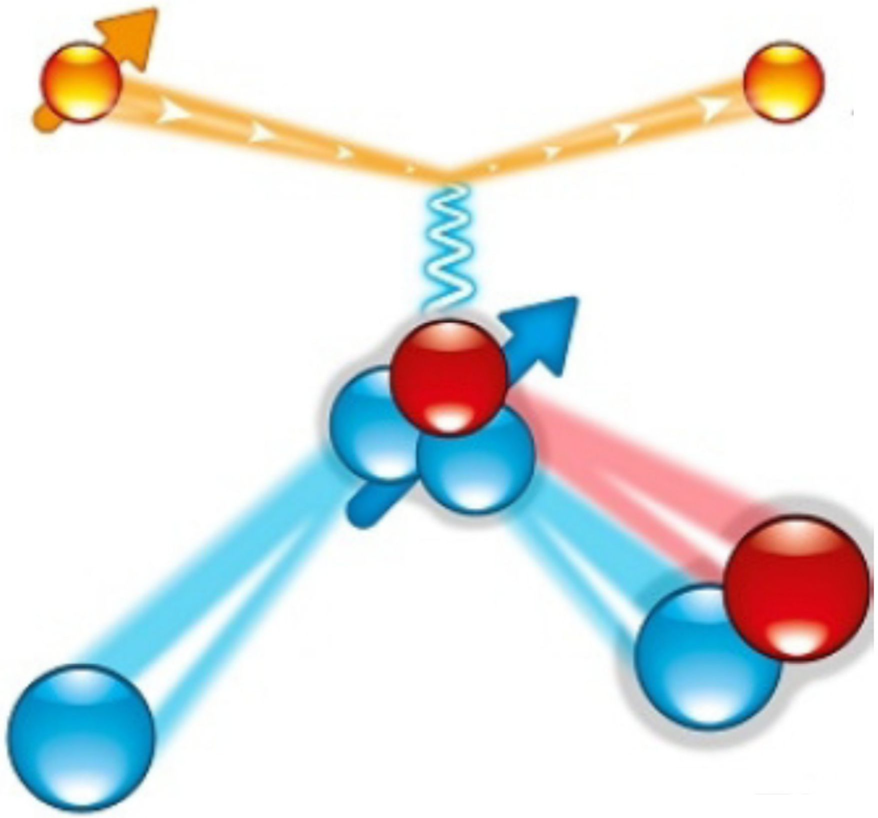
SFB 1044-Workshop: Electromagnetic observables for low-energy nuclear physics

3 October 2018

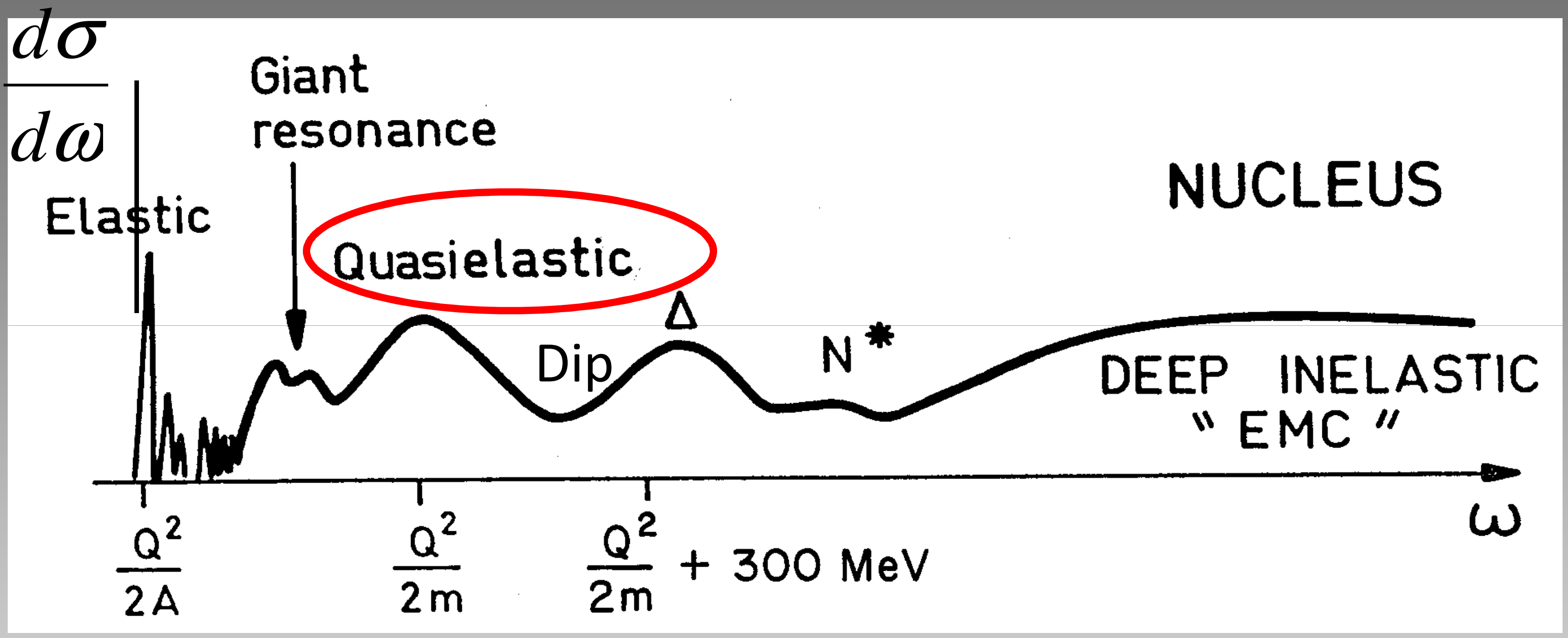


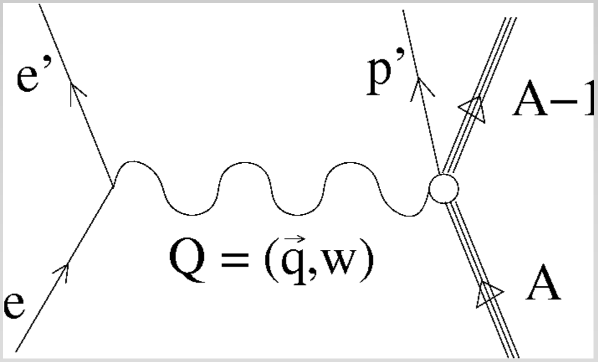
Eli Piasetzky

Tel Aviv University, ISRAEL

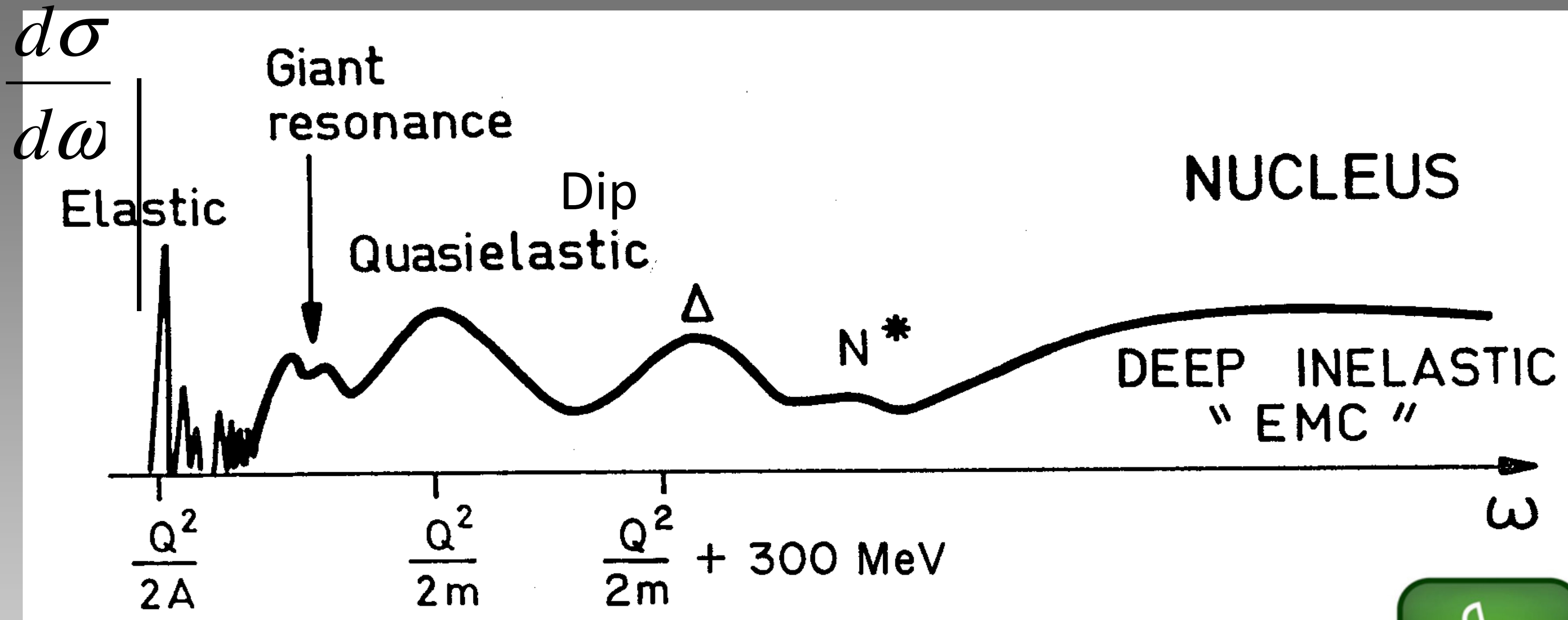
Quasi-elastic electron scattering experiments **@ Mainz**

Quasi-elastic electron Scattering



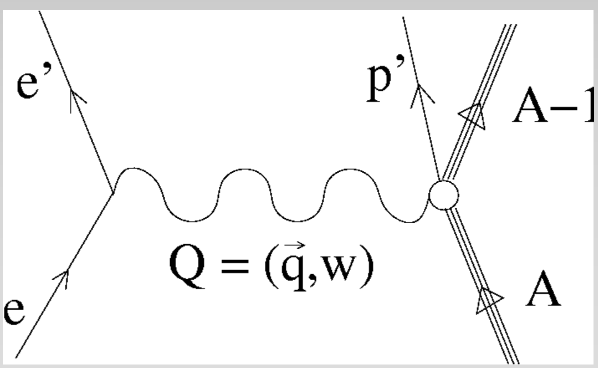


Quasi-elastic electron Scattering



or ν

*

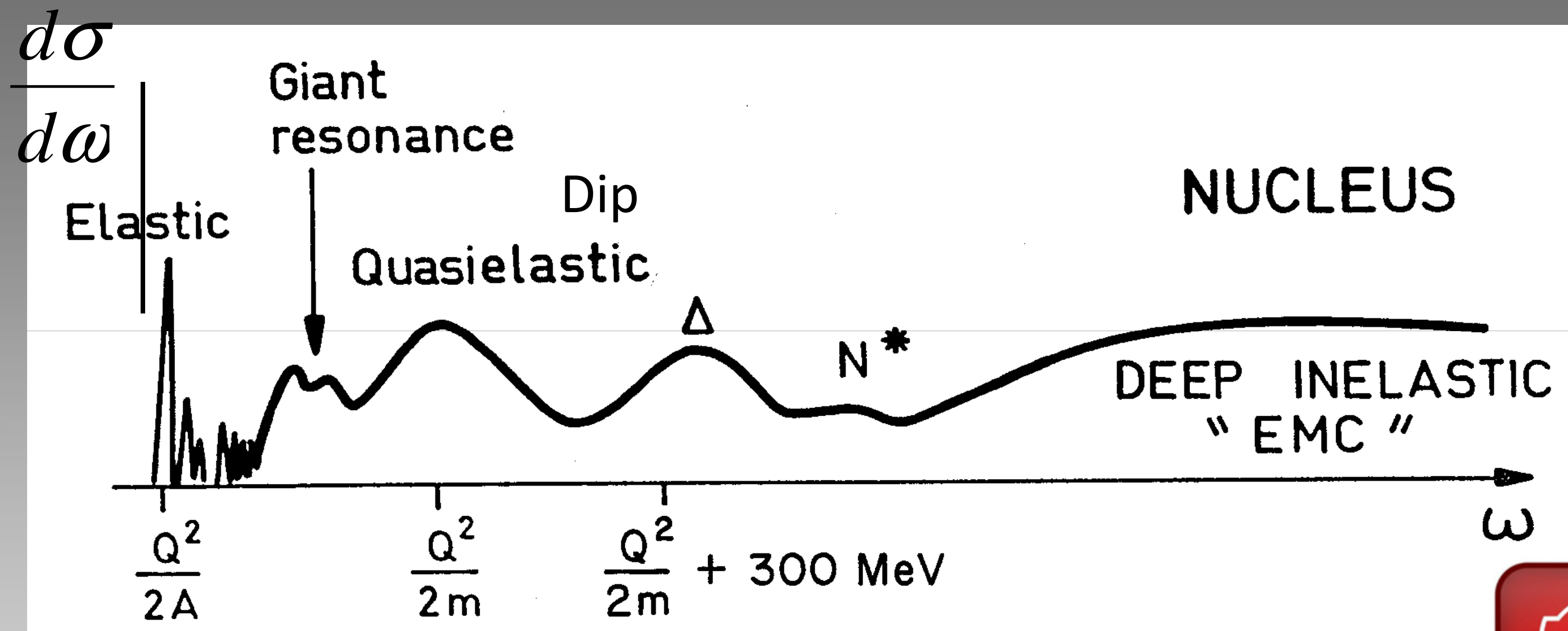


Best experimental information on:

- $S(E_{,}\vec{p})$
- 'Free' neutron
- Difference between bound and free nucleons

Quasielastic $\approx$ scattering off a single bound nucleon

Quasi-elastic electron Scattering



or ν

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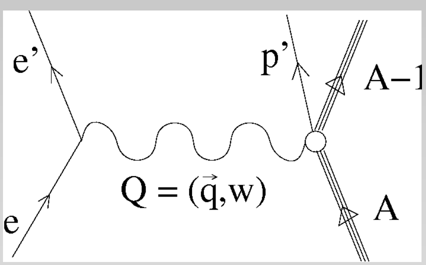
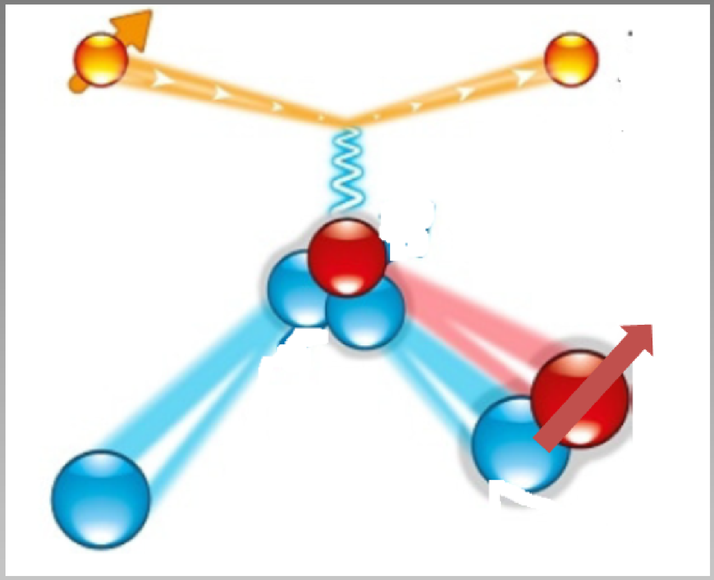


Quasielastic ≈ scattering off a single bound nucleon

≈ **a car**

MAINZ: low energy, high intensity, high resolution

Measurement of polarization transferred to a proton bound in nuclei



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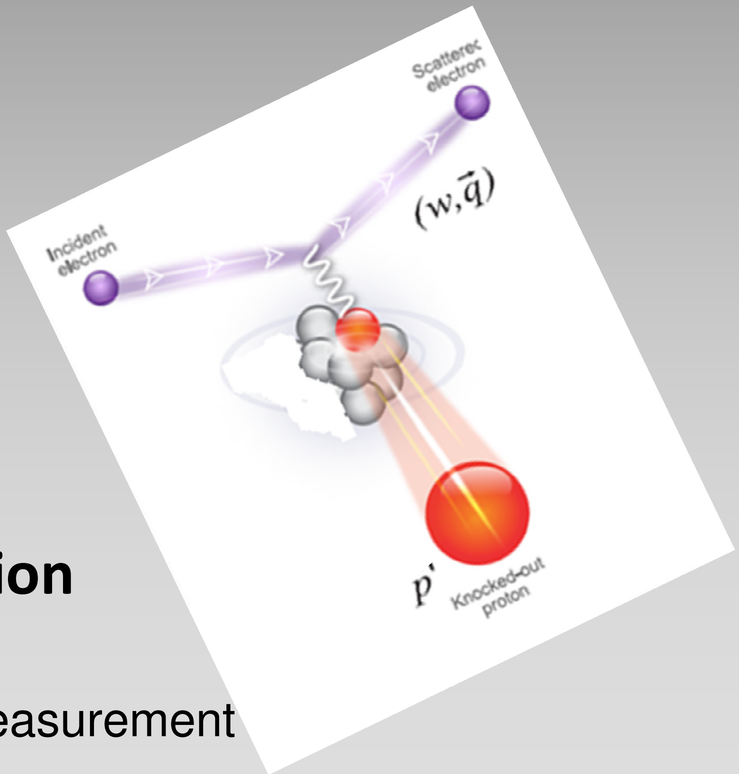
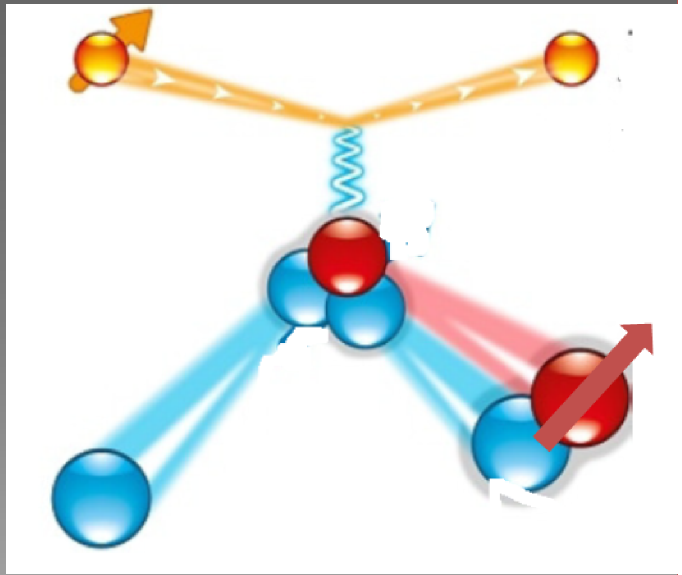


Quasi elastic- scattering with no polarization

The reduction of the single-particle strength in QE measurement

Measurement of polarization transferred to a proton bound in nuclei



* In collabortion with Jechiel Lichtenstadt and Sebouh Paul
Tel Aviv University

: **A1 Collaboration**: **I. Yaron** , **D. Izraeli** ,P. Achenbach, H. Arenhövel , J. Beričič , R. Böhm , D. Bosnar , L. Debenjak , M., O. Distler , A. Esser , I. Friščić , R. Gilman , I. Korover , J. Lichtenstadt, H. Merkel , D. G. Middleton , M. Mihovilovič , U. Müller, E. Piasetzky S. Širca , S. Strauch J. Pochodzalla , G. Ron , B. S. Schlimme , M. Schoth , F. Schulz , C. Sfienti , M. Thiel , A. Tyukin , A. Weber .

