Determination of the Argon Spectral Functions at JLab

Omar Benhar*
INFN, Sezione di Roma. I-00185 Roma, Italy

*On behalf of the Jefferson Lab E12-14-012 Collaboration

NuInt 2024
14th International Workshop on Neutrino-Nucleus Interactions
Principia Institute, São Paulo, Brazil
April 15-20, 2024

Outline

- The nuclear spectral function
  - Definition and physical interpretation
  - Experimental determination from the $(e, e'p)$ cross section
    - Plane Wave Impulse Approximation (PWIA)
    - Factorisation of the nuclear cross sections
    - Corrections: Final State Interactions and processes involving two-nucleon currents (MEC)
- The E12-14-012 Experiment at Jefferson Lab
  - Measurements of the ${}^{40}_{18}\mathrm{Ar}(e, e'p)$ and ${}^{48}_{22}\mathrm{Ti}(e, e'p)$ cross sections
  - Data analysis
- Applications
- Outlook

The Nuclear spectral function

- ⋆ fundamental quantity describing single-particle dynamics in interacting many-particle systems

- ⋆ trivially related to the two-point Green's function through

$$P(\mathbf{k}, E) = -\frac{1}{\pi} \mathrm{Im}\, G(\mathbf{k}, E)$$

implying

$$P(\mathbf{k}, E) = \sum_n |\langle (A-1)_n | a_{\mathbf{k}} | A_0 \rangle|^2 \delta(E + E_n - E_0)$$

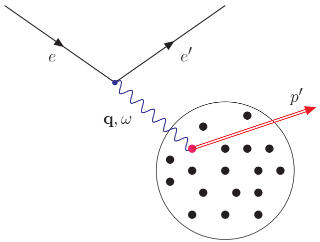
- ⋆ describes the probability of removing a nucleon of momentum $\mathbf{k}$ from the nuclear ground state leaving the residual system with excitation energy $E = E_0 - E_{\rm thr}$, $E_{\rm thr}$ being the nucleon emission threshold

THE $(e, e'p)$ REACTION

- Consider the process $e + A \to e' + p + (A - 1)$ in which both the outgoing electron and the proton, carrying momentum p', are detected in coincidence, and the recoiling nucleus can be left in either a bound or a continuum state

  Define missing momentum and missing energy

$$\mathbf{p}_m = \mathbf{p}' - \mathbf{q}$$
$$E_m = \omega - T_{\mathbf{p}'} - T_{A-1}$$
$$\approx \omega - T_{\mathbf{p}'}$$



- Within the Plane Wave Impulse Approximation (PWIA), which amounts to assuming that Final State Interactions (FSI) be negligible, the *measured* $\mathbf{p}_m$ and E_m can be identified with the initial energy and momentum of the knocked-out nucleon, the distribution of which is described by the target spectral function

FACTORISATION OF THE $(e, e'p)$ CROSS SECTION

- under the assumptions
  - $J_A^\mu(q) \approx \sum_i j_i^\mu(q)$ (single nucleon coupling)
  - $|X\rangle \approx |(A-1)_n, \mathbf{p_n}\rangle \otimes |\mathbf{p}'\rangle$ $|(A-1)_n, \mathbf{p}'\rangle \approx |(A-1)_n\rangle \otimes |\mathbf{p}'\rangle$ (factorization of the final state)

  expected to be valid at large momentum transfer, the nuclear transition amplitude reduces the simple form

$$\langle (A-1)_n, \mathbf{p}'|J_A^\mu|0\rangle \to \sum_i M_n(\mathbf{k})\langle \mathbf{p}'|j_i^\mu|\mathbf{k}\rangle$$

- The nuclear amplitude M_n is independent of momentum transfer, and can be accurately calculated using many-body theory and a state-of-the-art model of the nuclear Hamiltonian
- The matrix element of the current between free-nucleon states can be computed using the fully relativistic expression. Constrained by proton and deuteron data
- The resulting $(e, e'p)$ cross section takes the simple and transparent form

$$\frac{d\sigma_A}{dE_{e'} d\Omega_{e'} dE_p d\Omega_p} \propto \sigma_{ep} P(p_m, E_m)$$

COMMENTS OF FACTORISATION AND THE SPECTRAL FUNCTION

- ⋆ The y-scaling analysis of inclusive data provides clear cut and model independent evidence of factorisation of the eA cross section

- ⋆ The spectral function is an intrinsic property of the target, independent of both the nature of the beam particle and the kinematics of the scattering process

- ⋆ To the extent to which FSI and interactions involving two-nucleon currents can be treated as corrections, the spectral function formalism can be used to describe any

$$e + A \to e' + X \quad , \quad \nu_\ell + A \to \ell + X$$

processes, provided a reliable description of the elementary cross sections σ_{eN} and $\sigma_{\nu N}$ is available

