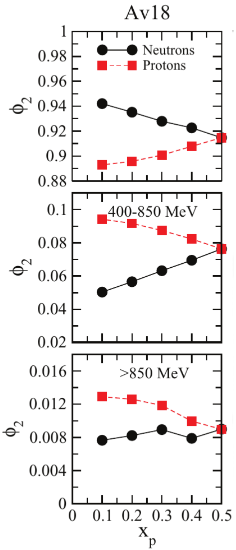
Asymmetry Dependence of High-Momentum Content



A. Rios *et al.*, PRC **89**, 044303 (2014)

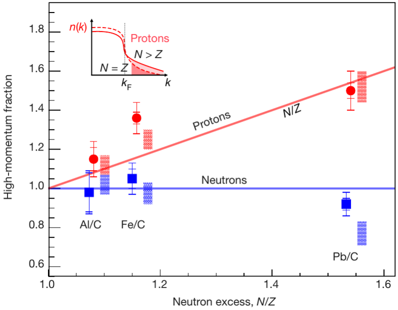
$$\phi_2 = \int_{k_1}^{k_2} dk k^2 n_\tau(k)$$

Asymmetry Dependence of High-Momentum Content



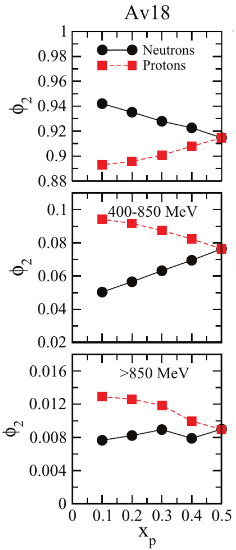
A. Rios *et al.*, PRC **89**, 044303 (2014)

CLAS Collaboration, Nature **560**, 617 (2018)

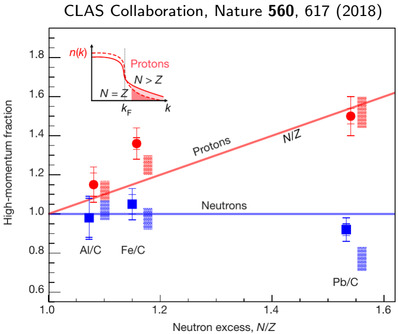


$$\phi_2 = \int_{k_1}^{k_2} dk k^2 n_\tau(k)$$

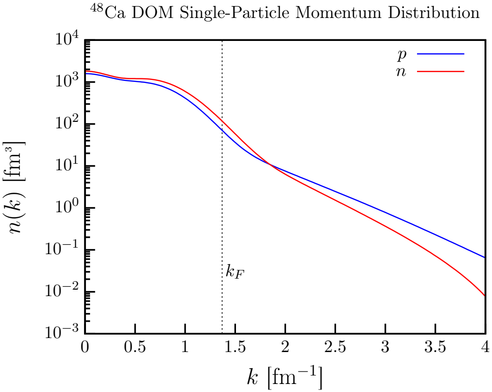
Asymmetry Dependence of High-Momentum Content



A. Rios *et al.*, PRC **89**, 044303 (2014)

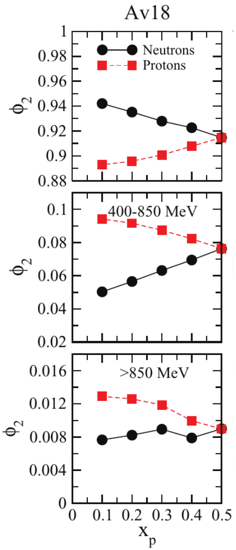


$$\phi_2 = \int_{k_1}^{k_2} dk k^2 n_\tau(k)$$



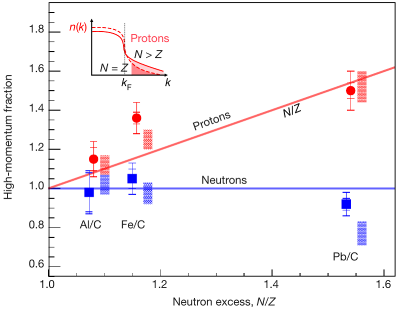
A	n_{high}	p_{high}
^{40}Ca	0.14	0.14
^{48}Ca	0.14	0.156