Polarization-transfer measurement to a large-virtuality bound proton in the deuteron

Phys. Lett. B 769 (2017) 21-24.

A1 Collaboration

I. Yaron[a,1], D. Izraeli[a,1], P. Achenbach[b], H. Arenhövel[b], J. Beričič[c], R. Böhm[b], D. Bosnar[d], E.O. Cohen[a], L. Debenjak[c], M.O. Distler[b], A. Esser[b], I. Friščić[d,2], R. Gilman[e], I. Korover[a,f], J. Lichtenstadt[a], H. Merkel[b,*], D.G. Middleton[b], M. Mihovilovič[b], U. Müller[b], E. Piasetzky[a], J. Pochodzalla[b], G. Ron[g], B.S. Schlimme[b], M. Schoth[b], F. Schulz[b], C. Sfienti[b], S. Širca[c,h], S. Strauch[i], M. Thiel[b], A. Tyukin[b], A. Weber[b]

Components of polarization-transfer to a bound proton in a deuteron measured by quasi-elastic electron scattering

Phys. Lett. B 781 (2018) 107-111.

A1 Collaboration

D. Izraeli[a,*], I. Yaron[a], B.S. Schlimme[b], P. Achenbach[b], H. Arenhövel[b], A. Ashkenazi[a], J. Beričič[c], R. Böhm[b], D. Bosnar[d], E.O. Cohen[a], M.O. Distler[b], A. Esser[b], I. Friščić[d,1], R. Gilman[e], I. Korover[a,f], J. Lichtenstadt[a], I. Mardor[a,g], H. Merkel[b], D.G. Middleton[b], M. Mihovilovič[c,b], U. Müller[b], M. Olivenboim[a], E. Piasetzky[a], J. Pochodzalla[b], G. Ron[h],
* M. Schoth[b], F. Schulz[b], C. Sfienti[b], S. Širca[i,c], S. Štajner[c], S. Strauch[j], M. Thiel[b], A. Tyukin[b], A. Weber[b]

Measurement of polarization-transfer to bound protons in carbon and its virtuality dependence

Phys. Lett. B 781 (2018) 95-98.

A1 Collaboration

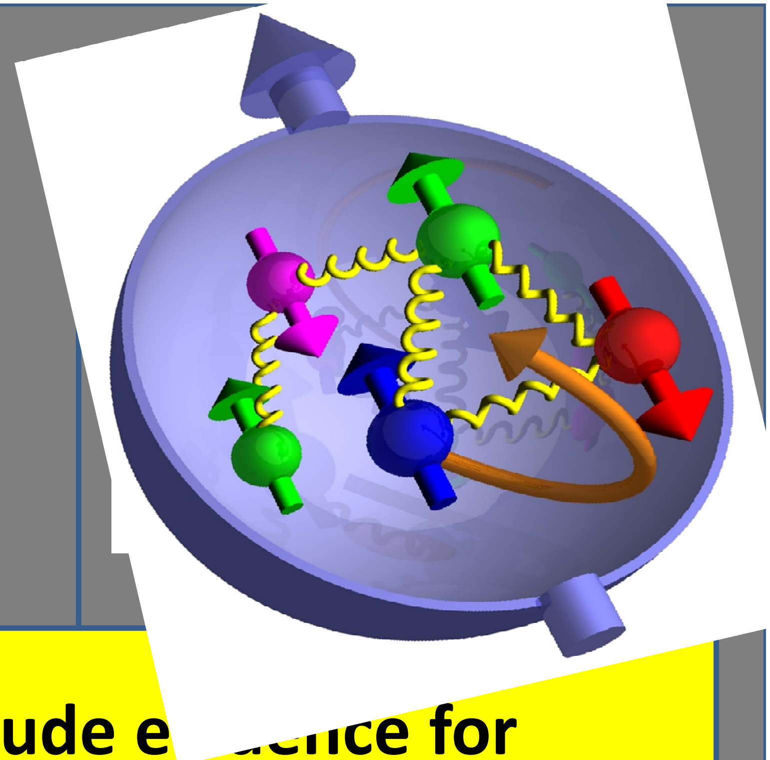
D. Izraeli[a,*,1], T. Brecelj[b,1], P. Achenbach[c], A. Ashkenazi[a], R. Böhm[c], E.O. Cohen[a], M.O. Distler[c], A. Esser[c], R. Gilman[d], T. Kolar[b], I. Korover[a,e], J. Lichtenstadt[a], I. Mardor[a,f], H. Merkel[c], M. Mihovilovič[b,c], U. Müller[c], M. Olivenboim[a], E. Piasetzky[a], G. Ron[g], B.S. Schlimme[c], M. Schoth[c], C. Sfienti[c], S. Širca[h,b], S. Štajner[b], S. Strauch[i], M. Thiel[c], A. Weber[c], I. Yaron[a]

Polar polarization: a new method for polarimetry analysis

D. Izraeli,[a,1] I. Mardor,[a,b] E. O. Cohen,[a] M. Duer,[a] T. Y. Izraeli,[c] I. Korover,[a,d] J. Lichtenstadt[a] and E. Piasetzky[a]

2018 JINST 13 P07209.

Nucleons are complex objects .
Are nucleons being modified in the nuclear medium ?



The challenge is to observe or exclude e[illegible]ence for changes in the bound nucleon compare to a free one.

Do nucleons change their quark-gluon structure in the nuclear medium ?

In-Medium vs. Free
Structure Function

(EMC like)

Do nucleons change global properties (radius, mass ...) ?

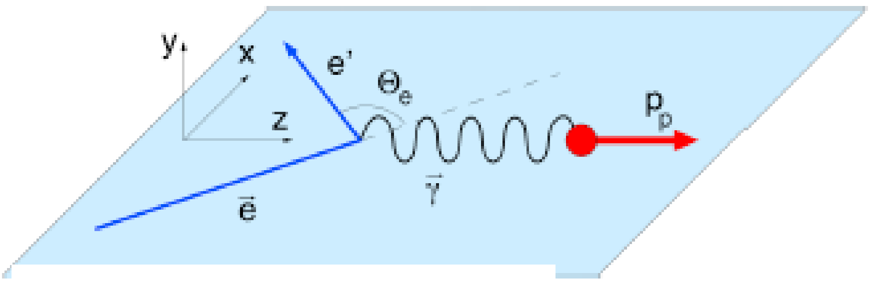
In-Medium vs. Free
Form Factors

The observable of choice:

The polarization of the knockout proton in QE scattering

Free proton

$$\frac{G_{Ep}}{G_{Mp}} = -\frac{P'_x}{P'_z}\frac{(E_i + E_f)}{2m}\tan\frac{\theta_e}{2}$$



Bound proton

$$A(\vec{e}, e'\vec{p})$$

$$R = \left(\frac{P'_x}{P'_z}\right)_A \Big/ \left(\frac{P'_x}{P'_z}\right)_H$$

*G_{Ep}/G_{Mp}

* obtained from a single measurement with syst. and stat. uncertainties ~1%.

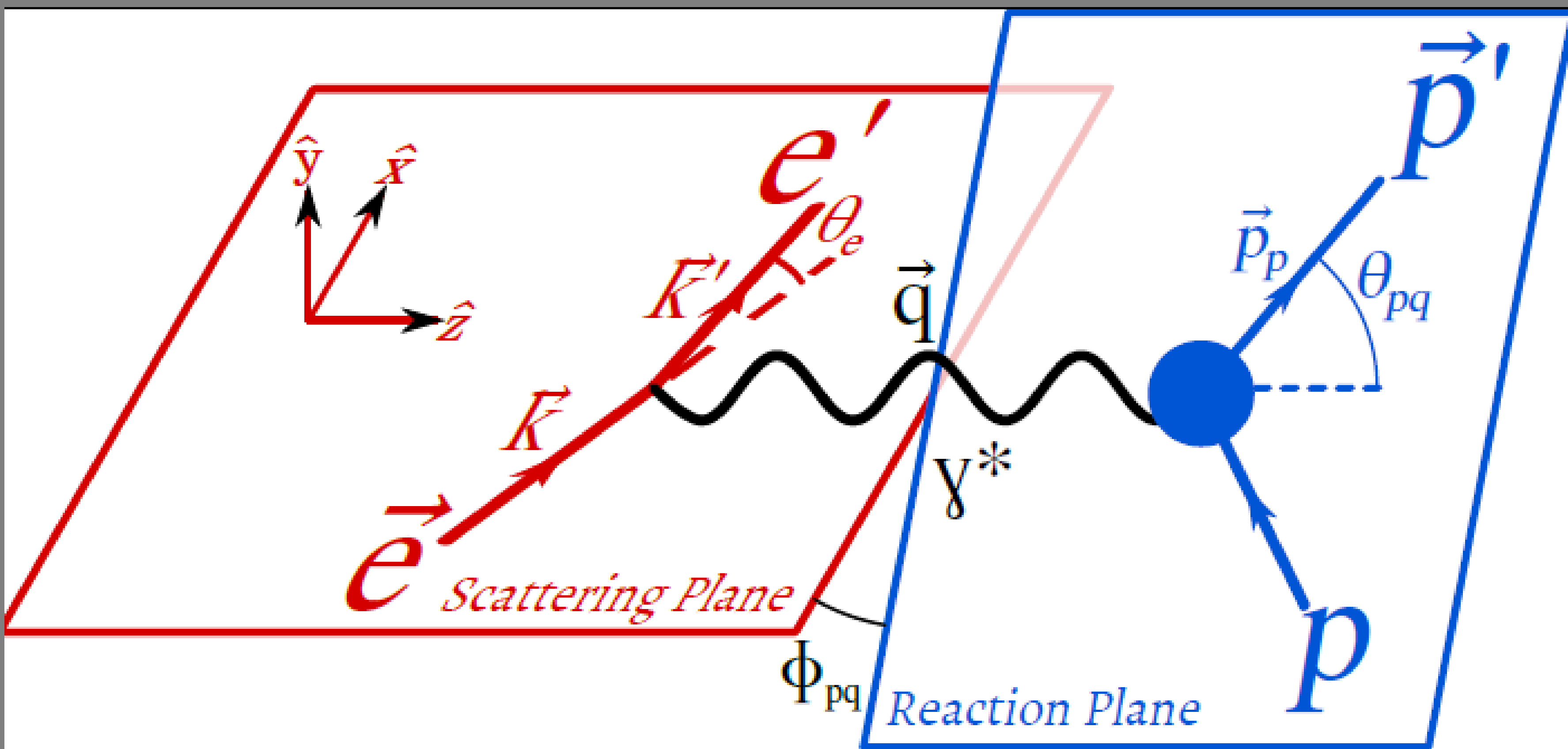
*sensitive to the properties of the nucleon (size, charge dist…

*only moderately sensitive to nuclear effect s (MEC, IC, FSI).

*Minimal affected by radiative corrections.

The polarization of the knockout proton in quasi-elastic scattering

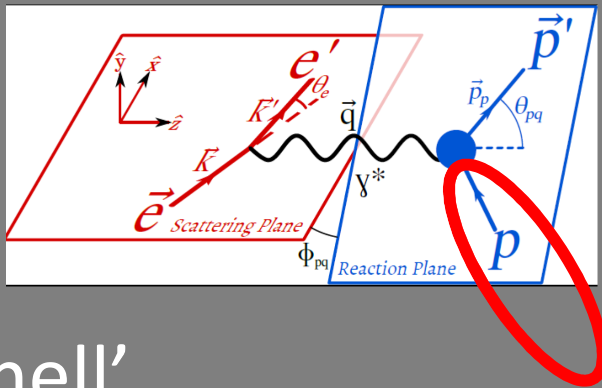
$$A(\vec{e}, e'\vec{p})$$



$$\vec{p}_{miss} = \vec{q} - \vec{p}_p$$

Without FSI: $\vec{p}_{miss} = -\vec{p}_i$

Virtuality



Only the struck proton is ‘off=shell’

$$\nu = p_{miss}^2 - M_p^2 \neq 0$$

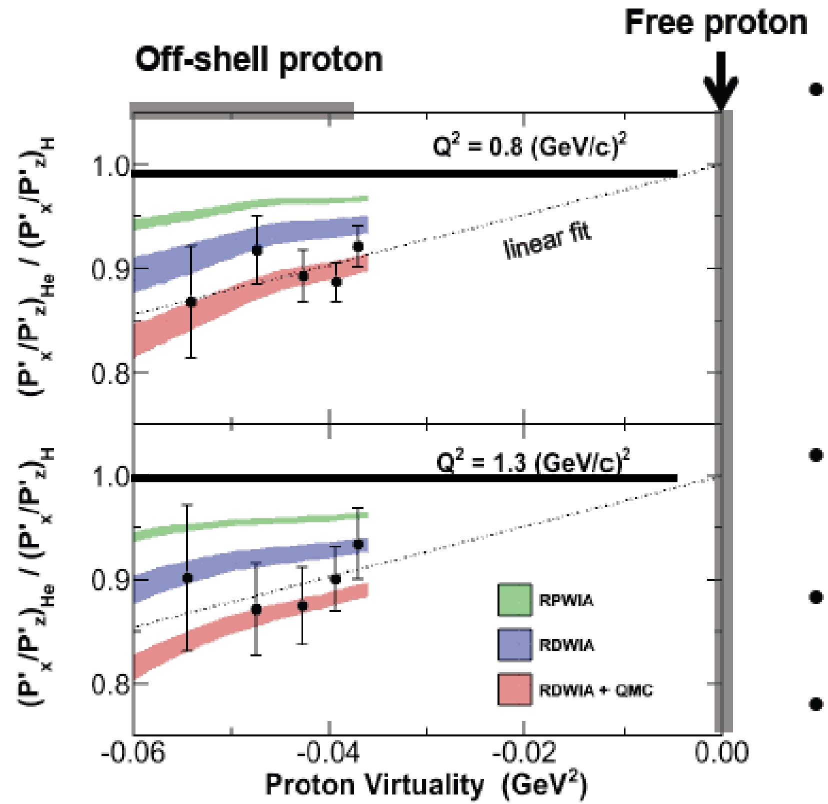
$$\nu \equiv \left(M_A - \sqrt{\equiv M_{A-1}^2 + |\vec{p}|_{\text{miss}}^2}\right)^2 - |\vec{p}|_{\text{miss}}^2 - M_p^2$$

$^4He(\vec{e},e'\vec{p})$ Px/Pz polarization transferred ratio

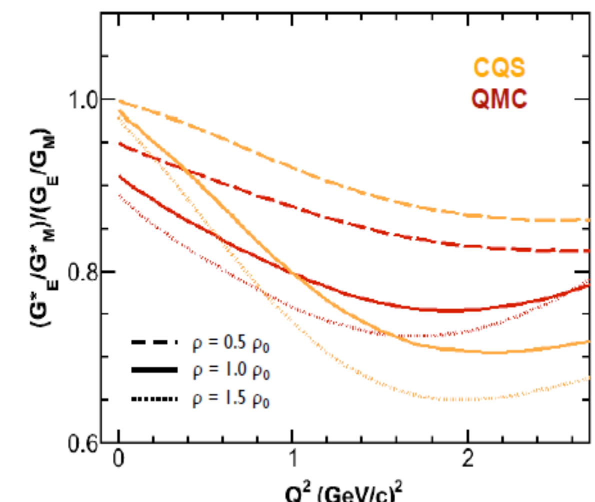
QE ^{4}He ≠ free proton
≠ calc. with free FF

Can be explained by:
Medium FF≠ Free

Jlab E03-104 Data



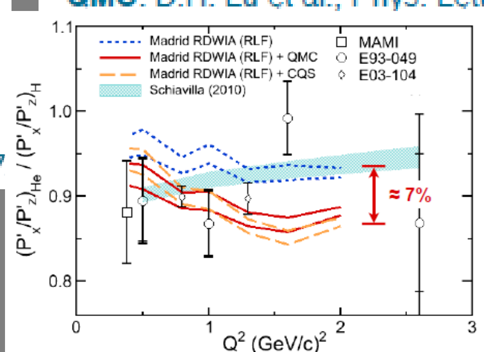
Calculations by the Madrid group
see: C. Ciofi degli Atti, L.L. Frankfurt, L.P. Kaptari, M.I. Strikman, Phys. Rev. C **76**, 055206 (2007



CQS: Chiral Quark Soliton
QMC: Quark Meson Coupling

CQS: J.R. Smith and G.A. Miller, Phys. Rev. C **70**, 065205 (2004)
QMC: D.H. Lu et al., Phys. Lett. B 417, 217 (1998)

S. Dieterich et al. PL B500, 47 (2001).
S. Strauch et al. PRL. 91 052301 (2003).
M. Paolone et al. PRL. 91 052301 (2003).



Also proposed SCX FSI

Px/Pz polarization transferred ratio $\quad {}^{4}He(\vec{e},e'\vec{p})$

QE ^{4}He ≠ free proton

≠ calc. with free FF

BUT is it due to:

in-medium FF modification

or

unaccounted nuclear effects ?

Does it depend on ?