ANALYTIC STRUCTURE OF $P(\mathbf{k}, E)$ AND CORRELATIONS

- The analytic structure of the spectral function is dictated by the Källèn-Lehman representations of the Green's function

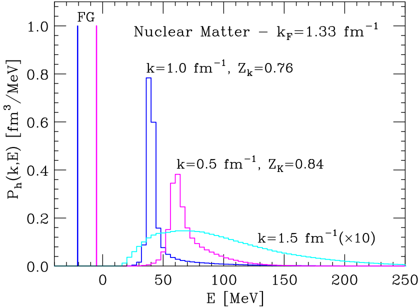
$$P(\mathbf{k}, E) = \sum_{h \in \{F\}} Z_h |M_h(\mathbf{k})|^2 F_h(E - E_h) + P_B(\mathbf{k}, E)$$

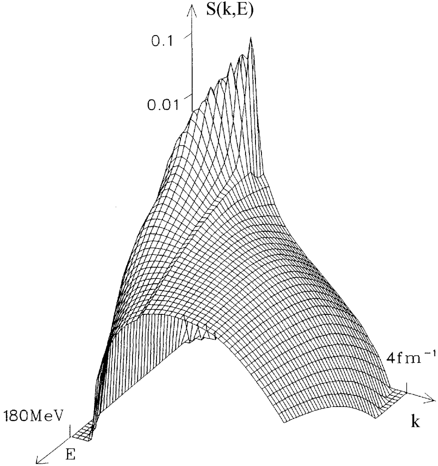
  $F_h(E - E_h)$ features a collection of peaks of width Γ_h, located at energies $E = E_h$ corresponding to the poles of $G(\mathbf{k}, E)$.

- In independent-particle models based on the mean-field approximation (MFA) such as the nuclear shell model
  - Spectroscopic factors $Z_h \to 1$
  - $M_h(\mathbf{k}) = \langle h | a_{\mathbf{k}} | 0 \rangle \to \phi_h(\mathbf{k})$, the momentum-space wave function of the single-particle state h
  - Energy distribution $F_h(E - E_h) \to \delta(E - E_h)$
  - Smooth contribution $P_B(\mathbf{k}, E) \to 0$. Correlation effects not taken into account in MFA

$P(\mathbf{k}, E)$ OF ISOSPIN-SYMMETRIC NUCLEAR MATTER

Equilibrium density, full microscopic calculation based on a realistic nuclear Hamiltonian



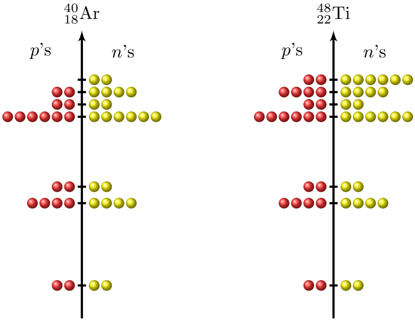


- The spectral functions of many medium-heavy nuclei have been obtained from the analysis of $(e, e'p)$ cross sections within the Distorted-Wave-Impulse-Approximation (DWIA)

The E12-14-012 Experiment at Jefferson Lab

Why Argon and Titanium?

- ⋆ The proton and neutron spectral functions of Argon are both needed, to describe neutrino and antineutrino interactions in liquid Argon detectors
- ⋆ The Ar$(e, e'p)$ cross section only provides information on protons
- ⋆ Useful information on the neutron energy and momentum distribution can be obtained from Ti$(e, e'p)$ data, by exploiting the similarity between the proton spectrum of $^{48}_{22}$Ti and the neutron spectrum of $^{40}_{18}$Ar



⋆ Experiment E12-14-012—approved by PAC42 in 2014—measured the $^{40}_{18}\mathrm{Ar}(e, e'p)$ and $^{48}_{22}\mathrm{Ti}(e, e'p)$ cross sections in Jefferson Lab Hall A
Data were collected in February and March 2017

Measurement of the Spectral Function of ^{40}Ar through the (e, e′p) reaction

Proposal (PR12-14-012) submitted to the
Jefferson Lab Program Advisory Committee PAC 42
July 2014

O. Benhar[a] and G.M. Urciuoli
INFN and Department of Physics, "Sapienza" Università di Roma, I-00185 Roma, Italy

C. Mariani[ab], C.-M. Jen[a], J. M. Link, and M. L. Pitt
Center for Neutrino Physics, Virginia Tech, Blacksburg, VA, 24061, USA

D. B. Day[a], D. G. Crabb, D. Keller, R. Lindgren, N. Liyanage, O. A. Rondon, and J. Zhang
Department of Physics, University of Virginia, Charlottesville, VA, 22904, USA