Asymmetry Dependence of High-Momentum Content

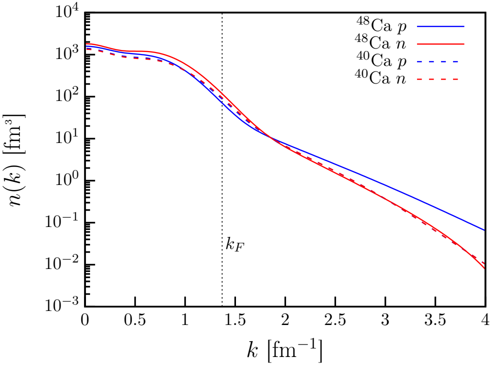


A. Rios *et al.*, PRC **89**, 044303 (2014)

CLAS Collaboration, Nature **560**, 617 (2018)



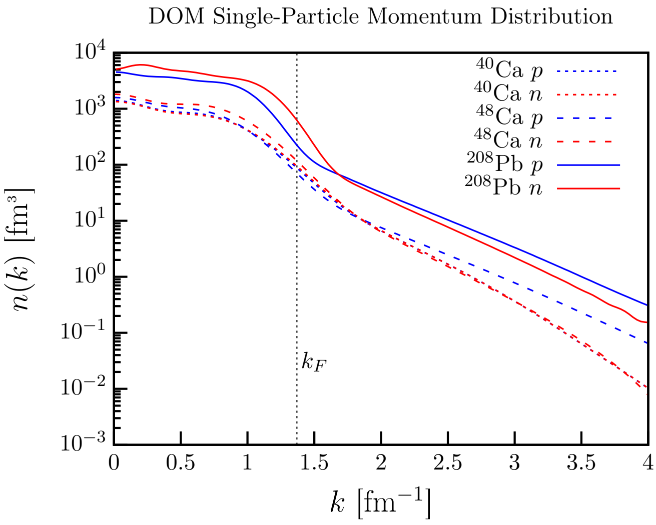
DOM Single-Particle Momentum Distributions



$$\phi_2 = \int_{k_1}^{k_2} dk k^2 n_\tau(k)$$

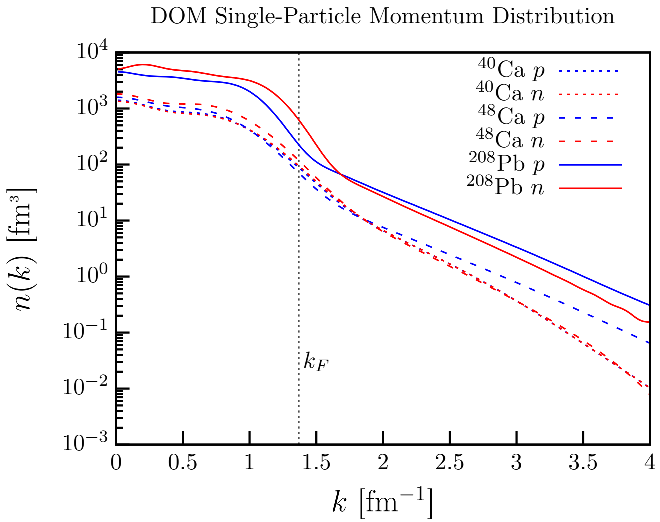
A	n_{high}	p_{high}
^{40}Ca	0.14	0.14
^{48}Ca	0.14	0.156

^{208}Pb Momentum Distribution

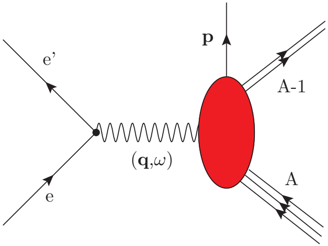


^{208}Pb Momentum Distribution

A	n_{high}	p_{high}
^{40}Ca	0.14	0.14
^{48}Ca	0.14	0.156
^{208}Pb	0.106	0.132

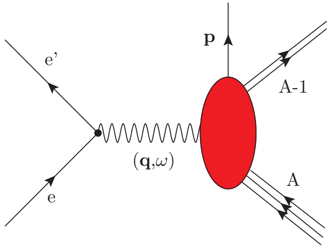


Combining Reaction and Structure with $(e, e'p)$



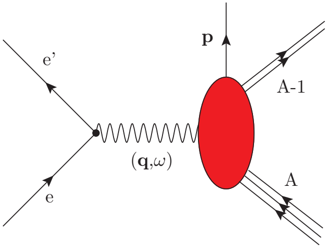
Combining Reaction and Structure with $(e, e'p)$