The virtuality (momentum off -shellness)

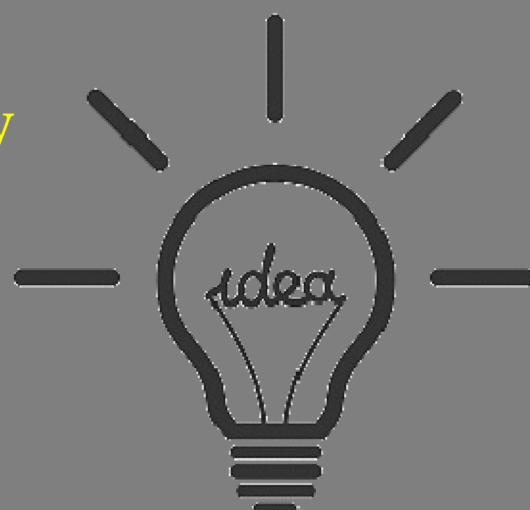
or

The local nuclear density

$d(\vec{e},e'\vec{p})$

$^{12}C(\vec{e},e'\vec{p})$

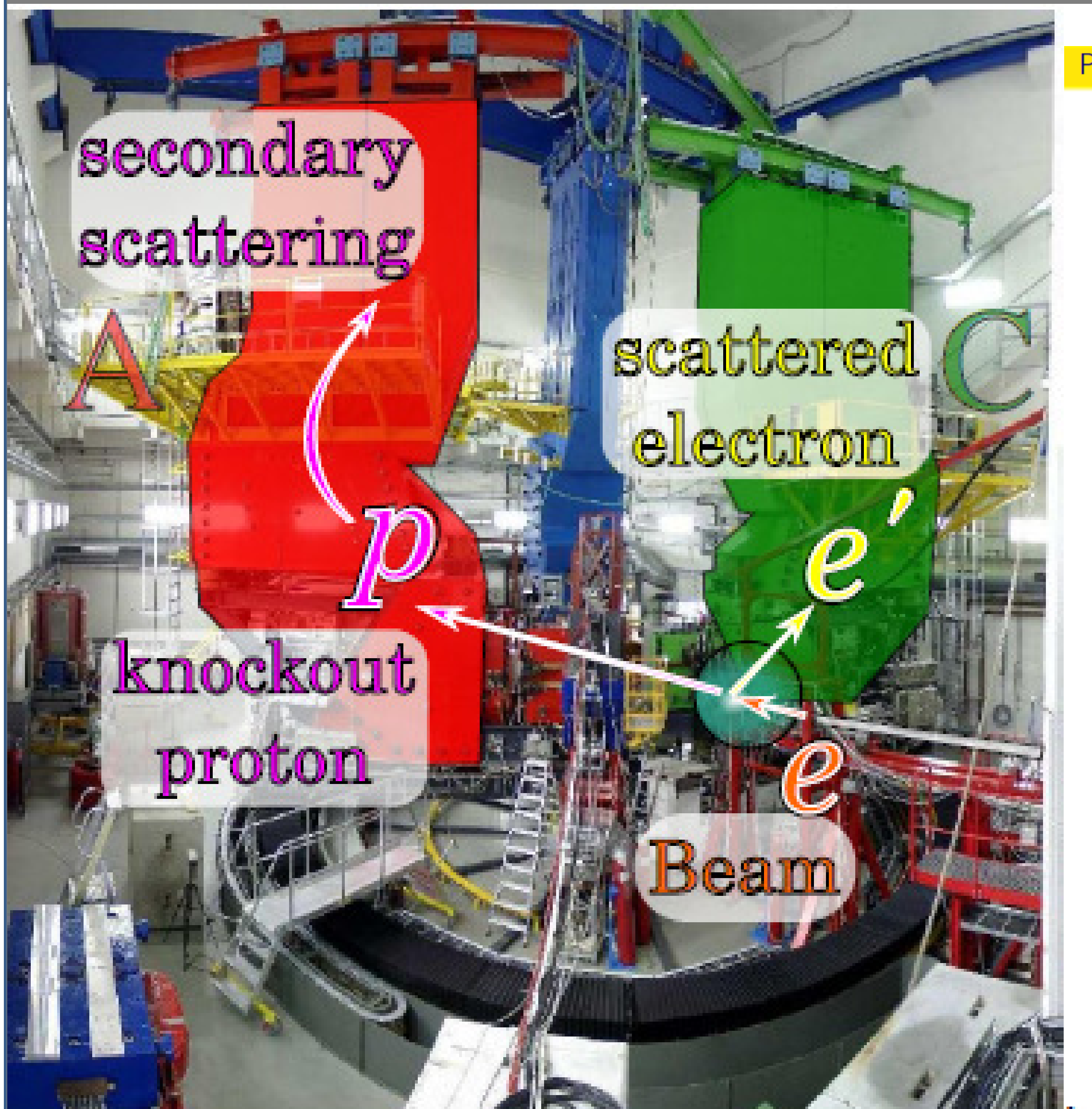
s- and p- shell removal



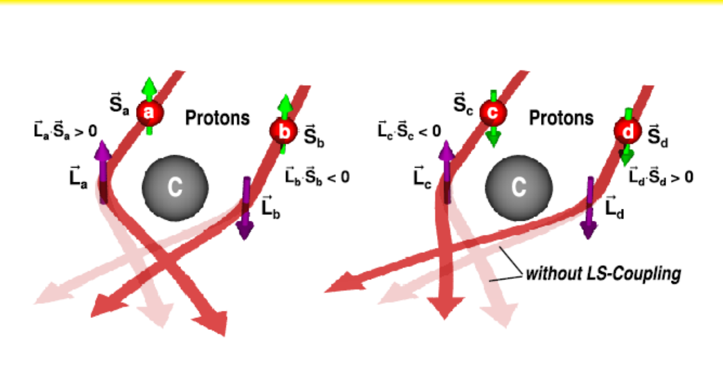
Use a large-virtuality bound proton in the deuteron

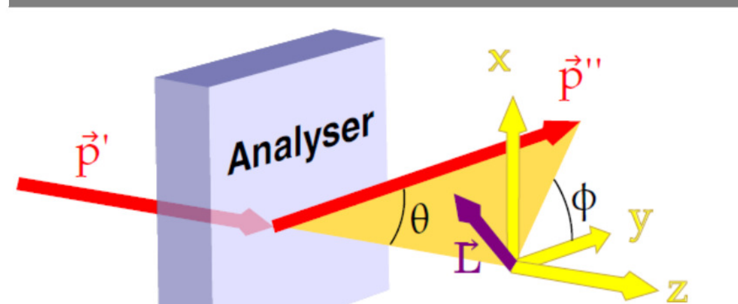
MAMI / A1

$$d(\vec{e},e'\vec{p})$$



Polarization-transfer Measurement





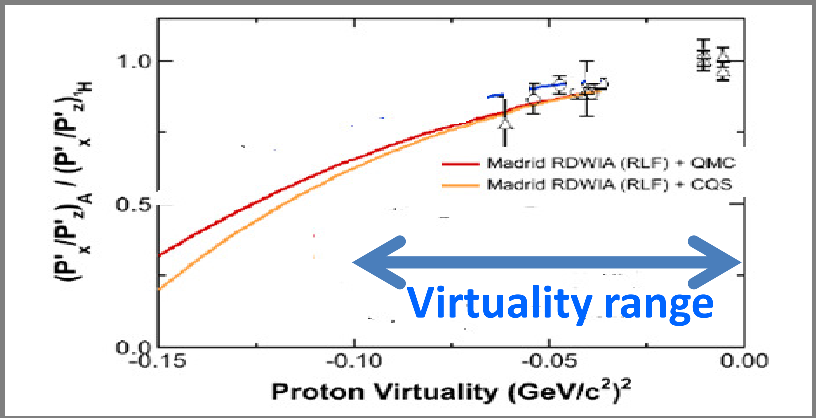
$$f(\phi) \propto 1 \pm A_C\, P_\rho \cos(\phi - \phi_0)$$

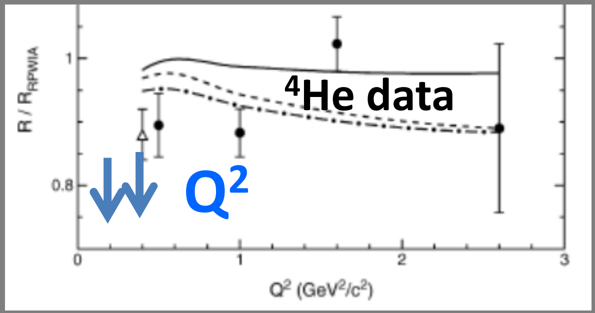
$d(\vec{e},e'\vec{p})$

MAMI / A1 June –July 2012

-

^{4}He data





I. Yaron et al. PLB 769 (2017) 21-24.

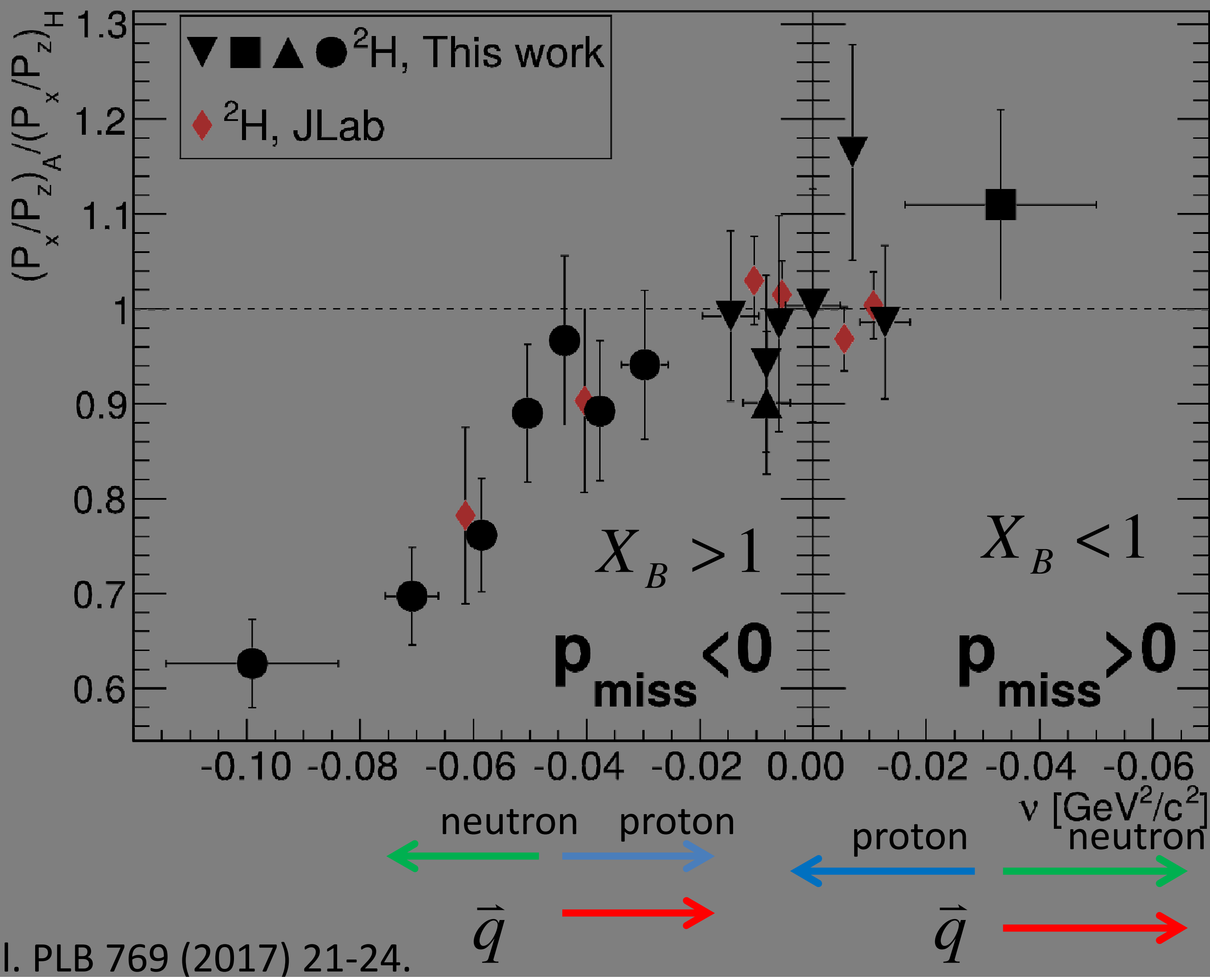
Px/Pz polarization transferred ratios

- Deuteron QF ≠ free
- Strong virtuality dependence
- No Q^2 dependence

JLab (Hu et al.) Q^2=, 0.43 1.00

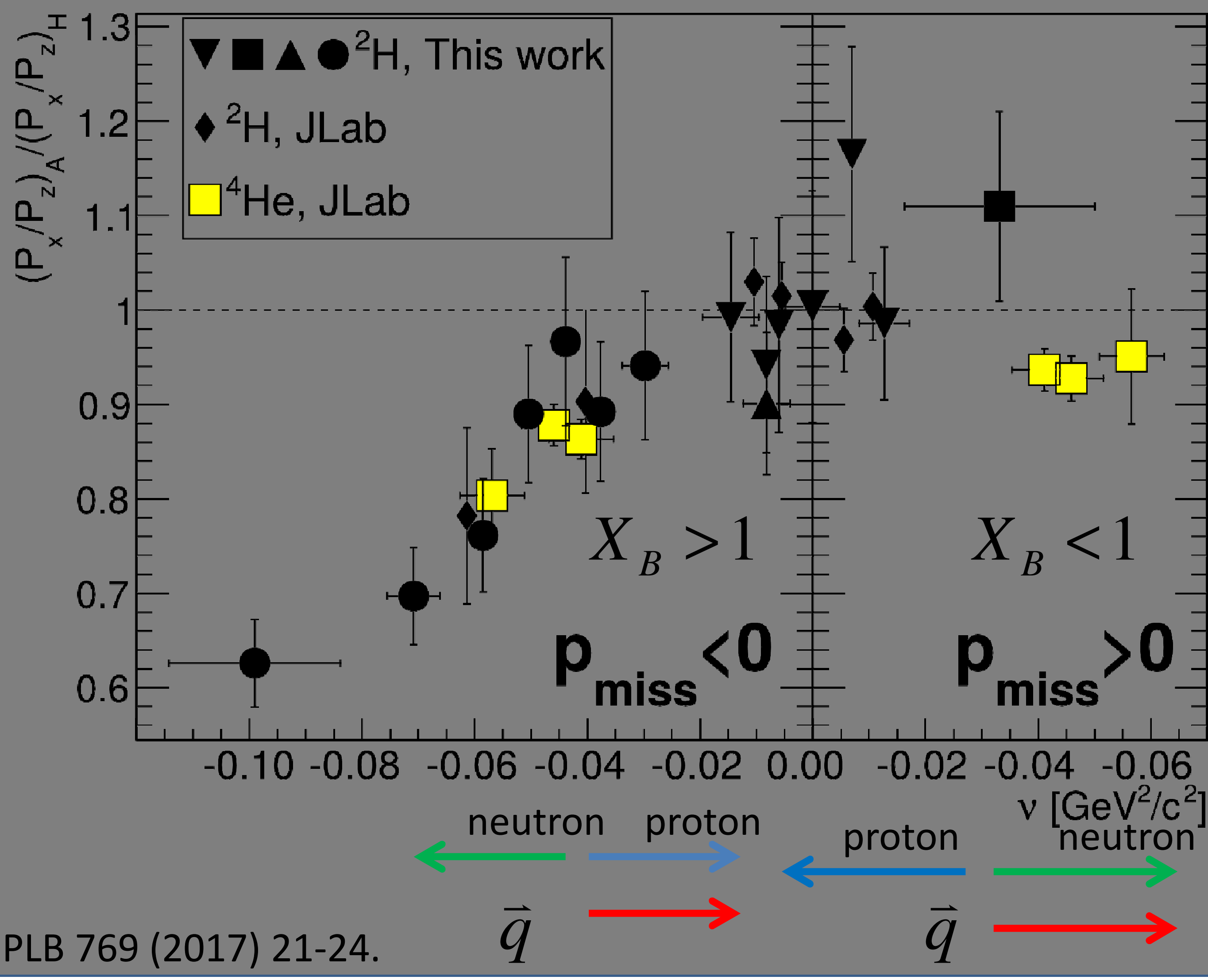
MAINZ Q^2= 0.175, 0.4

[(GeV/c)²]



I. Yaron et al. PLB 769 (2017) 21-24.

No Nuclear density (B.E.) dependence !



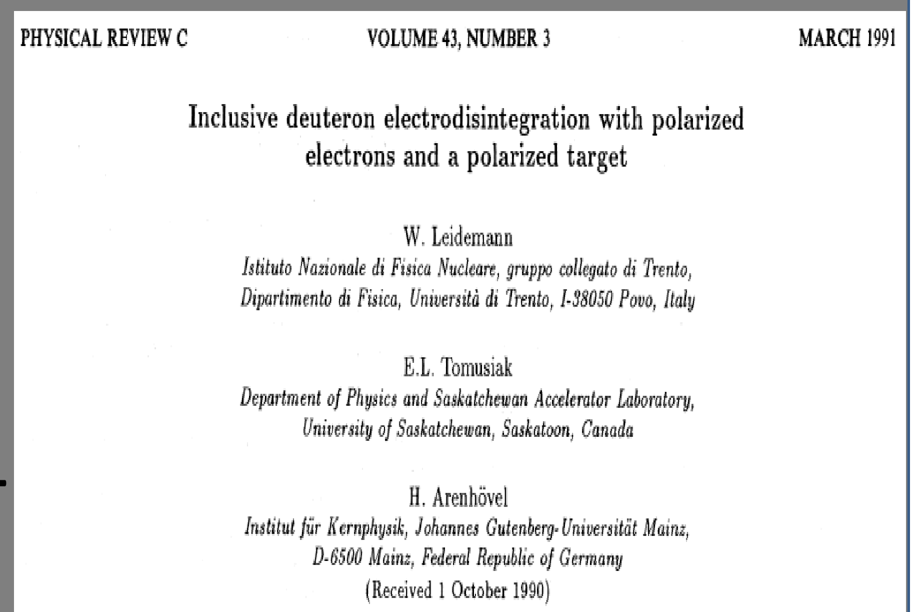
I. Yaron et al. PLB 769 (2017) 21-24.

Compare to calculations with free FFs

H. Arenhovel (7 models)

1. NORMAL (DWIA)
2. PWBA
3. NORMAL+MEC
4. NORMAL+MEC+IC
5. NORMAL+REL
6. PWBA (RC)
7. NORMAL+MEC+IC+REL

For each bin the calculation were done for
The same kinematical condition as the real
data in that bin $\mathbf{f(E', \theta_e, \theta_{pq}, \varphi_{pq})}$.