D. W. Higinbotham[a], D. Gaskell, O. Hansen,
C. E. Keppel, L. Myers, B. Sawatzky, and S. Wood
Thomas Jefferson National Accelerator Facility, Newport News, VA, 23606, USA

A. Ankowski and M. Sakuda
Department of Physics, Okayama University, Okayama 700-8530, Japan

C. Giusti and A. Meucci
Department of Physics and INFN, University of Pavia, I-27100 Pavia, Italy

G. Garvey, X. Jiang, and G. B. Mills
Los Alamos National Laboratory, Los Alamos, NM, 87545, USA

P. A. Souder, R. Holmes, and R. Beminiwattha
Department of Physics, Syracuse University, Syracuse, NY, 13210, USA

(Dated: March 30, 2016)

[a] Spokesperson
[b] Contact Person, email: mariani@vt.edu

1

Publications & Theses

- H. Dai *et al.*, Phys. Rev. C **98**, 014617 (2018)
- H. Dai *et al.*, Phys. Rev. C **99**, 054608 (2019)
- M. Murphy *et al.*, Phys. Rev. C **100**, 054606 (2019)
- L. Gu *et al.*, Phys. Rev. C **103**, 034604 (2021)
- L. Jiang *et al.*, Phys. Rev. D **105**, 112002 (2022)
- L. Jiang *et al.*, Phys. Rev. D **107**, 012025 (2023)

- 4 PhD Theses (3 @ VT + 1 @ UVA)

- ⋆ Argon & Titanium target
- ⋆ Beam energy $E_e = 2.222$ GeV; parallel kinematics
- ⋆ Five kinematic settings

	E'_e (GeV)	θ_e (deg)	$\|\mathbf{p}'\|$ (MeV)	$\theta_{p'}$ (deg)	$\|\mathbf{q}\|$ (MeV)	p_m (MeV)	E_m (MeV)
kin1	1.777	21.5	915	−50.0	865	50	73
kin2	1.716	20.0	1030	−44.0	846	184	50
kin3	1.799	17.5	915	−47.0	741	174	50
kin4	1.799	15.5	915	−44.5	685	230	50
kin5	1.716	15.5	1030	−39.0	730	300	50

kin1

Collected Data	Hours	Events(k)
Ar	29.6	43955
Ti	12.5	12755
Dummy	0.75	955

kin3

Collected Data	Hours	Events(k)
Ar	13.5	73176
Ti	8.6	28423
Dummy	0.6	2948

kin2

Collected Data	Hours	Events(k)
Ar	32.1	62981
Ti	18.7	21486
Dummy	4.3	5075
Optics	1.15	1245
C	2.0	2318

kin4

Collected Data	Hours	Events(k)
Ar	30.9	158682
Ti	23.8	113130
Dummy	7.1	38591
Optics	0.9	4883
C	3.6	21922

kin5

Collected Data	Hours	Events(k)
Ar	12.6	45338
Ti	1.5	61
Dummy	5.9	16286
Optics	2.9	160

kin5 - Inclusive

Collected Data	Minutes	Events(k)
Ar	57	2928
Ti	50	2993
Dummy	56	3235
C	115	3957

- ⋆ Overall kinematic coverage

$$15 \leq p_m \leq 300 \text{ MeV} \quad , \quad 12 \leq E_m \leq 80 \text{ MeV}$$

Determination of the Target Spectral Function

- The reduced measured cross-section defined as

$$P_D(p_m, E_m) = \frac{1}{|\mathbf{p}'|E_{\mathbf{p}'}} \frac{1}{\sigma_{ep}} \frac{d\sigma_A}{dE_{e'} d\Omega_{e'} dE_p d\Omega_p} \ ,$$

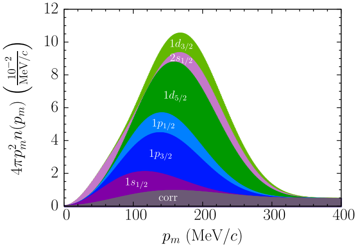
  obtained using the off-shell extrapolation of the electron-proton cross section of De Forest (cc1 model), has been fitted using the model *distorted* spectral function

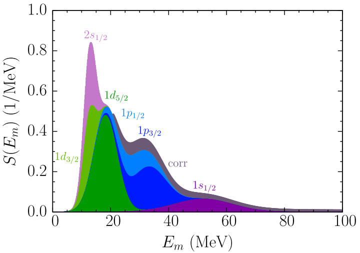
$$P_D(p_m, E_m) = \sum_h Z_h |\phi_h^D(\mathbf{p}_m)|^2 F_h(E_m - E_h) + P^D_{\rm corr}(p_m, E_m) \ ,$$