- $(e, e'p)$ probes the momentum content of nuclei



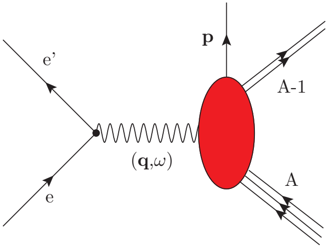
Combining Reaction and Structure with $(e, e'p)$

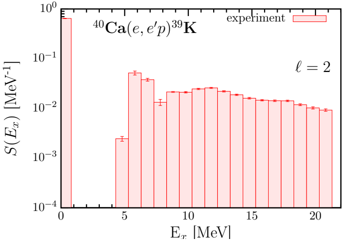
- $(e, e'p)$ probes the momentum content of nuclei
- Excitation spectrum provides evidence of many-body correlations



Combining Reaction and Structure with $(e, e'p)$

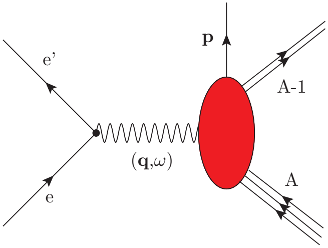
- $(e, e'p)$ probes the momentum content of nuclei
- Excitation spectrum provides evidence of many-body correlations

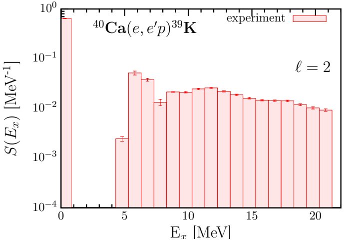




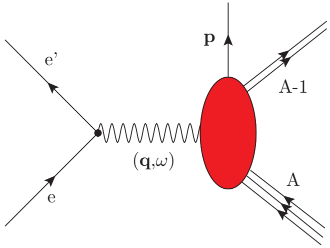
Combining Reaction and Structure with $(e, e'p)$

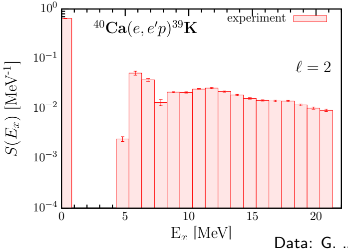
- $(e, e'p)$ probes the momentum content of nuclei
- Excitation spectrum provides evidence of many-body correlations
- Spectroscopic factor, $\mathcal{Z}$, quantifies correlations

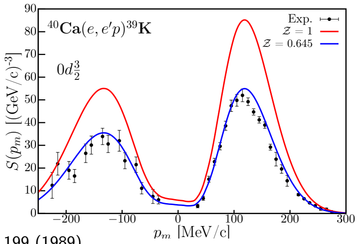




- $(e, e'p)$ probes the momentum content of nuclei
- Excitation spectrum provides evidence of many-body correlations
- Spectroscopic factor, $\mathcal{Z}$, quantifies correlations



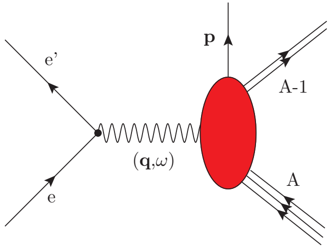


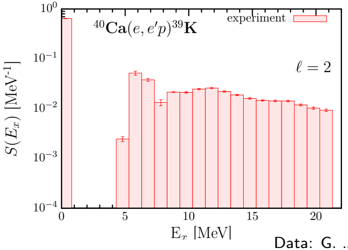


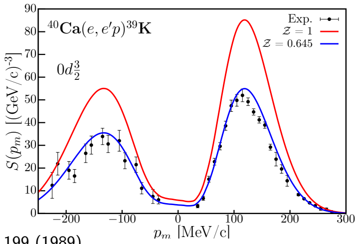
Data: G. .J. Kramer *et al.*, Phys. Lett. B **227**, 199 (1989)