PHYSICAL REVIEW C VOLUME 43, NUMBER 3 MARCH 1991

Inclusive deuteron electrodisintegration with polarized electrons and a polarized target

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E.L. Tomusiak
Department of Physics and Saskatchewan Accelerator Laboratory,
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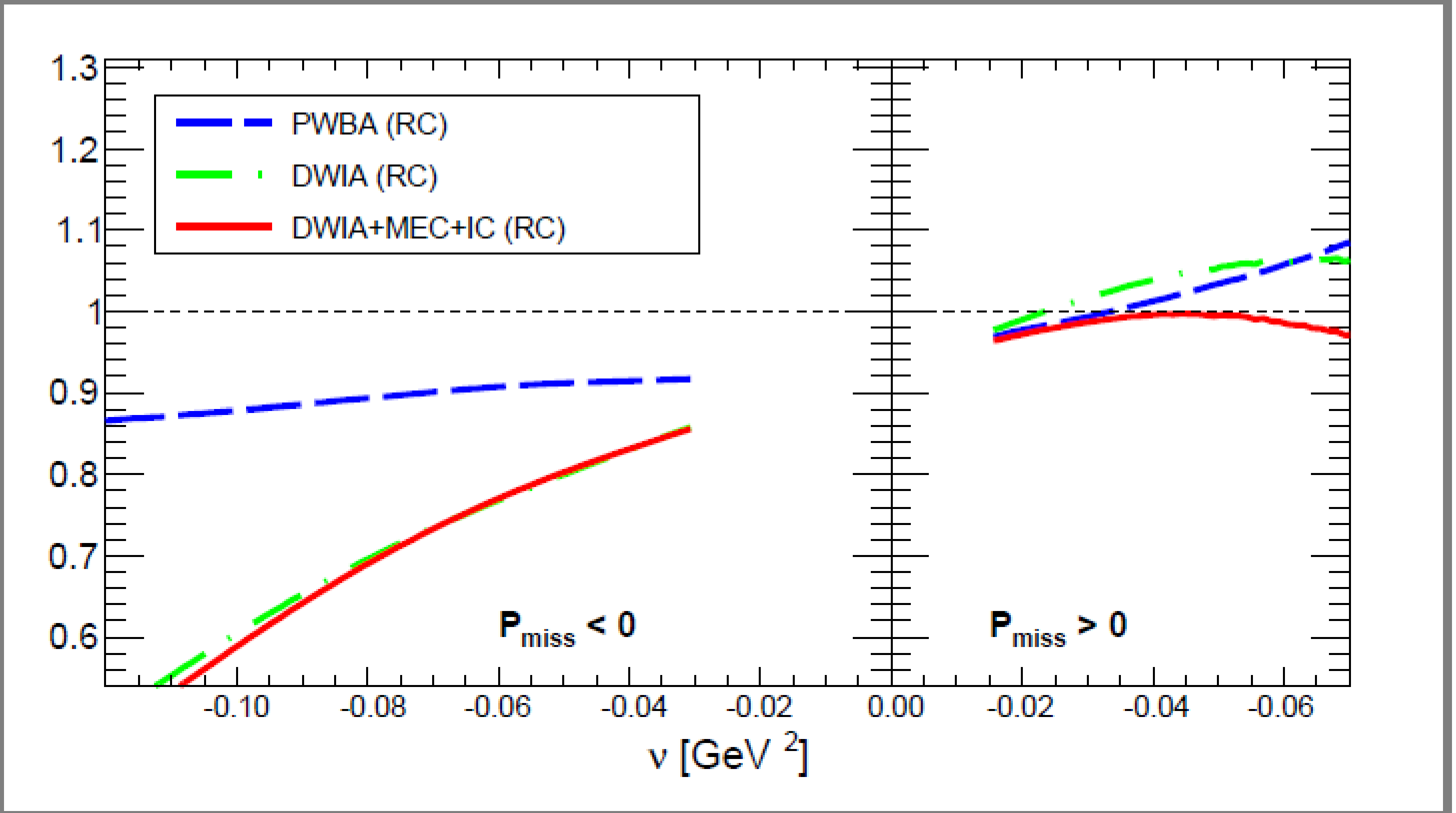
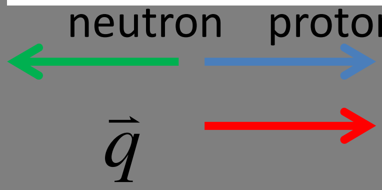
H. Arenhövel
Institut für Kernphysik, Johannes Gutenberg-Universität Mainz,
D-6500 Mainz, Federal Republic of Germany
(Received 1 October 1990)

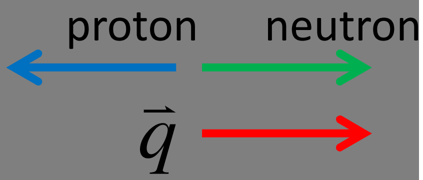
Compare to calculations (free FFs)

Virtuality dependence:

- reproduced by calculations.
- due to FSI.

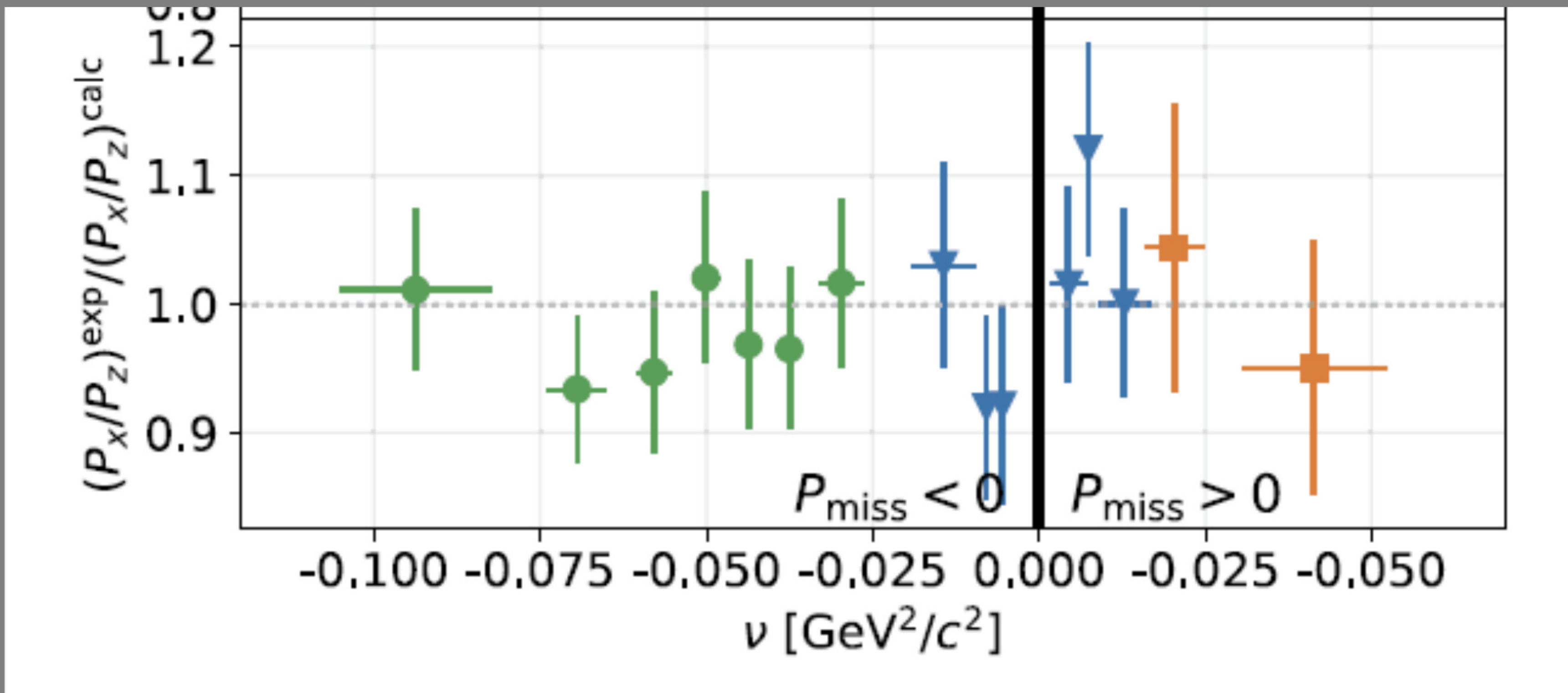






Even better comparison to calculations (free FFs)

- * data reproduced by the calculations within uncertainties ~1%
  - no need for modifications in G_E/G_M



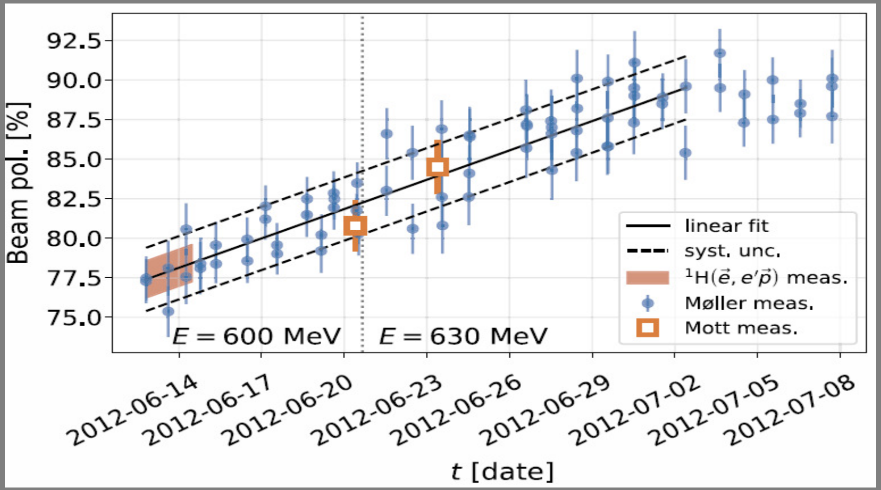
* Analysis of 3 components.

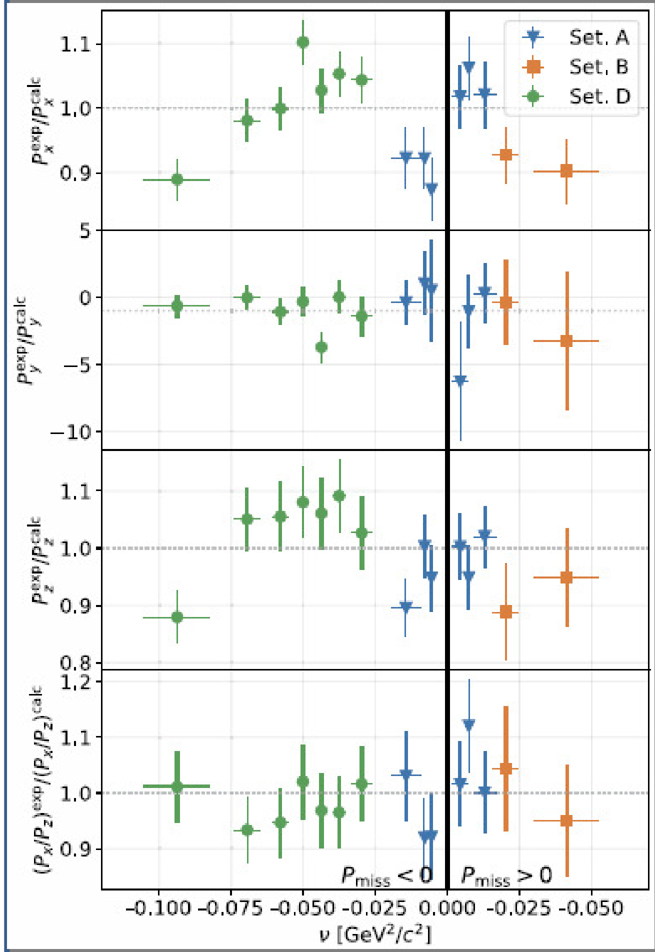
D. Izraeli et al. Phys. Lett. B 781 (2018) 107-111.

Extraction of ^{2}H polarization transfer components

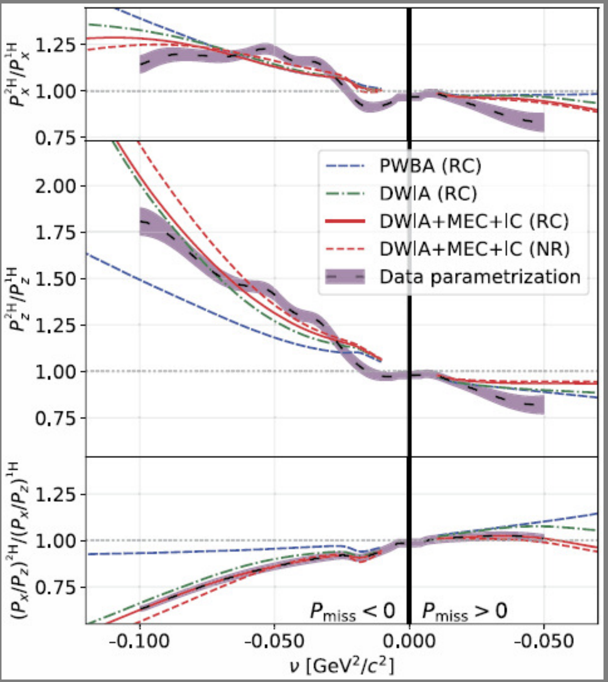
- Used fitted beam-polarization

- Overall normalization determined by $^{1}H(\vec{e},e'\vec{p})$ measurements





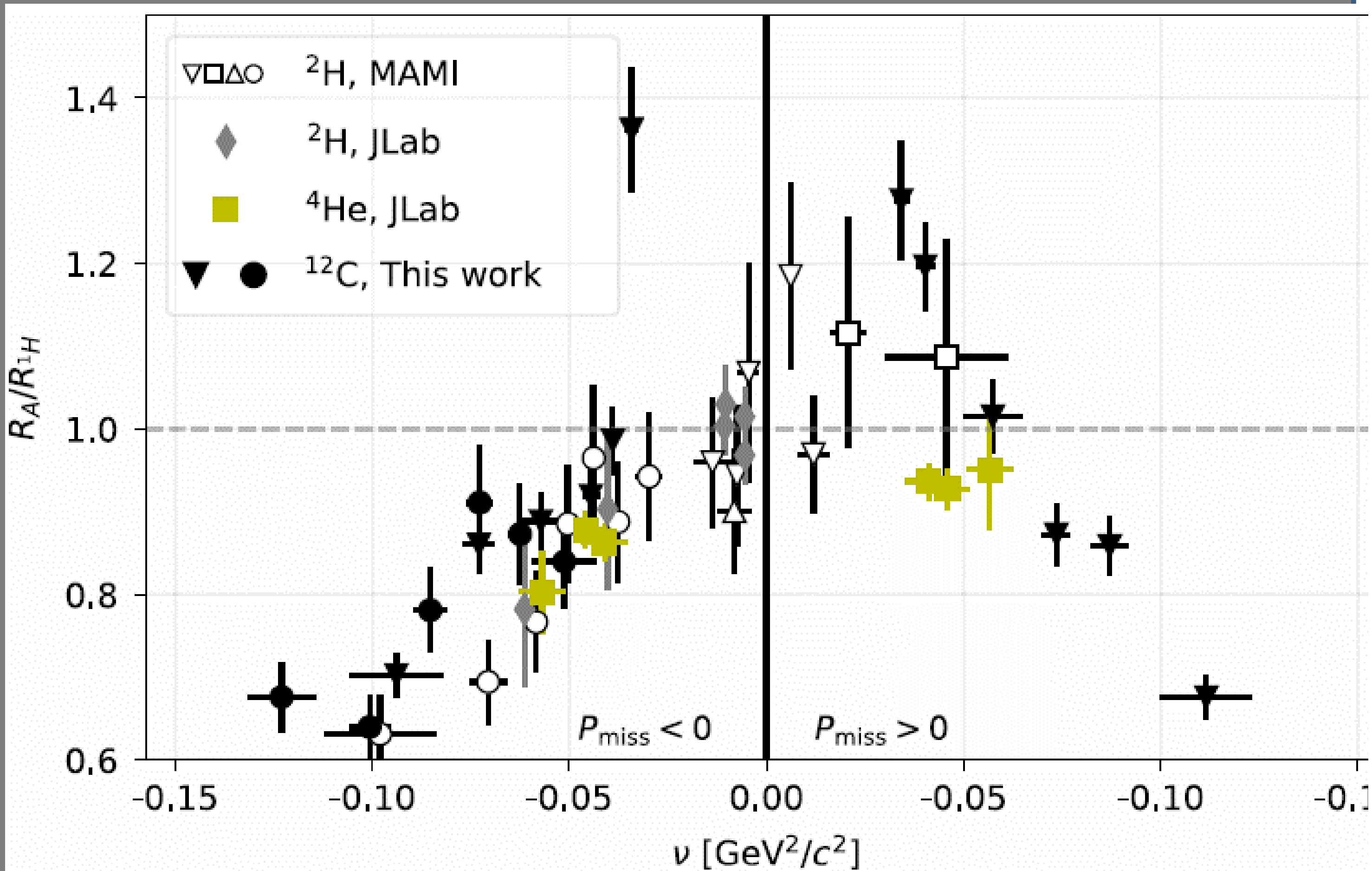
- **Main deviation** from the free is due to **FSI** and **Pz**.



D. Izraeli et al. Phys. Lett. B 781 (2018) 107-111.

Dependent on nuclear local density:

$^{12}C(\vec{e},e'\vec{p})$



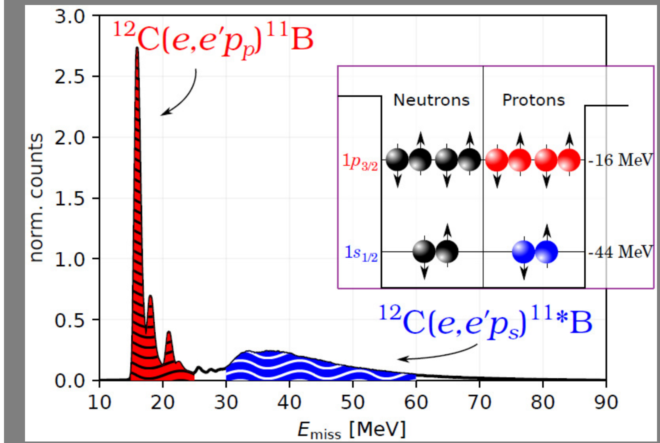
- **R_A/R_{1H}** for **^{2}H**, **^{4}He**, **^{12}C(S)**, **^{12}C(P)** are consistent, even when obtained in different kinematics.

- Data suggest **universal behavior**, independent of **average local density** and **Q^2**.