- The unit normalised distorted momentum distributions, $|\phi_h^D(\mathbf{p}_m, \mathbf{p})|^2$ are obtained from Relativistic Mean Field calculations (code provided by Carlotta Giusti)
- The energy distributions $F_h(E_m - E_h)$, of width Γ_h, have been assumed to have Maxwell-Boltzmann shape
- Correlation contribution, accounting for 20% of the strength, described following a simple model developed by Ciofi degli Atti & SImula

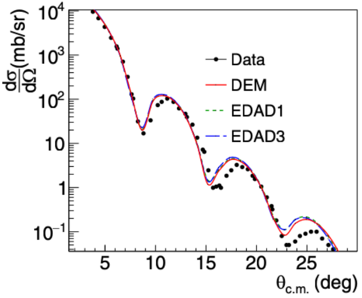
Main Elements of the Argon Analysis

Missing momentum (top) and missing energy (bottom) distributions





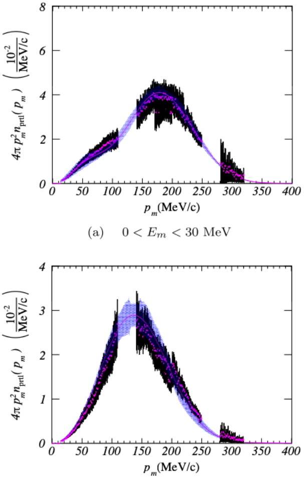
Differential cross section for elastic scattering of 800 MeV protons on Argon. Theoretical results obtained from the optical potential employed in the analysis



Step 1: Analysis of Momentum Distribution

- ⋆ The spectroscopic factors have been determined from momentum distributions—obtained from integration over three missing energy ranges—using constraints from previous experiments

		All priors	w/o p_m	w/o corr.
α	N_α		S_α	
$1d_{3/2}$	2	0.89 ± 0.11	1.42 ± 0.20	0.95 ± 0.11
$2s_{1/2}$	2	1.72 ± 0.15	1.22 ± 0.12	1.80 ± 0.16
$1d_{5/2}$	6	3.52 ± 0.26	3.83 ± 0.30	3.89 ± 0.30
$1p_{1/2}$	2	1.53 ± 0.21	2.01 ± 0.22	1.83 ± 0.21
$1p_{3/2}$	4	3.07 ± 0.05	2.23 ± 0.12	3.12 ± 0.05
$1s_{1/2}$	2	2.51 ± 0.05	2.05 ± 0.23	2.52 ± 0.05
Corr.	0	3.77 ± 0.28	3.85 ± 0.25	Excluded
$\sum_\alpha S_\alpha$		17.02 ± 0.48	16.61 ± 0.57	14.12 ± 0.42
d.o.f		206	231	232
χ^2/d.o.f.		1.9	1.4	2.0



(a) $0 < E_m < 30$ MeV

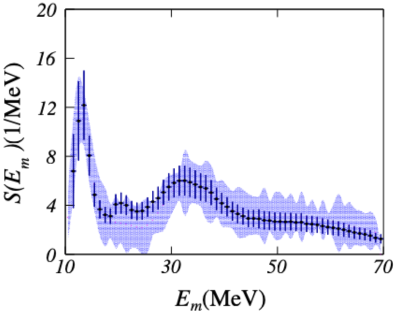
(b) $30 < E_m < 54$ MeV

Step 2: Analysis of Missing Energy Distribution

⋆ The energies and widths of the shell-model states have been determined from the missing energy distributions, using the priors obtained from the momentum distribution analysis

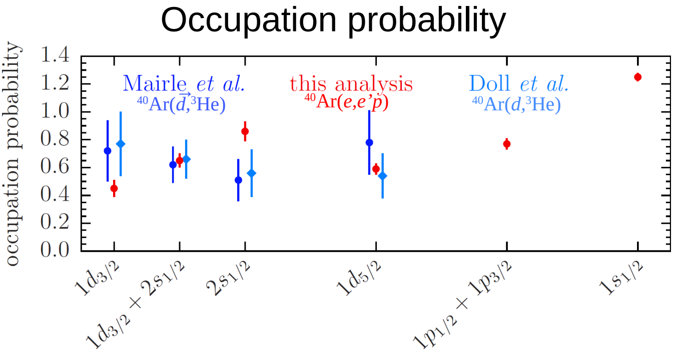
	E_α (MeV)		σ_α (MeV)	
α	w/ priors	w/o priors	w/ priors	w/o priors
$1d_{3/2}$	12.53 ± 0.02	10.90 ± 0.12	1.9 ± 0.4	1.6 ± 0.4
$2s_{1/2}$	12.92 ± 0.02	12.57 ± 0.38	3.8 ± 0.8	3.0 ± 1.8
$1d_{5/2}$	18.23 ± 0.02	17.77 ± 0.80	9.2 ± 0.9	9.6 ± 1.3
$1p_{1/2}$	28.8 ± 0.7	28.7 ± 0.7	12.1 ± 1.0	12.0 ± 3.6
$1p_{3/2}$	33.0 ± 0.3	33.0 ± 0.3	9.3 ± 0.5	9.3 ± 0.5
$1s_{1/2}$	53.4 ± 1.1	53.4 ± 1.0	28.3 ± 2.2	28.1 ± 2.3
Corr.	24.1 ± 2.7	24.1 ± 1.7	…	…