Combining Reaction and Structure with $(e, e'p)$

- $(e, e'p)$ probes the momentum content of nuclei
- Excitation spectrum provides evidence of many-body correlations
- Spectroscopic factor, $\mathcal{Z}$, quantifies correlations
- Distorted-wave impulse approximation for exclusive reaction (C. Giusti's DWEEPY code)

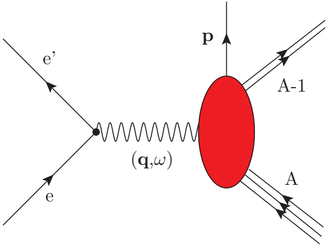




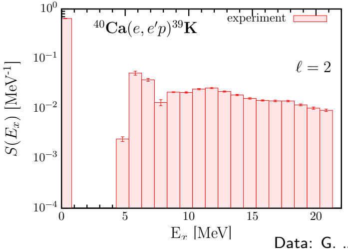


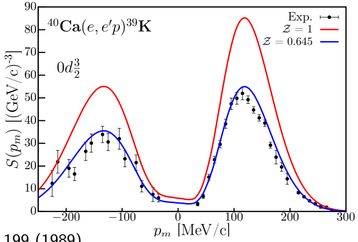
Data: G. .J. Kramer *et al.*, Phys. Lett. B **227**, 199 (1989)

- $(e, e'p)$ probes the momentum content of nuclei
- Excitation spectrum provides evidence of many-body correlations
- Spectroscopic factor, $\mathcal{Z}$, quantifies correlations
- Distorted-wave impulse approximation for exclusive reaction (C. Giusti's DWEEPY code)



$$J^{\mu}(\mathbf{q}) = \int \chi^{(-)*}_{E\alpha}(\mathbf{r}) j^{\mu}(\mathbf{r}) \phi_{E\alpha}(\mathbf{r}) [\mathcal{Z}_{\alpha}(E)]^{1/2} e^{i\mathbf{q}\cdot\mathbf{r}} d^3 r$$

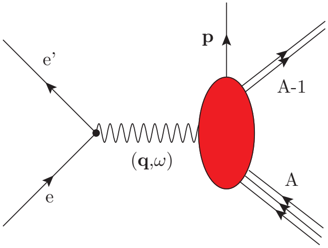




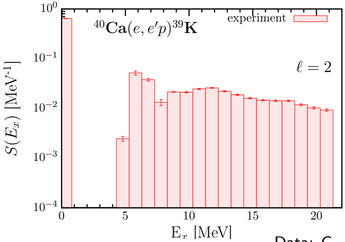
Data: G. J. Kramer *et al.*, Phys. Lett. B **227**, 199 (1989)

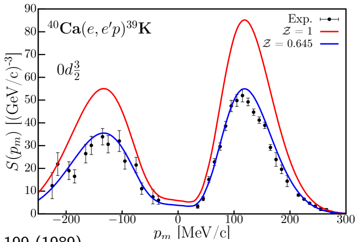
Combining Reaction and Structure with $(e, e'p)$

- $(e, e'p)$ probes the momentum content of nuclei
- Excitation spectrum provides evidence of many-body correlations
- Spectroscopic factor, $\mathcal{Z}$, quantifies correlations
- Distorted-wave impulse approximation for exclusive reaction (C. Giusti's DWEEPY code)
- DOM can provide all ingredients



$$J^\mu(\mathbf{q}) = \int \chi^{(-)*}_{E\alpha}(\mathbf{r}) j^\mu(\mathbf{r}) \phi_{E\alpha}(\mathbf{r}) [\mathcal{Z}_\alpha(E)]^{1/2} e^{i\mathbf{q}\cdot\mathbf{r}} d^3r$$