D. Izraeli et al., PLB 781 (2018) 95-98.

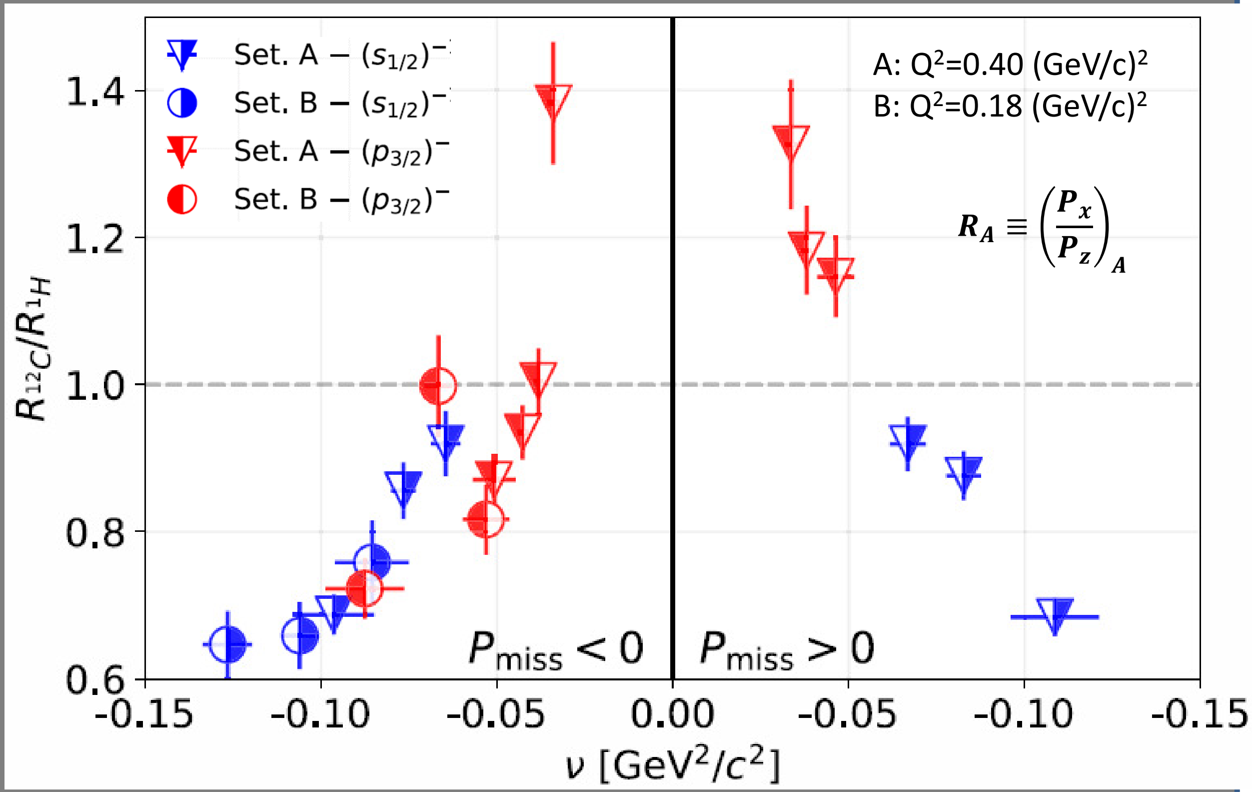
$^{12}C(\vec{e},e'\,\vec{p})$

s- and p- shell removal



$E_{miss} = \omega - T_p - T_{11B}$

E_{miss} < 28 MeV:
p-shell knockout
28 < E_{miss} < 50 MeV:
s-shell and **multi-particle** knockout



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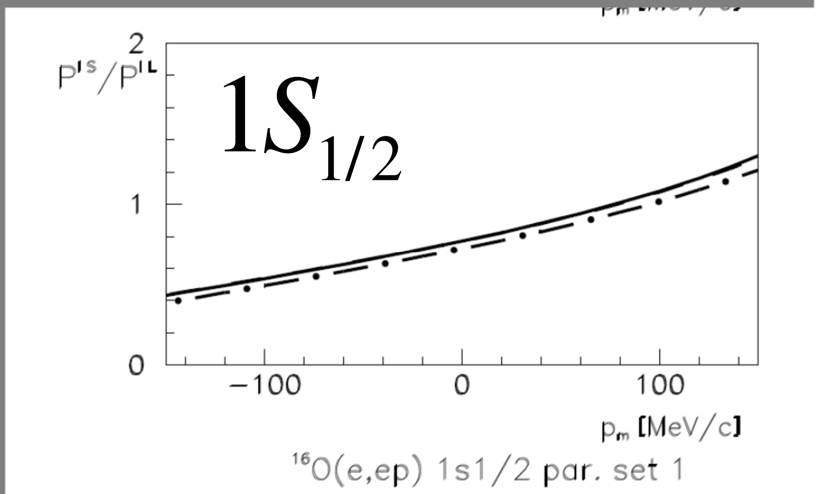
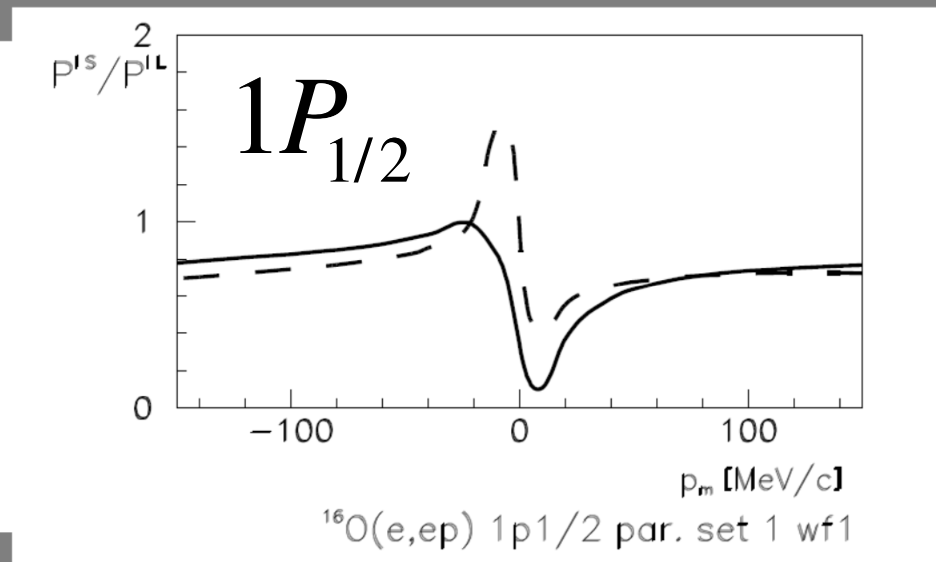
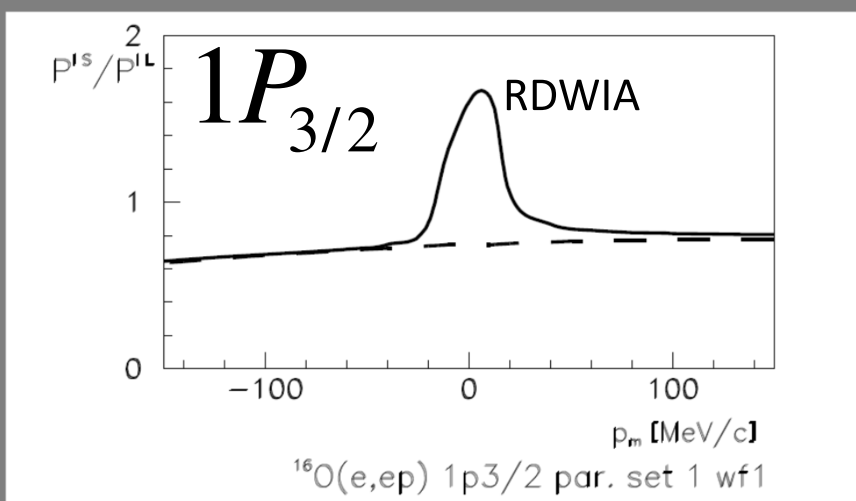
The calculated behavior around p_{miss}=0 for different states







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

Parallel kinematics

Calculations by Giusti Carlotta

Summary

Data: QF ≠ free

- Smooth universal virtuality dependence.
- no Q^2 – dependence.
- No nuclear density (B.E.) dependence
- Main difference between QE and free is in Pz .

Comparing to <u>deuteron </u>calculations

- calculations predicts the smooth Px/Pz virtuality dependence (FSI, Pz).
- No need for G_E/G_M medium modification.

Free vs. bound nucleon

Large virtuality: universality

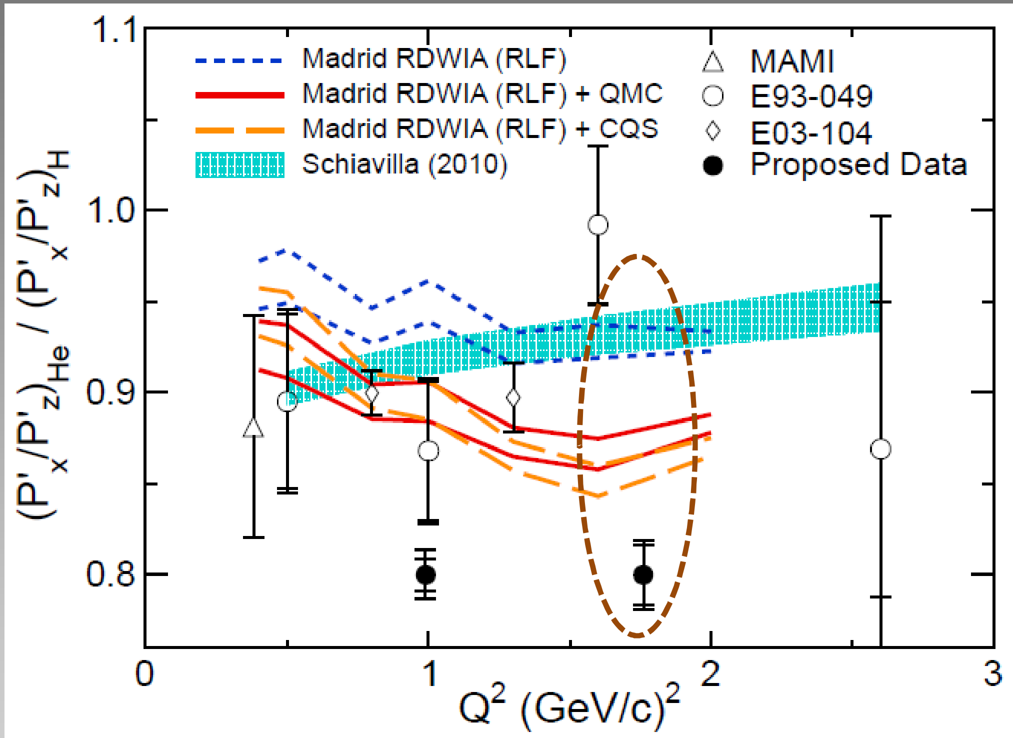
Small virtuality: Nuclear structure dependence

*

TEL AVIV UNIVERSITY

Outlook (JLab.)

- $^{4}He(\vec{e},e'\vec{p})$ @
- Q^2 = 1.0, 1.8 $(GeV/c)^2$, -200 < p_{miss} < +300 MeV/c
  - Nuclear **medium effects** are expected to **increase with virtuality**

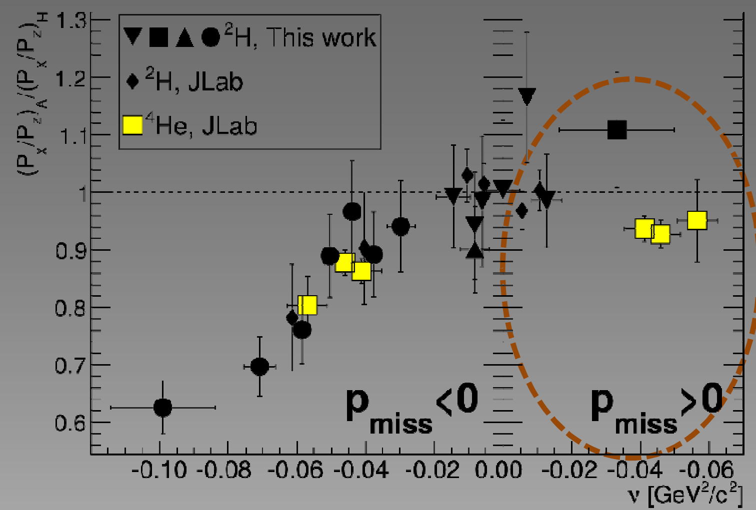


S. Strauch et al., JLAB E12-11-002

	Small Q2	Large Q2
Small virtuality	MAINZ/JLab	JLab
Large virtuality	MAINZ	

Outlook (MAINZ)

Data available analysis in progress



Deuteron

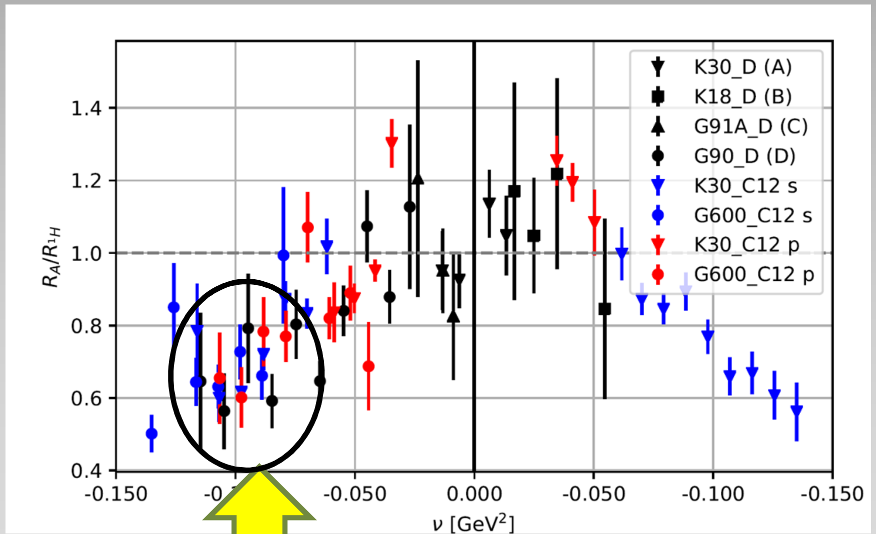
Data: March 2017.

Analysis: S. Paul, Tel Aviv Univ.

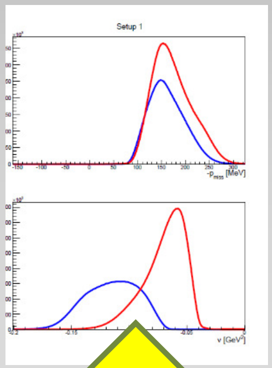
Carbon

Data: March 2017.

Analysis: T. Kolar , Ljubljana



- Compare **s and p** at **same virtuality**



- **polarization components**, not only ratios

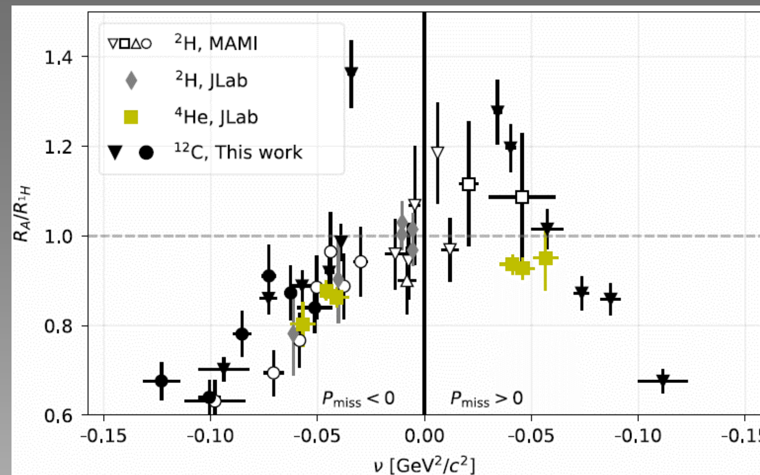
(p_x^s/p_x^p) and (p_z^s/p_z^p)

Analysis: T. Brecelj , Ljubljana

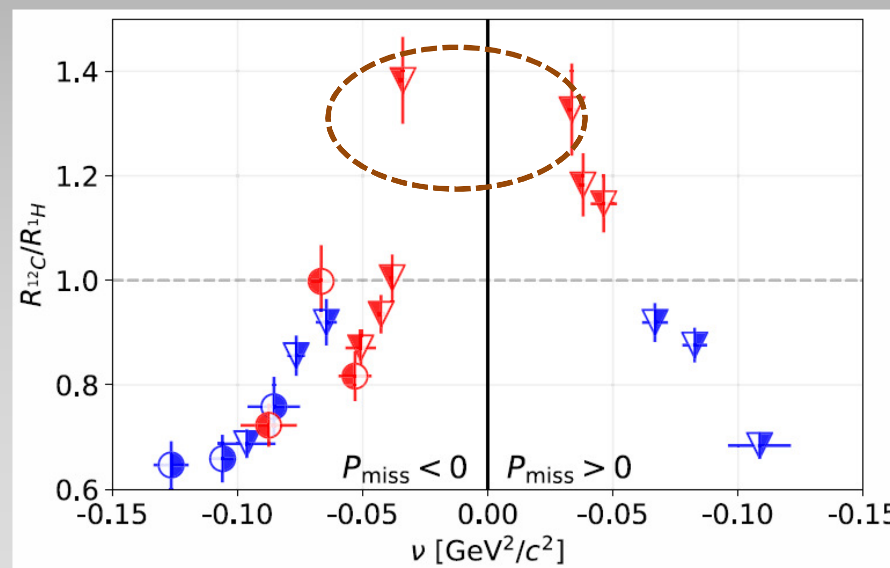
Outlook (MAINZ)

New measurement

A> 12 and large virtuality check universality



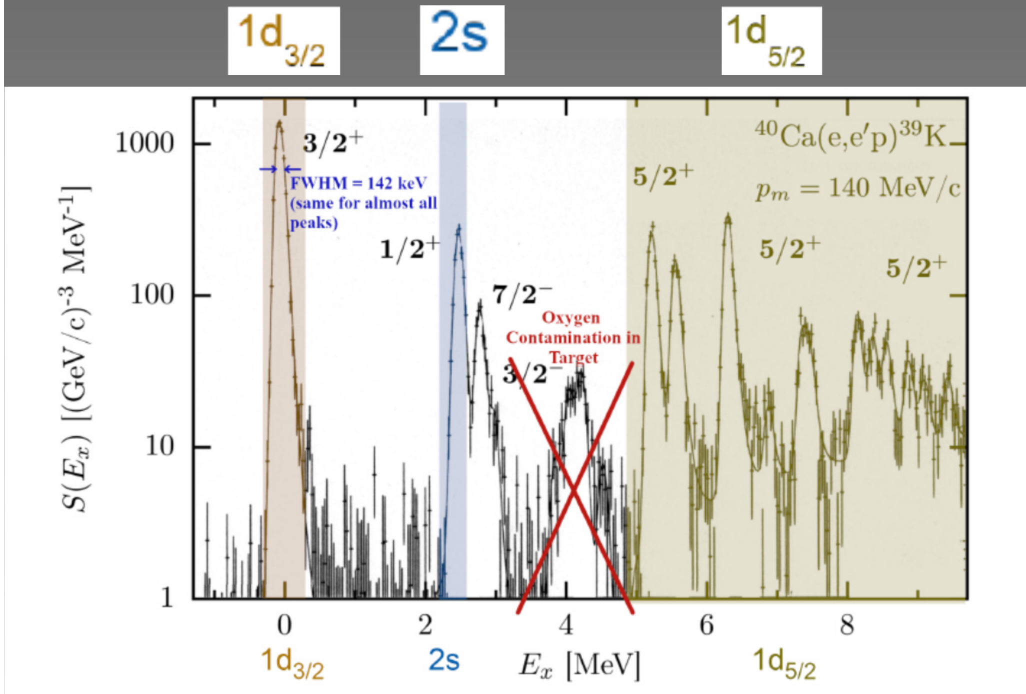
Small virtuality Compare different shells (Depndence on L and J)



We propose a measurement on Ca

$$^{40}Ca(\vec{e},e'\vec{p})$$

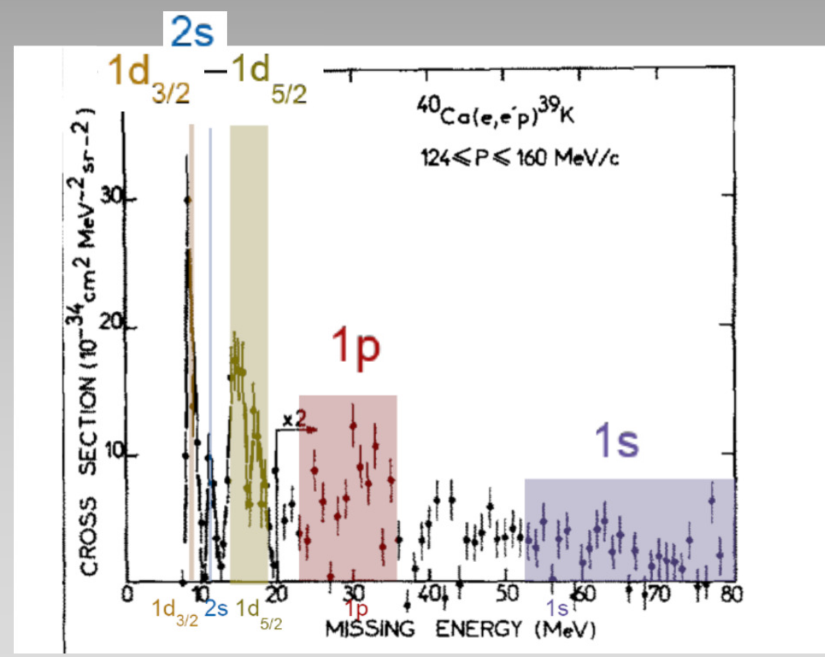
$^{40}Ca(\vec{e},e'\vec{p})$



NIKHEF (low energy excitations, high resolution)

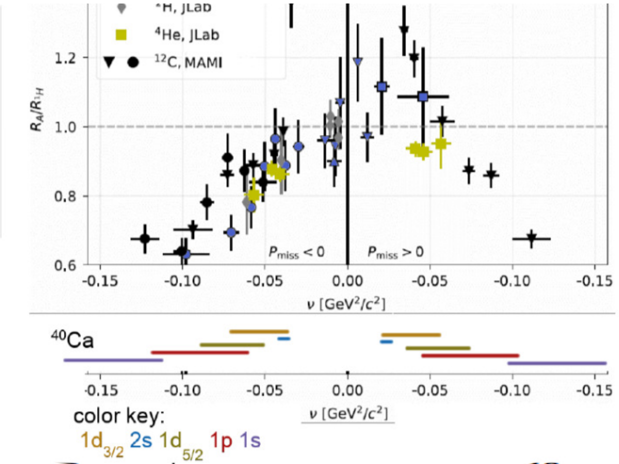
L. Lapidkas, NP A553 (1993) 297; M. C. Atkinson et al., arXiv:1808.08895v1.