$15 \leq p_m \leq 110$ MeV



Comparison with Previous Argon Data

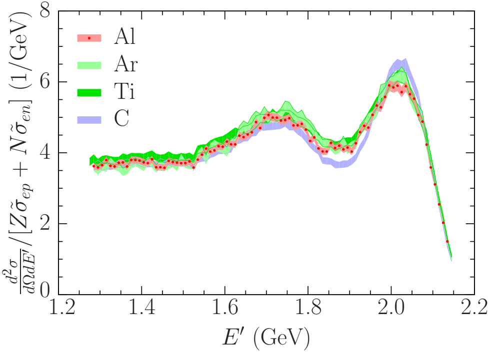
- Nucleon knock-out from Argon has been also studied in the proton pick-up reaction $^{40}Ar(^{2}H,^{3}He)$ using both inpolarised and polarised deuteron beams



- The results of present analysis turn out to be largely compatible with previous data (figure courtesy of A. Ankowski)

Applications: Inclusive Cross Sections

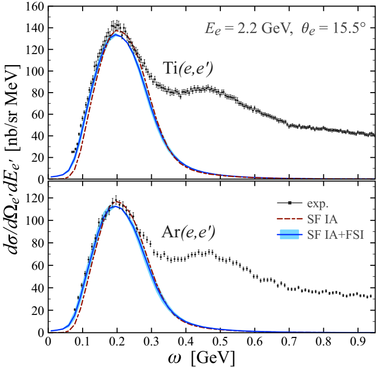
- inclusive data have been collected at beam energy $E = 2.22$ GeV and electron scattering angle $\theta_e = 15.54$ deg using different targets.
  H. Dai *et al.*, PRC **98**, 014617 (2018); PRC **99**, 054608 (2019)
  M. Murphy *et al.*, PRC **100**, 054606 (2019)



- Consistency with previous inclusive data confirmed by y-scaling and superscaling analyses

Comparison to the Results of Theoretical Studies

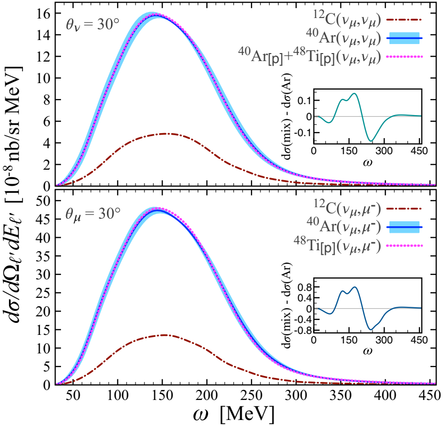
- The proton and neutron spectral functions of ^{40}Ar and ^{48}Ti have been calculated by C. Barbieri, N. Rocco, and G. Somà using the self-consistent Green's function formalism and a chiral nuclear Hamiltonian [PRC **100**, 062501(R) (2019)]



- Position and width of the quasi elastic peak are described to remarkable accuracy

Comparing Argon and Titanium

- Theoretical calculations of Barbieri *et al.* [PRC **100**, 062501(R) (2019)]



- Results obtained by replacing the neutron spectral function of ^{40}Ar with the experimentally accessible proton spectral function of ^{48}Ti are quite encouraging.

IMPLEMENTATION IN NUWRO

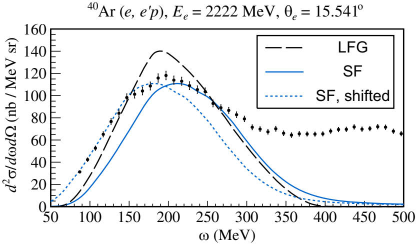
- First implementation of the Argon spectral functions obtained from the JLab data [PRD **109**, 073004 (2024)]

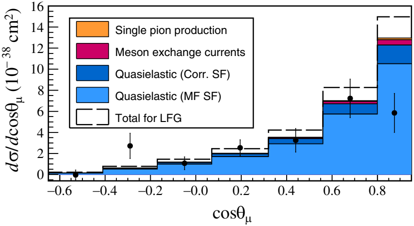
PHYSICAL REVIEW D **109**, 073004 (2024)