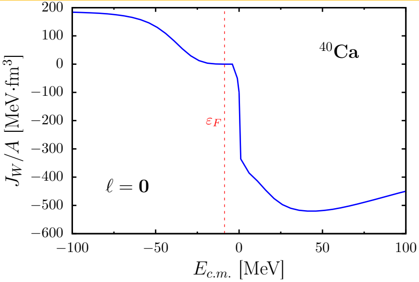


Data: G. .J. Kramer *et al.*, Phys. Lett. B **227**, 199 (1989)

Spectroscopic factor, Occupation, and Depletion

- No imaginary component of Σ^* around ϵ_F

$$J_W^\ell(E) = (4\pi)^2 \int_0^\infty dr r^2 \int_0^\infty dr' r'^2 \mathrm{Im}\{\Sigma_\ell^*(r, r'; E)\}$$



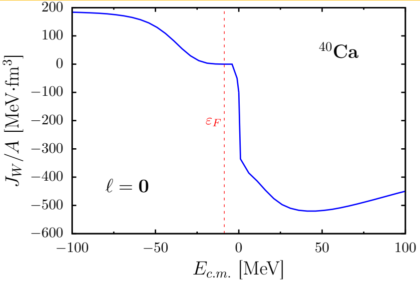
Spectroscopic factor, Occupation, and Depletion

- No imaginary component of Σ^* around ϵ_F

$$J_W^\ell(E) = (4\pi)^2 \int_0^\infty drr^2 \int_0^\infty dr' r'^2 \mathrm{Im}\{\Sigma_\ell^*(r, r'; E)\}$$

- Spectroscopic factor for states near ϵ_F is well defined from Σ^*

$$\mathcal{Z} = \left(1 - \frac{\partial \Sigma^*(\alpha_{qh}, \alpha_{qh}; E)}{\partial E}\bigg|_\epsilon\right)^{-1}$$



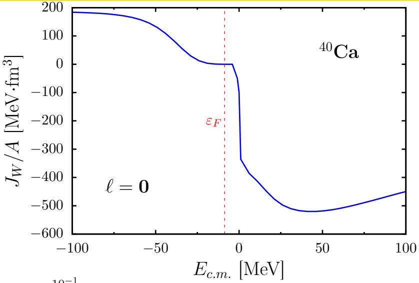
Spectroscopic factor, Occupation, and Depletion

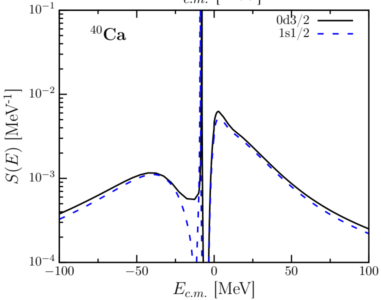
- No imaginary component of Σ^* around ϵ_F

$$J_W^\ell(E) = (4\pi)^2 \int_0^\infty dr r^2 \int_0^\infty dr' r'^2 \text{Im}\{\Sigma_\ell^*(r, r'; E)\}$$

- Spectroscopic factor for states near ϵ_F is well defined from Σ^*

$$\mathcal{Z} = \left(1 - \frac{\partial \Sigma^*(\alpha_{qh}, \alpha_{qh}; E)}{\partial E}\bigg|_\epsilon\right)^{-1}$$





Spectroscopic factor, Occupation, and Depletion

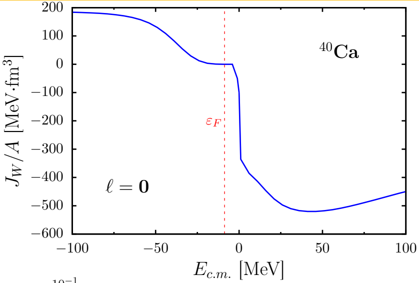
- No imaginary component of Σ^* around ϵ_F

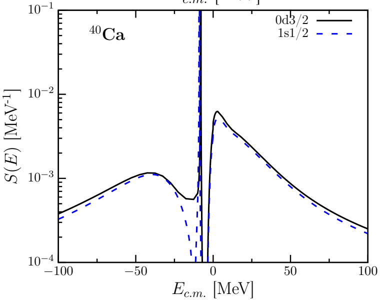
$$J_W^\ell(E) = (4\pi)^2 \int_0^\infty drr^2 \int_0^\infty dr' r'^2 \mathrm{Im}\{\Sigma_\ell^*(r,r';E)\}$$