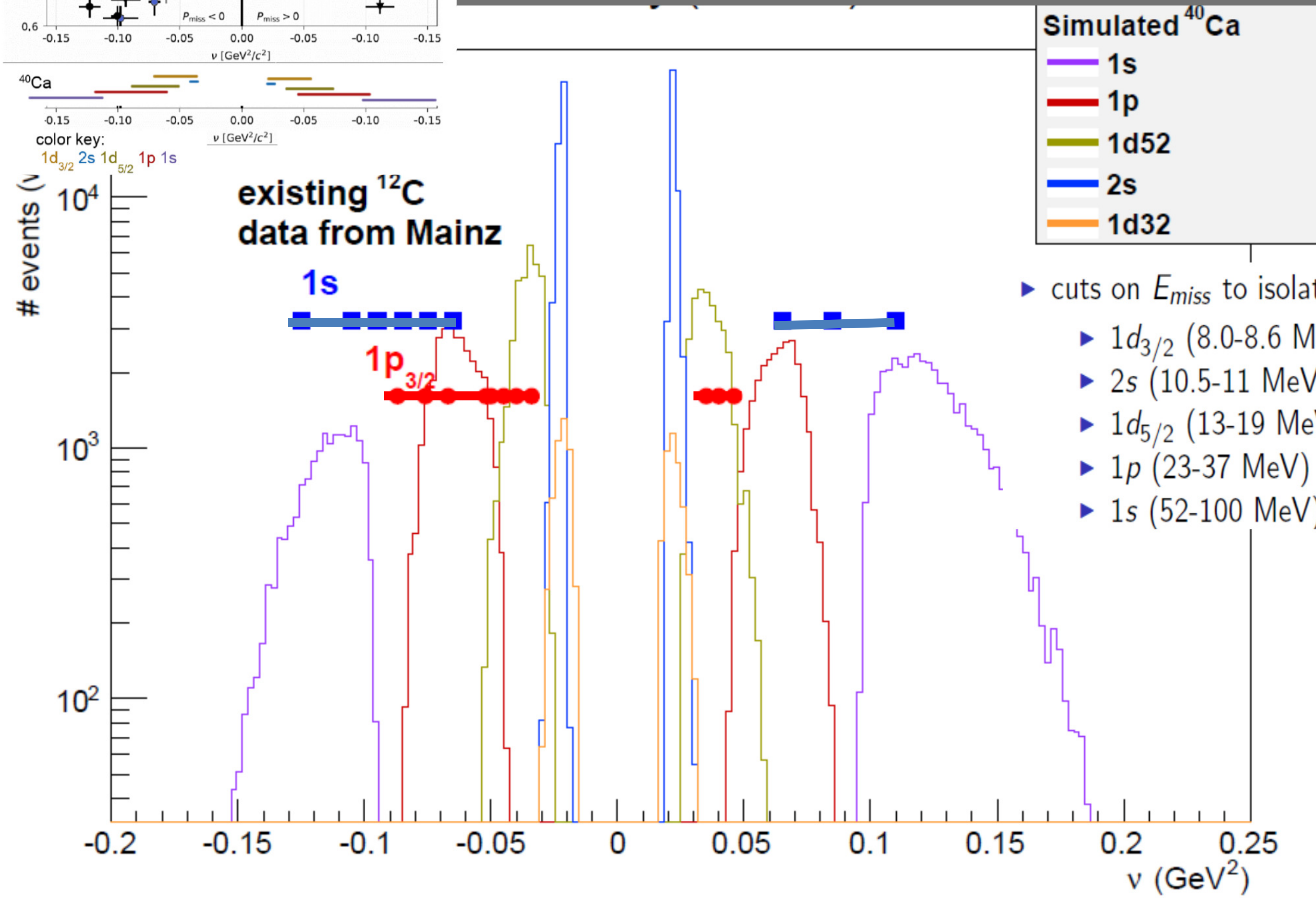
- cuts on E_{miss} to isolate:
  - $1d_{3/2}$ (8.0-8.6 MeV)
  - $2s$ (10.5-11 MeV)
  - $1d_{5/2}$ (13-19 MeV)
  - $1p$ (23-37 MeV)
  - $1s$ (52-100 MeV)



SACLAY (wide energy spectrum, low resolution)

J. Mougey et al. NP A262 (1976) 461.





- cuts on E_{miss} to isolate:
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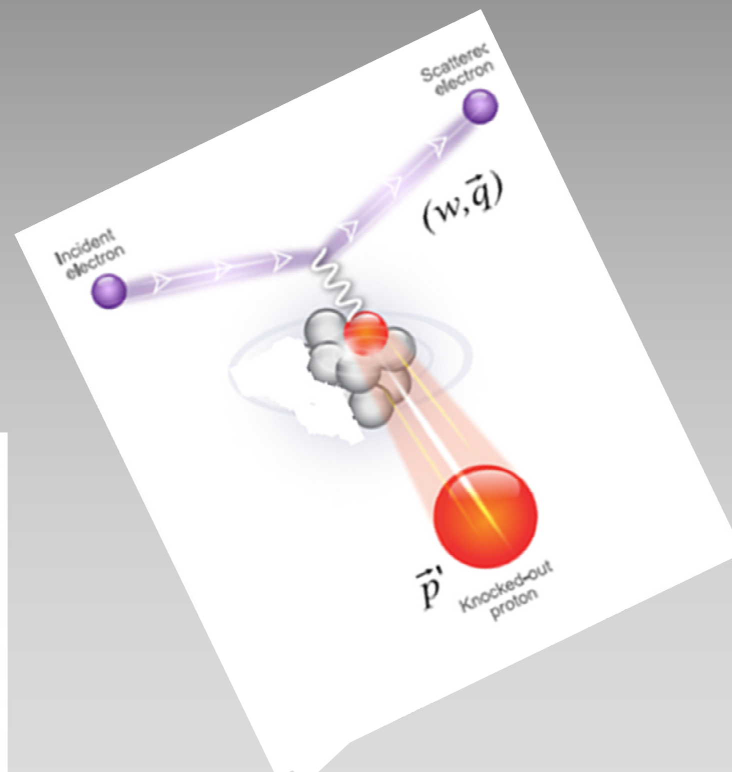
  - $2s$ (10.5-11 MeV)
  - $1d_{5/2}$ (13-19 MeV)
  - $1p$ (23-37 MeV)
  - $1s$ (52-100 MeV)

Quasi elastic scattering (no polarization)

The reduction of the single-particle strength in QE measurement

In collaboration with:
Sebouh Paul (Tel Aviv University)
Adi Ashkenazi and Or Hen (MIT)



A measurement of Short Range Correlation Pairs using

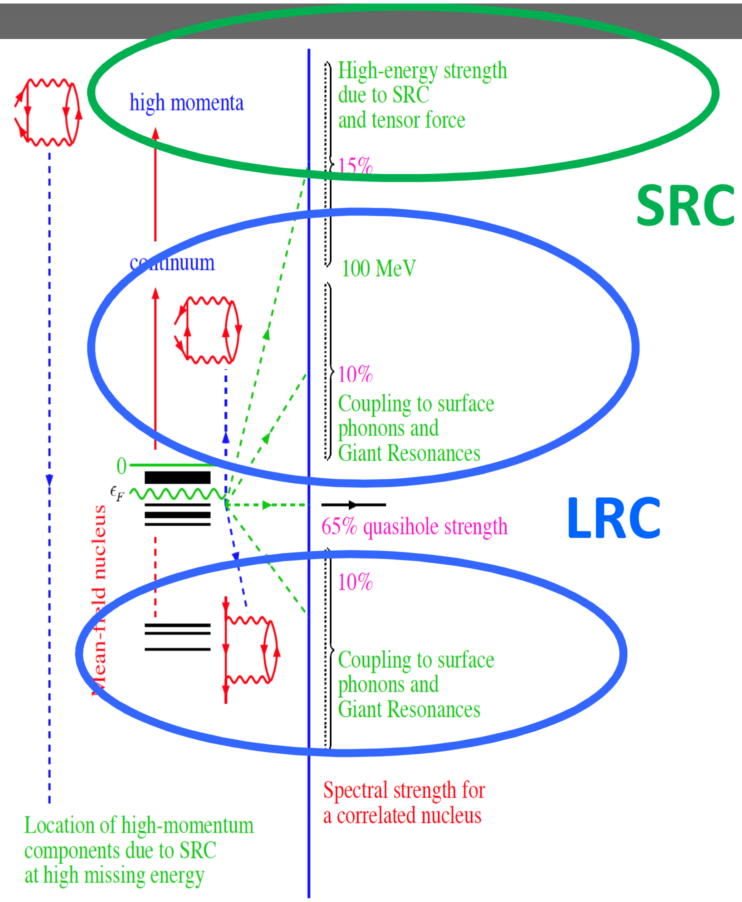
Recoil Tagging of $A(e,e',p_{rec})n$ processes

A Proposal for the Mainz MAMI A1 Collaboration

FIRST DRAFT 2.1

A. Ashkenazi*[2], E. O. Cohen[1], O.Hen[2], Y. Israel[1], D. Izraeli[1], I. Korover[1], E. Piasetzky[1], A. Schmidt[2], B. Schmookler[2], and R. C. Torres[2]

[1]School of Physics and Astronomy, Tel Aviv University, Israel.
[2]Massachusetts Institute of Technology, Cambridge, MA.



55. The distribution of single-particle strength in a nucleus like ^{208}Pb. The present summary is a synthesis of
[e]rimental and theoretical work discussed in this review. A slight reduction (from 15% to 10%) of the depletion
[ef]ct due to SRC must be considered for light nuclei like ^{16}O.

W.H. Dickhoff, C. Barbieri,
Progress in Particle and Nuclear
Physics 52 (2004) 377–496

J. A. Tostevin[1,2] and A. Gade
PHYSICAL REVIEW C 90, 057602 (2014)

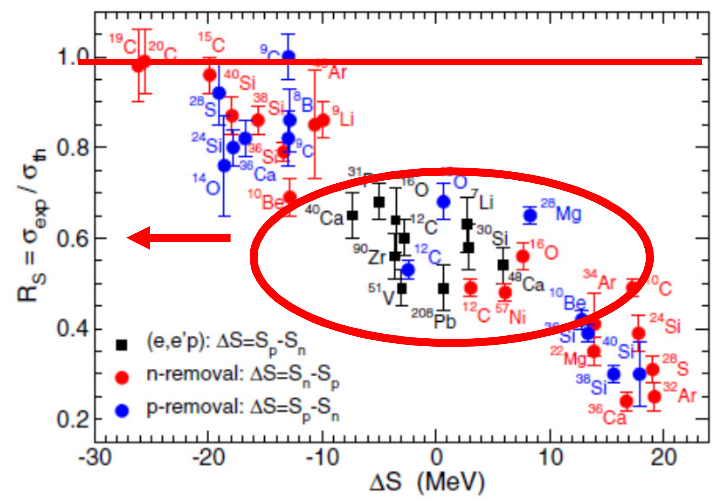
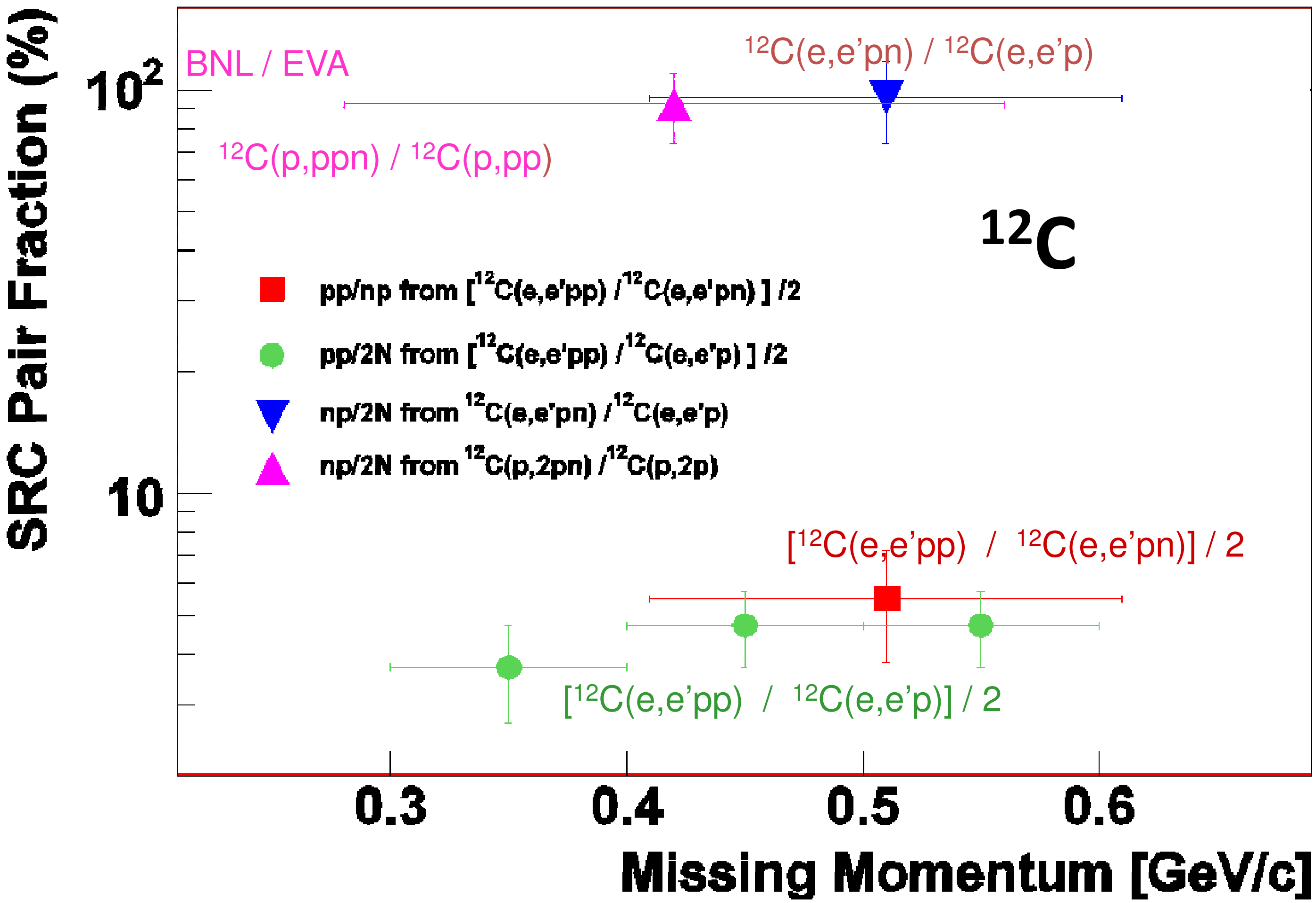
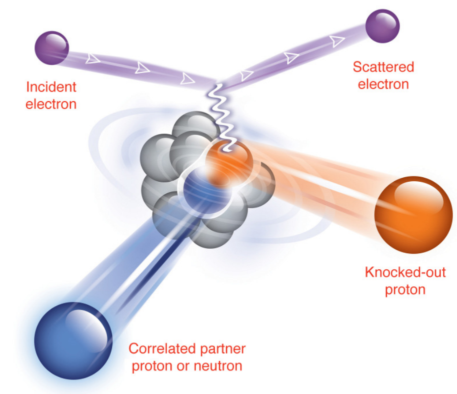


FIG. 1. (Color online) Compilation of the computed ratios R_s of the experimental and theoretical inclusive one-nucleon-removal cross sections for each of the projectile nuclei indicated. R_s is shown as a function of the parameter ΔS, used as a measure of the asymmetry of the neutron and proton Fermi surfaces. The red points are for neutron-removal cases and the blue points those for proton removal. The solid (black) squares, deduced from electron-induced proton knockout data, are identical to the earlier compilation of Ref. [5].

Piasetzky et al., PRL. 97 (2006) 162504.
R. Subedi et al., Science 320, 1476 (2008).