JLab spectral functions of argon in NuWro and their implications for MicroBooNE

Rwik Dharmapal Banerjee, Artur M. Ankowski,* Krzysztof M. Graczyk, Beata E. Kowal,
Hemant Prasad, and Jan T. Sobczyk
Institute of Theoretical Physics, University of Wrocław, plac Maxa Borna 9, 50-204, Wrocław, Poland

(Received 21 December 2023; accepted 6 March 2024; published 8 April 2024)



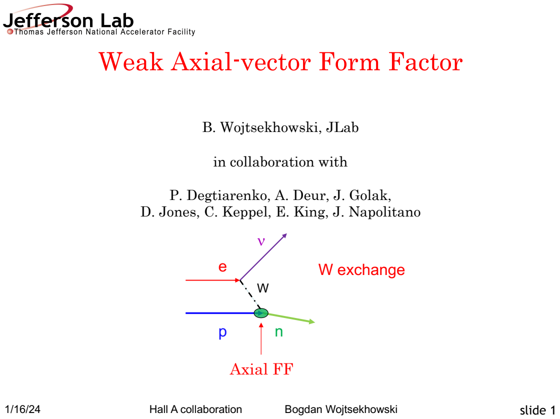


Summary & Outlook

- The Ar and Ti$(e, e'p)$ cross-sections measured at Jefferson Lab by the E12-14-012 collaboration have allowed a reliable determination of the Argon and Titanium spectral functions
- In addition to being interesting in their own right, the information obtained from JLab data —e.g. spectroscopic factors and width of the single-nucleon states—will be useful to derive *realistic* spectral functions from *simplified* nuclear models
- The results of early applications of the E12-14-012 data set—including theoretical studies of the inclusive cross sections, and analyses of electron and neutrino data based on the implementation in NuWro—are encouraging
- The extent to which a proton in Titanium is a good proxy for a neutron in Argon, as well as the feasibility of a neutron knockout experiment, need to be carefully investigated
- Electron scattering experiments may provide new insight into other outstanding issues, such as the determination of the nucleon axial form factor

Measurement of the Axial Form Factor at JLab

- Bogdan Wojtsekhowski's talk at the Winter Hall A Collaboration Meeting at JLab (January 16-17, 2024)

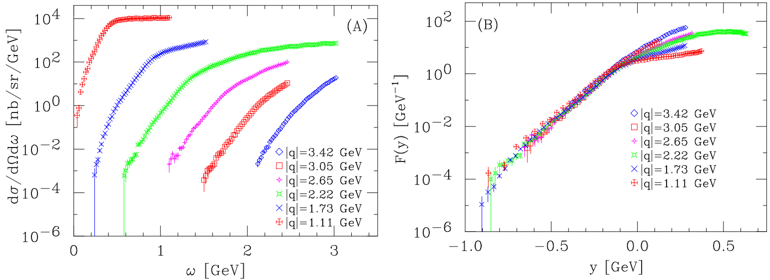


- Studies aimed at submitting a proposal to the JLab PAC are under way

Backup slides

y-SCALING OF INCLUSIVE DATA

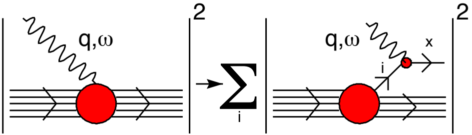
- JLab data of Arrington *et al.*, PRL **82**, 2056 (1999). Iron target evidence of factorisation of the eA cross section. PRL **82**, 2056 (1999)



- in the kinematical region in which scaling is observed the dominant reaction mechanism is quasi elastic single-nucleon knock out. Scaling violations originate from inelastic processes (at $y > 0$) and FSI (at $y \ll 0$)

Factorisation of the Nuclear Cross Section

- ⋆ In the PWIA regime, corresponding to $\lambda \ll d_{\rm NN} \sim 1.5$ fm , nuclear scattering reduces to the incoherent sum of scattering processes involving individual nucleons



- ⋆ Basic assumptions
  - ▷ $J^\mu_A(q) \approx \sum_i j^\mu_i(q)$ (single-nucleon coupling)
  - ▷ $|(A-1)_n, \mathbf{p}'\rangle \approx |(A-1)_n\rangle \otimes |\mathbf{p}'\rangle$ (factorization of the final state)
- ⋆ As a zero-th order approximation, Final State Interactions (FSI) and processes involving two-nucleon Meson-Exchange Currents (MEC) are neglected. Their effects are included as corrections.