- Spectroscopic factor for states near ϵ_F is well defined from Σ^*

$$\mathcal{Z} = \left(1 - \left.\frac{\partial \Sigma^*(\alpha_{qh},\alpha_{qh};E)}{\partial E}\right|_\epsilon\right)^{-1}$$

$$n_{n\ell j} = \int_{-\infty}^{\epsilon_f} dE S^h_{n\ell j}(E) \qquad d_{n\ell j} = \int_{\epsilon_f}^{\infty} dE S^p_{n\ell j}(E)$$





Spectroscopic factor, Occupation, and Depletion

- No imaginary component of Σ^* around ϵ_F

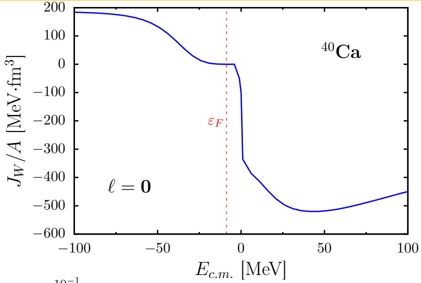
$$J_W^\ell(E) = (4\pi)^2 \int_0^\infty drr^2 \int_0^\infty dr' r'^2 \text{Im}\{\Sigma_\ell^*(r,r';E)\}$$

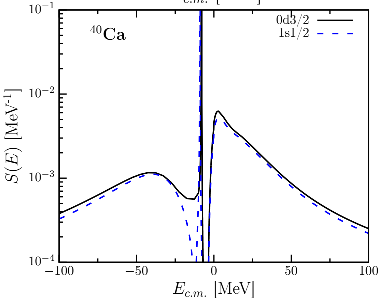
- Spectroscopic factor for states near ϵ_F is well defined from Σ^*

$$\mathcal{Z} = \left(1 - \frac{\partial \Sigma^*(\alpha_{qh},\alpha_{qh};E)}{\partial E}\bigg|_\epsilon\right)^{-1}$$

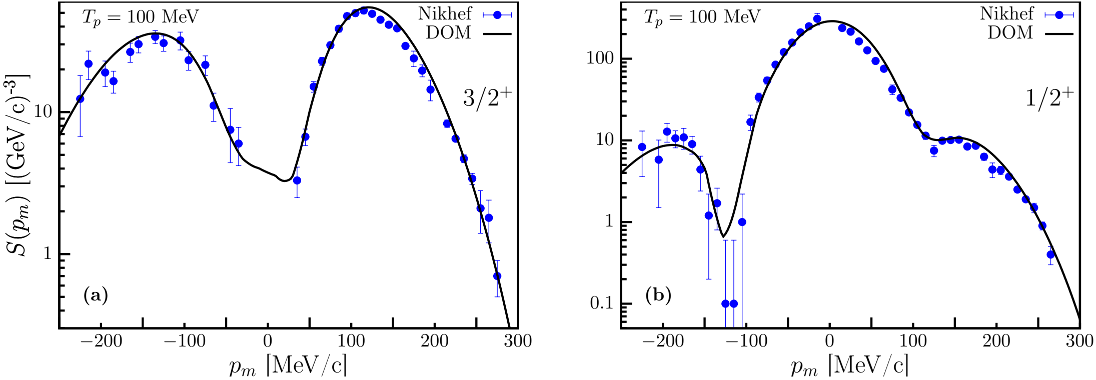
$$n_{n\ell j} = \int_{-\infty}^{\epsilon_f} dE S_{n\ell j}^h(E) \qquad d_{n\ell j} = \int_{\epsilon_f}^{\infty} dE S_{n\ell j}^p(E)$$

Orbital	$\mathcal{Z}$	$n_{n\ell j}$	$d_{n\ell j}$
$0d\frac{3}{2}$	0.71	0.80	0.17
$1s\frac{1}{2}$	0.60	0.82	0.15