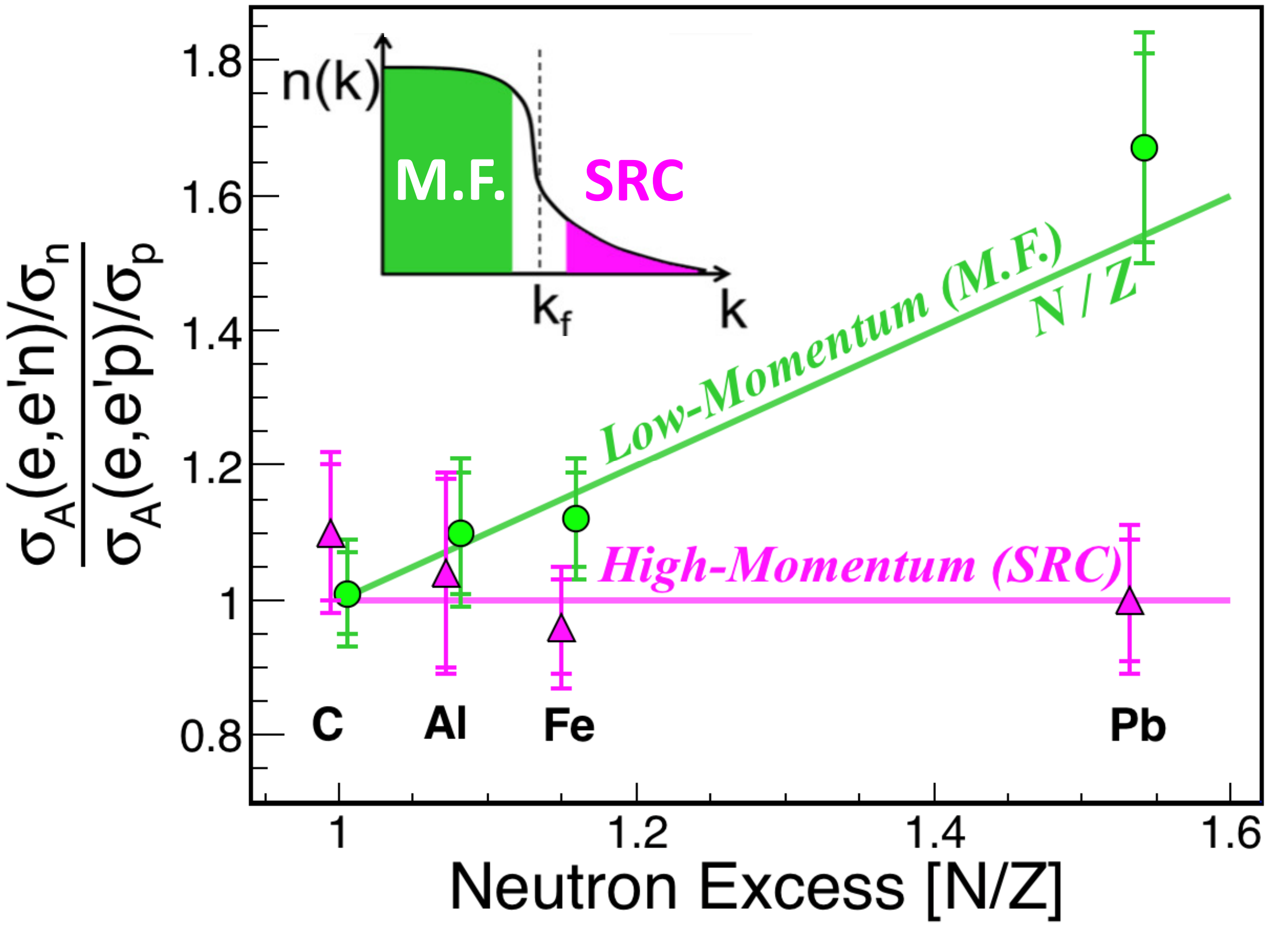


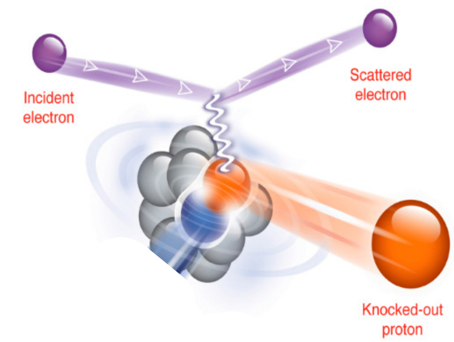
The high momentum tail in nuclei is dominated by SRC pairs

Most of the SRC pairs (90%) are np only 5% pp and 5% nn

Proton vs. Neutron Knockout

$A(e,e'p)\ \ A(e,e'n)$

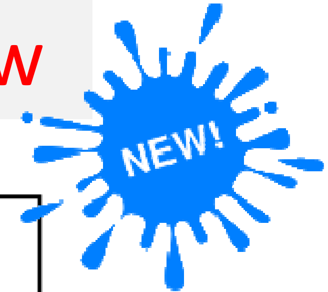


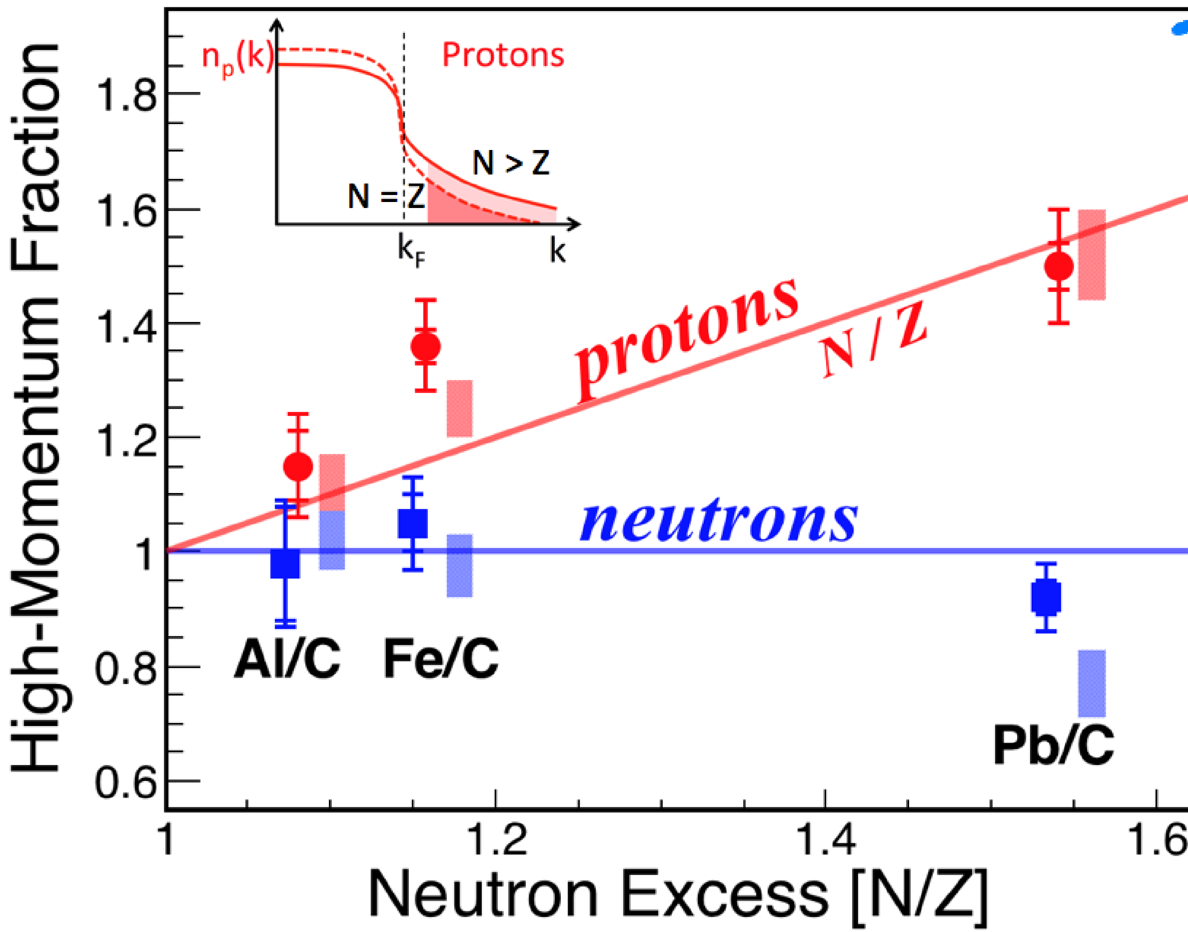


➔ Same # of high-momentum protons and neutrons

M. Duer et al. (CLAS Collaboration), Nature, 560 (2018) 617-621

Correlation Probability:
Neutrons saturate Protons grow





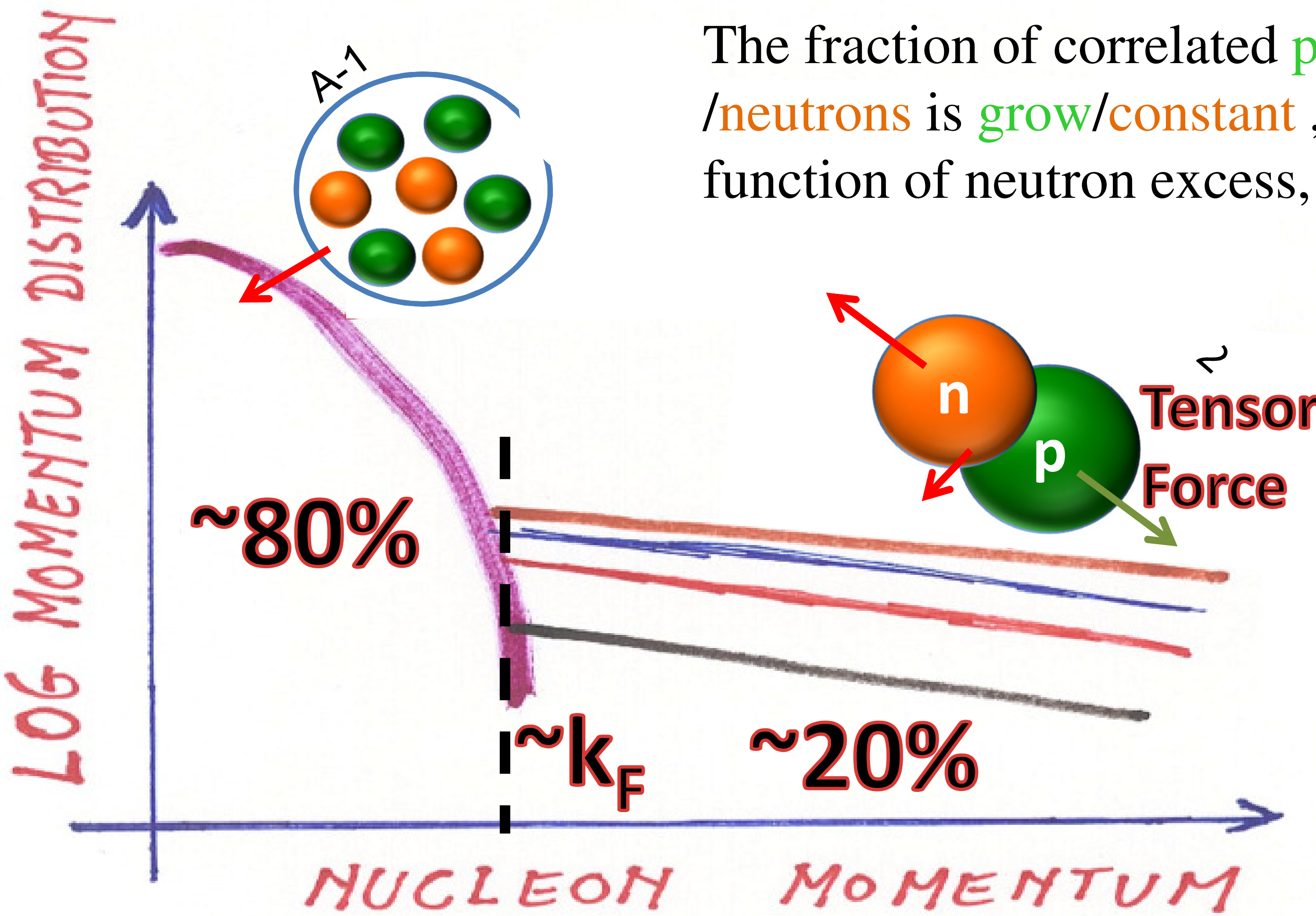
M. Duer et al. (CLAS Collaboration), Nature, 560 (2018) 617-621

np – dominance

$k > k_F$

#protons = #neutrons,
irrespectively of the neutron excess

The fraction of correlated protons /neutrons is grow/constant , as a function of neutron excess,



Isospin dependence of nucleon-nucleon correlations and the reduction of the single-particle strength in atomic nuclei

S. Paschalis,[1] A. O. Macchiavelli,[2] M. Petri,[1] O. Hen,[3] and E. Piasetzky[4]

NEW!

- Model the quenching of spectroscopic factors using 3 mains ingredients:

$$|g.s.\rangle = f|SP\rangle + \sqrt{\alpha}|PVC\rangle + \sqrt{\beta}|2p2h\rangle + \sqrt{\gamma}|SRC\rangle$$

Single-Particle | Particle-Vibration Coupling | Pairing | Short-Range Correlations

Long-Range Correlations

- Use data-driven parametrizations for the asymmetry dependence of each effect.

$$QF = 1 - \alpha(1 + \frac{33}{51}\frac{N-Z}{A})^2 -$$

α(g.s->g.s) ≠ α(g.s)->all

$$0.0324(1 - 6.07(\frac{N-Z}{A})^2)^2 -$$

Nuclear Physics **A431** (1984) 393-418
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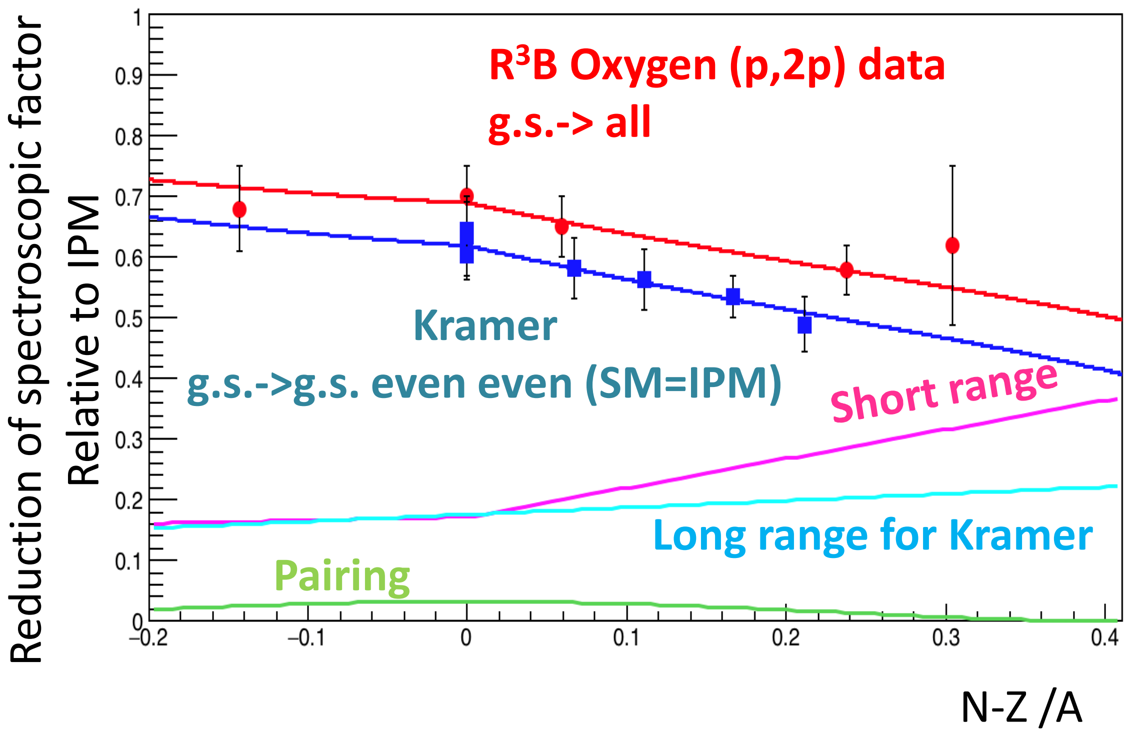
$$\gamma(1 + SL_{SRC}\frac{(N-Z)}{A})$$

SRC data, Duer at al.

- Use measured spectroscopic factors to determine relative amplitudes

Isospin dependence of nucleon-nucleon correlations and the reduction of the single-particle strength in atomic nuclei

S. Paschalis,[1] A. O. Macchiavelli,[2] M. Petri,[1] O. Hen,[3] and E. Piasetzky[4]



NEW!