The Factorised $(e, e'p)$ cross section

- Factorisation allows to rewrite the nuclear transition amplitude in the simple form

$$\langle (A-1)_n, \mathbf{p}' | J_A^\mu | 0 \rangle \to \sum_i M_n(\mathbf{k}) \langle \mathbf{p}' | j_i^\mu | \mathbf{k} \rangle$$

  - The nuclear amplitude M_n is independent of momentum transfer
  - The matrix element of the current between free-nucleon states can be computed using the fully relativistic expression

- $(e, e'p)$ cross section

$$\frac{d\sigma_A}{dE_{e'} d\Omega_{e'} dE_p d\Omega_p} \propto \sigma_{ep} P(p_m, E_m)$$

- The spectral function describing the probability of removing a nucleon of momentum $\mathbf{p}$ from the nuclear ground state, leaving the residual system with excitation energy E, is trivially related to the two-point Green's function through

$$P(\mathbf{k}, E) = -\frac{1}{\pi} \mathrm{Im}\, G(\mathbf{k}, E)$$

FSI corrections within the DWIA

- The effects of FSI are described by a *distorted* mean-field spectral function

$$P^D_{MF}(\mathbf{p}_m, \mathbf{p}, E_m) = \sum_h Z_h |\phi^D_h(\mathbf{p}_m, \mathbf{p})|^2 F_h(E_m - E_h)$$

$$\sqrt{Z_h}\, \phi^D_h(\mathbf{p}_m, \mathbf{p}) = \int d^3p_i\, \chi^\star_p(\mathbf{p}_i + \mathbf{q}) \phi_h(\mathbf{p}_i)$$

where the *distorted wave* $\chi^\star_p(\mathbf{p}_i + \mathbf{q})$ is obtained from a *complex* optical potential

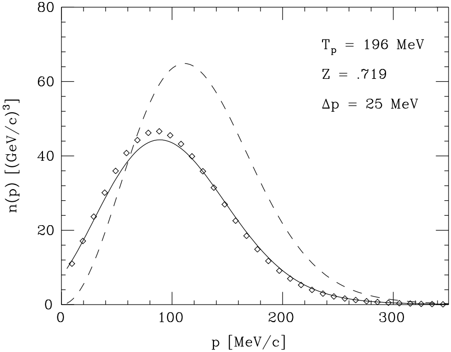
- The analysis of the large body of $(e, e'p)$ data shows that the effects of FSI can be strongly suppressed by measuring the cross section in *parallel kinematics*, that is with $\mathbf{p} \parallel \mathbf{q}$.
- In parallel kinematics, factorisation of the nuclear cross section is preserved to very high accuracy, the distorted momentum distribution only depends on missing momentum

$$n^D_h(p_m) = Z_h\, |\phi^D(p_m)|^2\ ,$$

and the effects of FSI can be easily identified

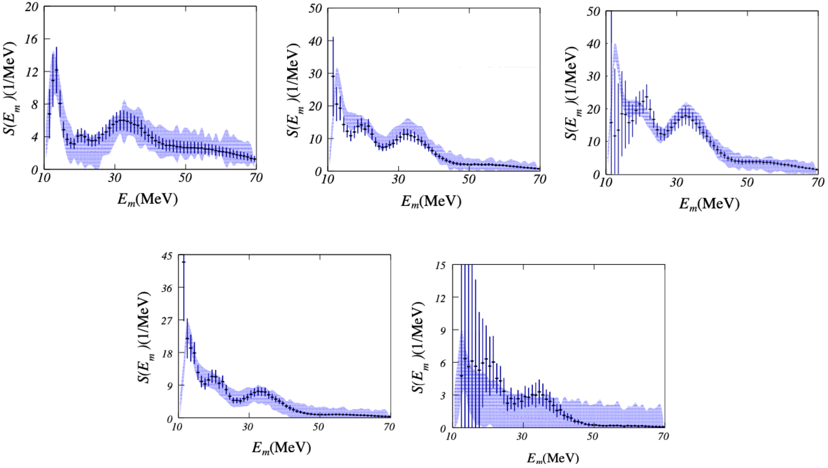
Distorted Momentum Distribution

- consider knock out of a p-shell proton with kinetic energy $T_p = 196$ MeV in parallel kinematics
- Distortion described by a *complex* optical potential (OP)

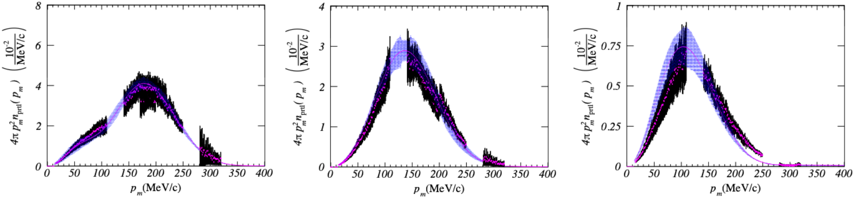


- FSI lead to a shift in missing momentum (real part of OP), and a significant quenching, typically by a factor ~ 0.7 (imaginary part of OP).