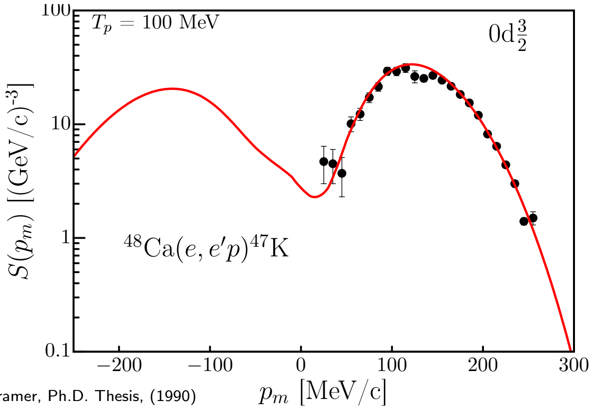
^{40}Ca(e,e'p)^{39}K Momentum Distributions (100 MeV)



T_p=100 MeV	0d$\frac{3}{2}$	1s$\frac{1}{2}$
Kramer *et al.*	0.65 ± 0.06	0.55 ± 0.05
DOM	0.71 ± 0.04	0.60 ± 0.03

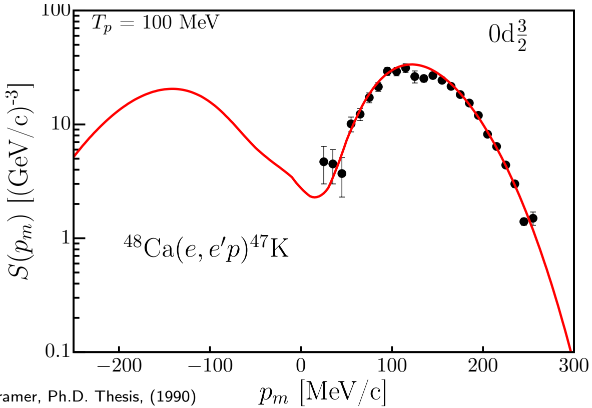
M. Atkinson *et al.*, PRC **98**, 044627 (2018)

^{48}Ca(e,e'p)^{47}K Momentum Distribution



Data: G.J. Kramer, Ph.D. Thesis, (1990)

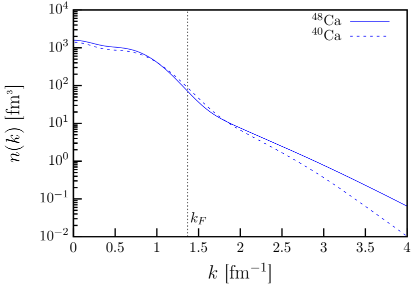
^{48}Ca(e,e'p)^{47}K Momentum Distribution

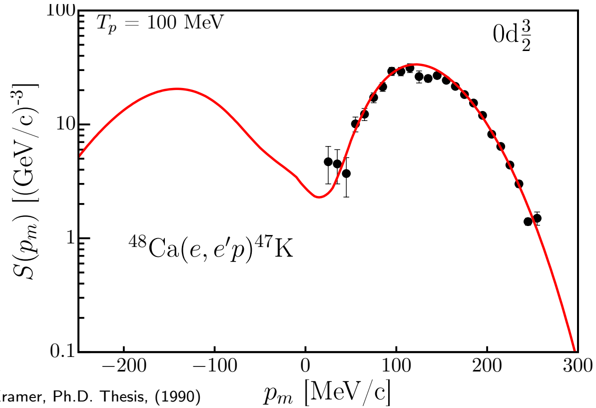


Data: G.J. Kramer, Ph.D. Thesis, (1990)