Argon Missing Energy Distributions



ARGON MISSING MOMENTUM DISTRIBUTIONS

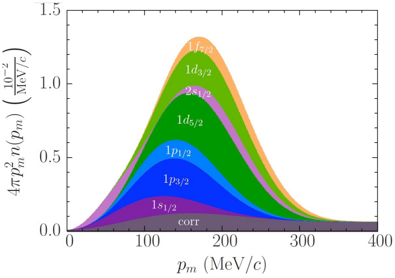


(a) $0 < E_m < 30$ MeV (b) $30 < E_m < 54$ MeV (c) $54 < E_m < 90$ MeV

⋆ The agreement—within uncertainty—between distributions corresponding to different kinematical settings supports the validity of the DWIA treatment of FSI, and, more generally, of factorisation

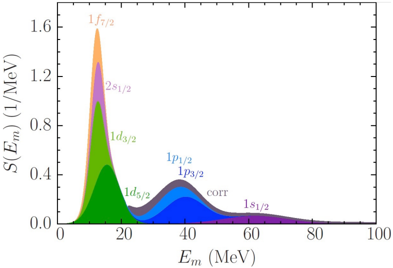
Titanium Missing Momentum Distributions

		all priors	w/o p_m	w/o corr.
α	N_α		S_α	
$1f_{7/2}$	2	1.53 ± 0.25	1.55 ± 0.28	1.24 ± 0.22
$1d_{3/2}$	4	2.79 ± 0.37	3.15 ± 0.54	3.21 ± 0.37
$2s_{1/2}$	2	2.00 ± 0.11	1.78 ± 0.46	2.03 ± 0.11
$1d_{5/2}$	6	2.25 ± 0.16	2.34 ± 0.19	3.57 ± 0.29
$1p_{1/2}$	2	2.00 ± 0.20	1.80 ± 0.27	2.09 ± 0.19
$1p_{3/2}$	4	2.90 ± 0.20	2.92 ± 0.20	4.07 ± 0.15
$1s_{1/2}$	2	2.14 ± 0.10	2.56 ± 0.30	2.14 ± 0.11
corr.	0	4.71 ± 0.31	4.21 ± 0.46	excluded
$\sum_\alpha S_\alpha$		20.32 ± 0.65	20.30 ± 1.03	18.33 ± 0.59
d.o.f		121	153	125
χ^2/d.o.f.		0.95	0.71	1.23



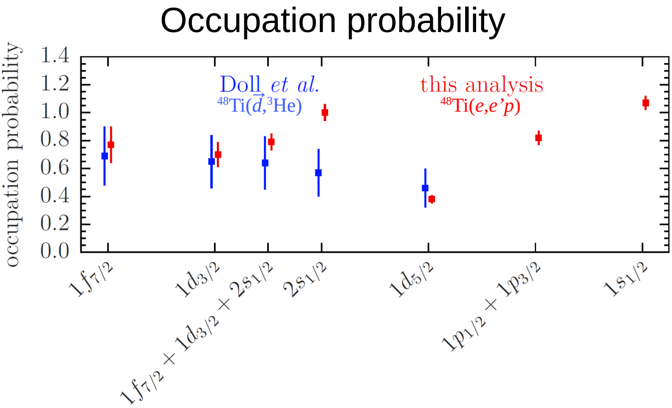
Titanium Missing Energy Distributions

	E_α (MeV)		σ_α (MeV)	
α	w/ priors	w/o priors	w/ priors	w/o priors
$1f_{7/2}$	11.32 ± 0.10	11.31 ± 0.10	8.00 ± 5.57	8.00 ± 6.50
$1d_{3/2}$	12.30 ± 0.24	12.33 ± 0.24	7.00 ± 0.61	7.00 ± 3.84
$2s_{1/2}$	12.77 ± 0.25	12.76 ± 0.25	7.00 ± 3.76	7.00 ± 3.84
$1d_{5/2}$	15.86 ± 0.20	15.91 ± 0.22	2.17 ± 0.27	2.23 ± 0.29
$1p_{1/2}$	33.33 ± 0.60	33.15 ± 0.65	3.17 ± 0.45	3.03 ± 0.48
$1p_{3/2}$	39.69 ± 0.62	39.43 ± 0.68	5.52 ± 0.70	5.59 ± 0.70
$1s_{1/2}$	53.84 ± 1.86	52.00 ± 3.13	11.63 ± 1.90	13.63 ± 2.59
corr.	25.20 ± 0.02	25.00 ± 0.29	—	—



Comparison with Previous Titanium Data

- Nucleon knock-out from Argon has been also studied in the proton pick-up reaction ^{40}Ar(^{2}H,^{3}He) using both inpolarised and polarised deuteron beams



- The results of present analysis turn out to are largely compatible with previous data