T_p=100 MeV	0d$\frac{3}{2}$
^{40}Ca	0.71 ± 0.04
^{48}Ca	0.62

^{48}Ca(e,e'p)^{47}K Momentum Distribution

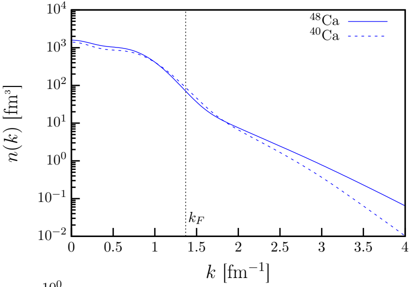


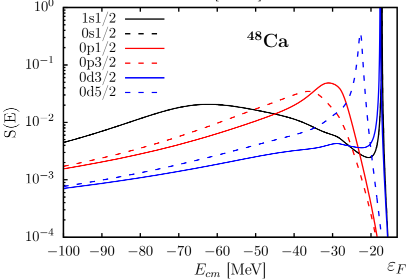


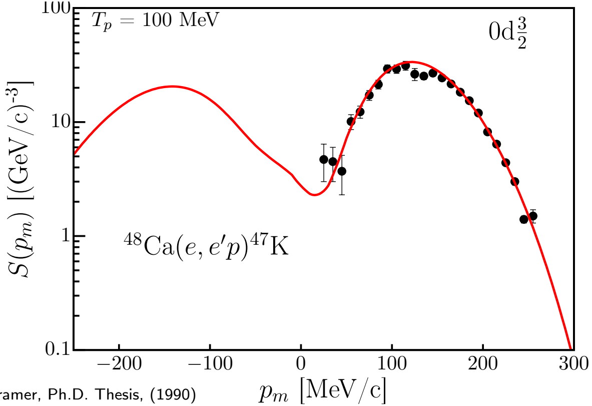
Data: G.J. Kramer, Ph.D. Thesis, (1990)

T_p=100 MeV	0d$\frac{3}{2}$
^{40}Ca	0.71 ± 0.04
^{48}Ca	0.62

^{48}Ca(e,e'p)^{47}K Momentum Distribution







Data: G.J. Kramer, Ph.D. Thesis, (1990)

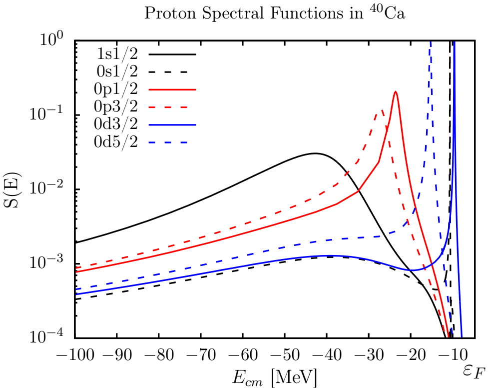
T_p=100 MeV	0d$\frac{3}{2}$
^{40}Ca	0.71 ± 0.04
^{48}Ca	0.62

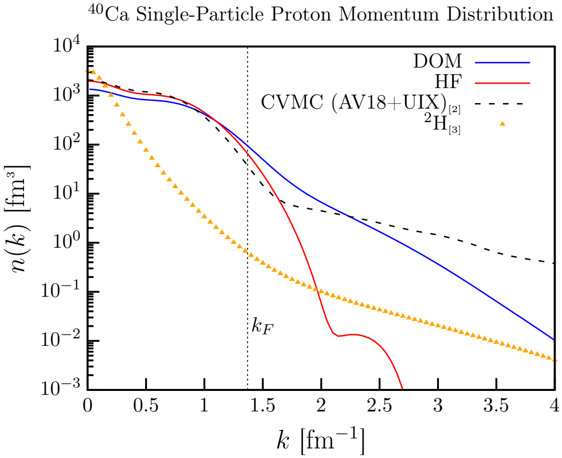
Thanks

- Willem Dickhoff - Advisor
- Robert Charity - DOM and data for DOM
- Henk Blok - $(e, e'p)$ data at Nikhef
- Louk Lapikás - $(e, e'p)$ data at Nikhef
- Carlotta Giusti - DWEEPY Code
- Hossein Mahzoon - DOM
- Lee Sobotka - Data for DOM

Comparing high-k

- Monte-Carlo results borrowed from Bob Wiringa's website[1]





[1] https://www.phy.anl.gov/theory/research/QMCresults.html
[2] R.B. Wiringa *et al.*, PRC **89**, 024305 (2014)
[3] D. Lonardoni *et al.*, PRC **96**, 024326 (2017)