- G. Kramer, H. Blok, and L. Lapikas, NPA, 679 (2001)
- J. Lee et al., PRC 73, 044608 (2006)
- L. Atar, Phys. Rev. Lett. 120 (5) (2018) 052501

Obtained: SRC fraction: 20 ± 7 %

LRC (g.s->g.s):~18%

LRC(g.s.->all):~11%

Pairing: small

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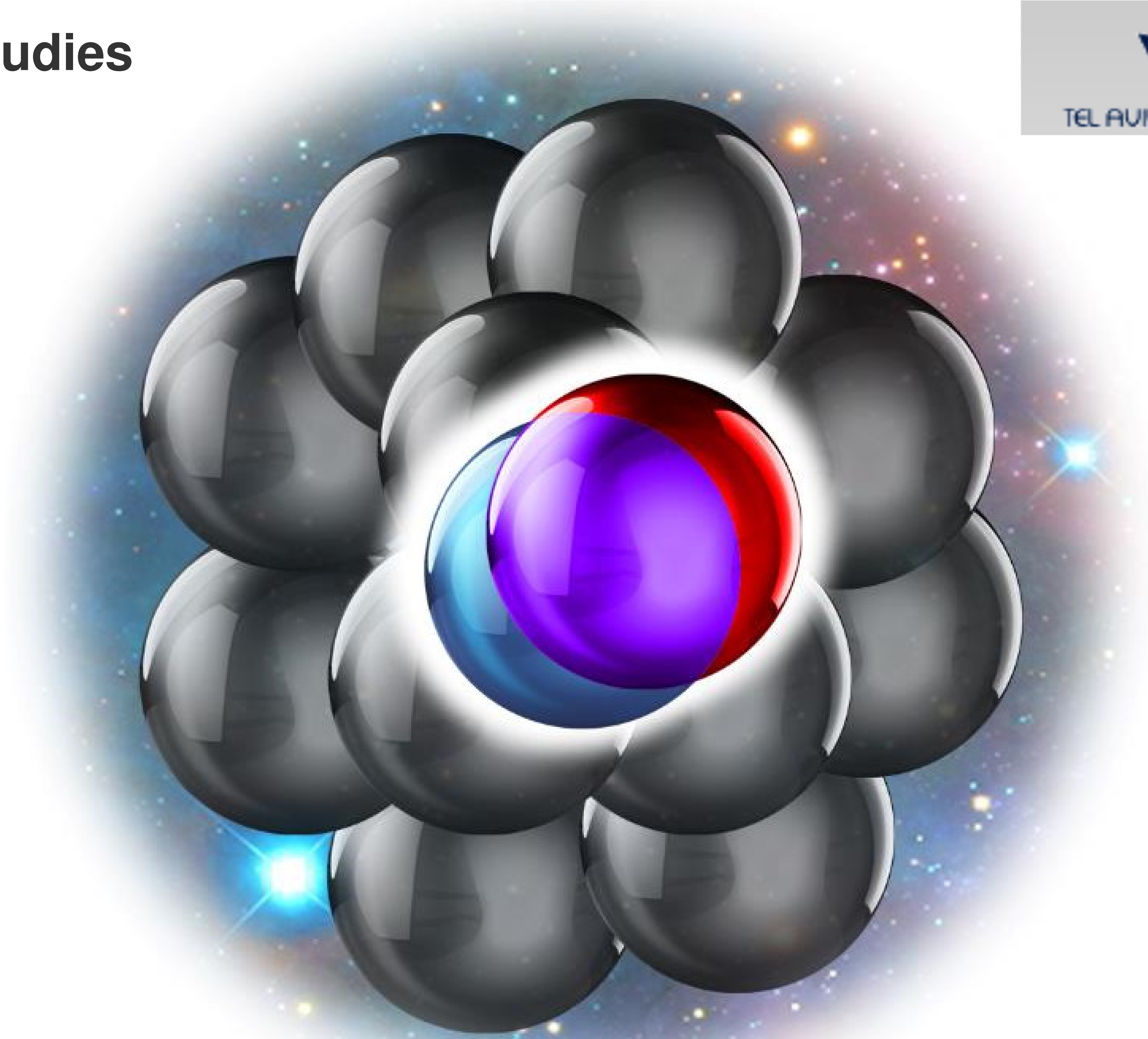
SRC studies

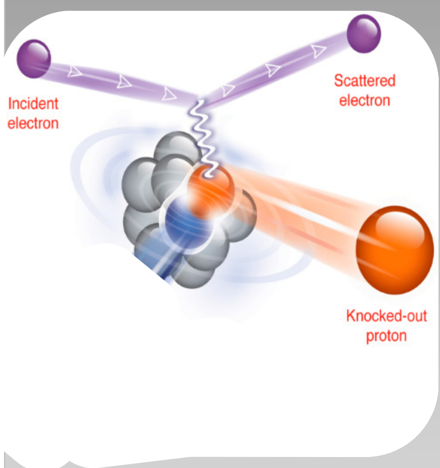


Deatiled Study Short-Range Pairing Mechanisms in Nuclei

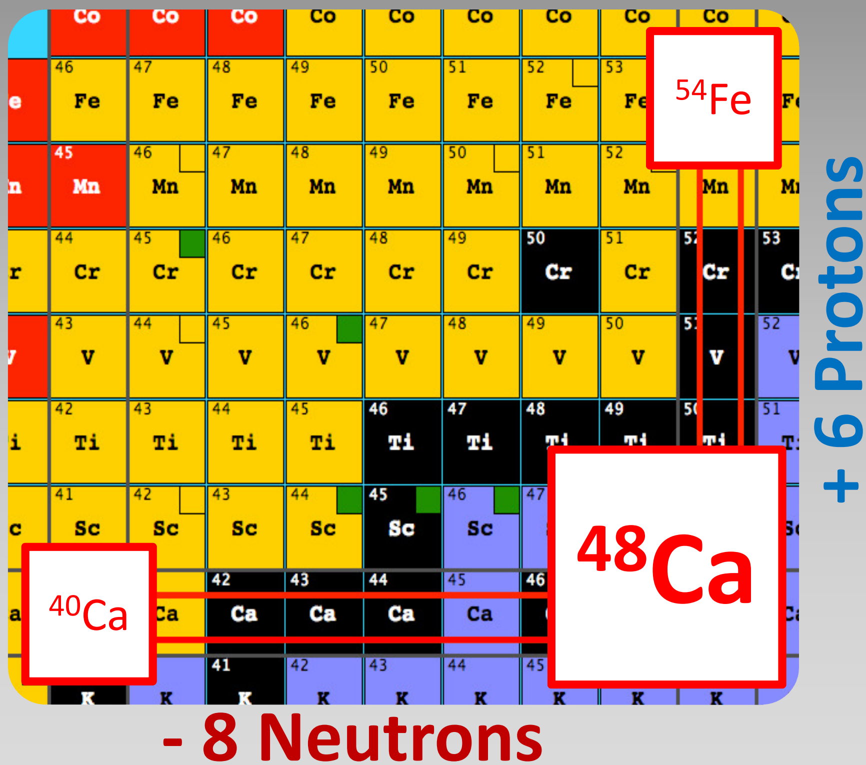
Outlook: Heavy Nuclei (JLab.)

The CaFe Experiment: Short-Range Pairing Mechanisms in Heavy Nuclei

Approved JLab Exp 12-16-004



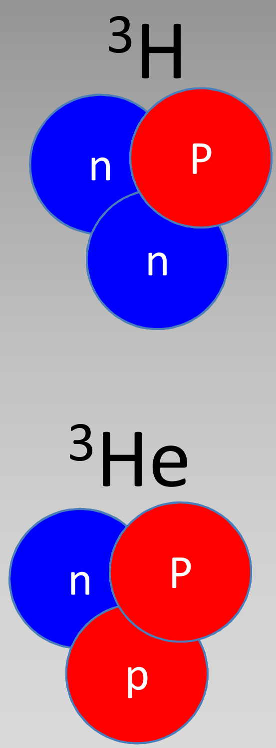
'leading'

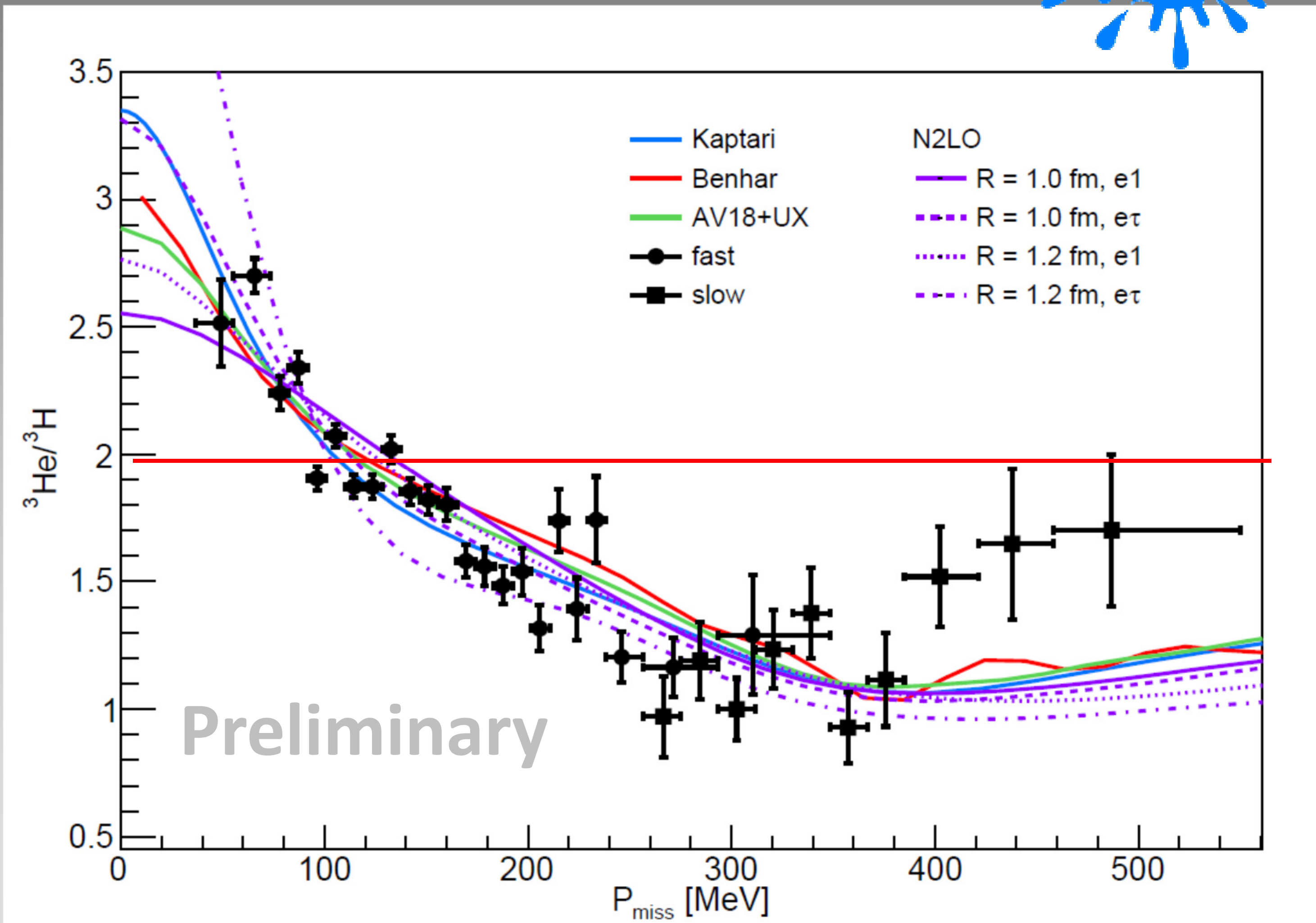


Outlook: light nuclei (JLab.)

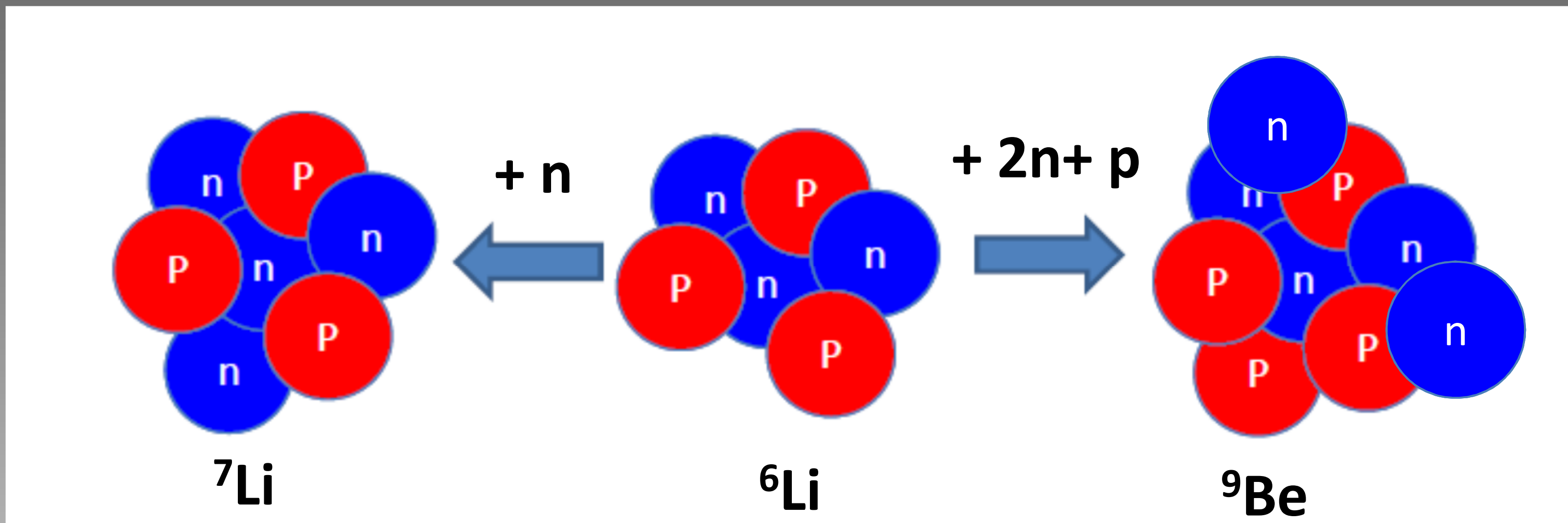
Proton and Neutron Momentum Distributions in *A*=3 Asymmetric Nuclei

JLab Exp 12-13-012





Outlook: light nuclei (MAINZ)



Study the relative probability of finding high-momentum proton ($p>p_F$) in these systems

A measurement of Short Range Correlation Pairs using

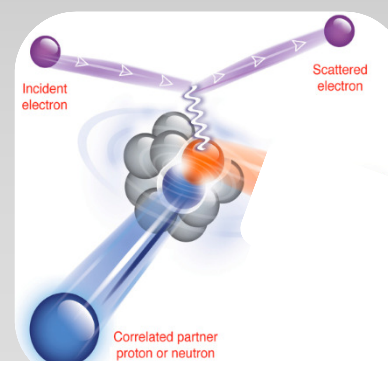
Recoil Tagging of A(e,e',p_{rec})n processes

A Proposal for the Mainz MAMI A1 Collaboration

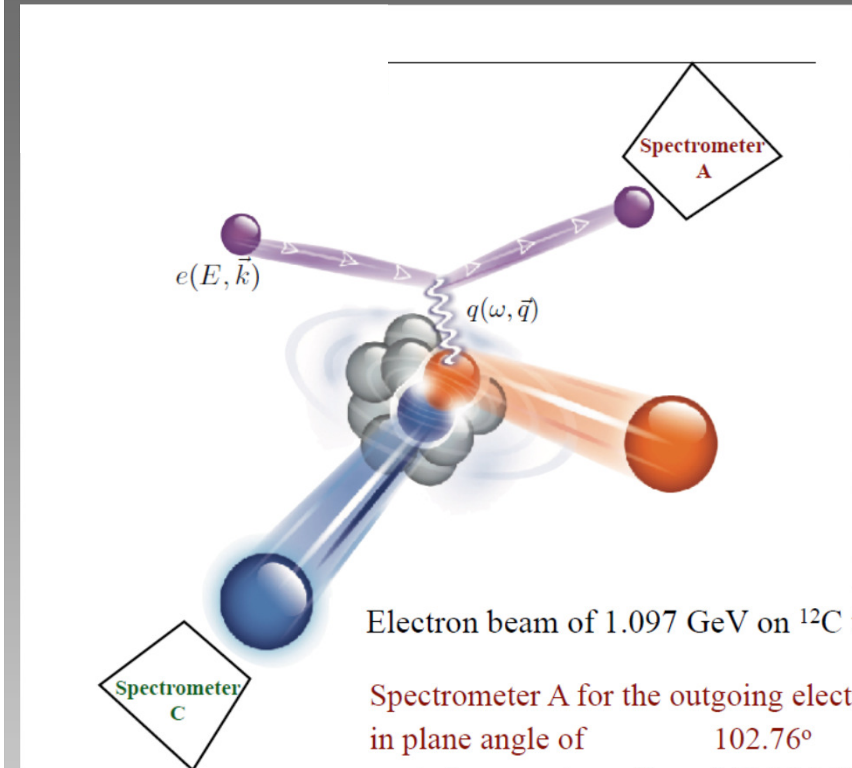
A. Ashkenazi*[2], E. O. Cohen[1], O.Hen[2], Y. Israel[1], D. Izraeli[1], I. Korover[1], E. Piasetzky[1],

A. Schmidt[2], B. Schmookler[2], and R. C. Torres[2]

'recoil'



Study SRC pairs with recoil tagging (MAINZ)



Electron beam of 1.097 GeV on ^{12}C target

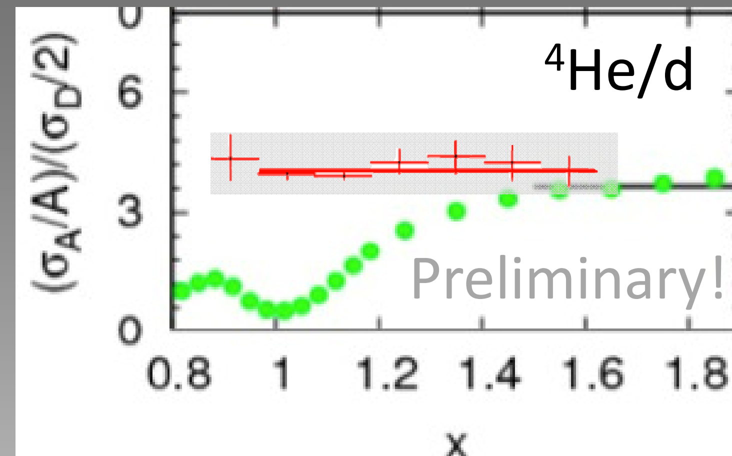
Spectrometer A for the outgoing electron at:
in plane angle of 102.76°
central momentum of 543.5 MeV

Spectrometer C for the recoil proton at:
in plane angle of 58.33°
central momentum of 387.2 MeV

$Q^2 = 1.5$ GeV^2
x = 1.48
angle between q and recoil ~ 35

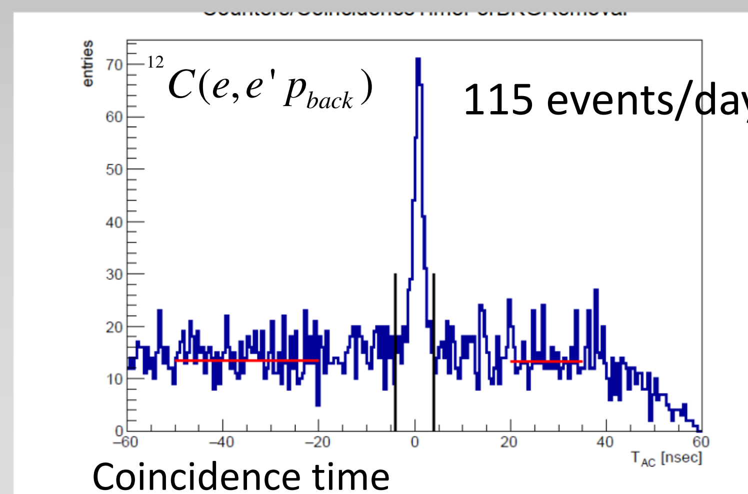
Beam time: 1 week per target
(~1000 events)

Counting SRCs using spectator tagging (JLab).



N. Moangma et al. (JLab Hall-A Collaboration)

Beam test at MAINZ (June 2017):



Summary

@ Mainz

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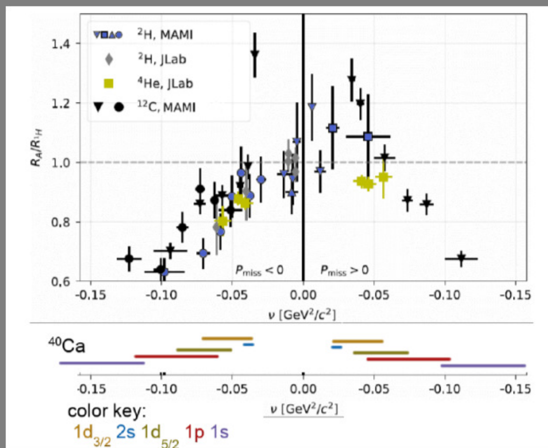
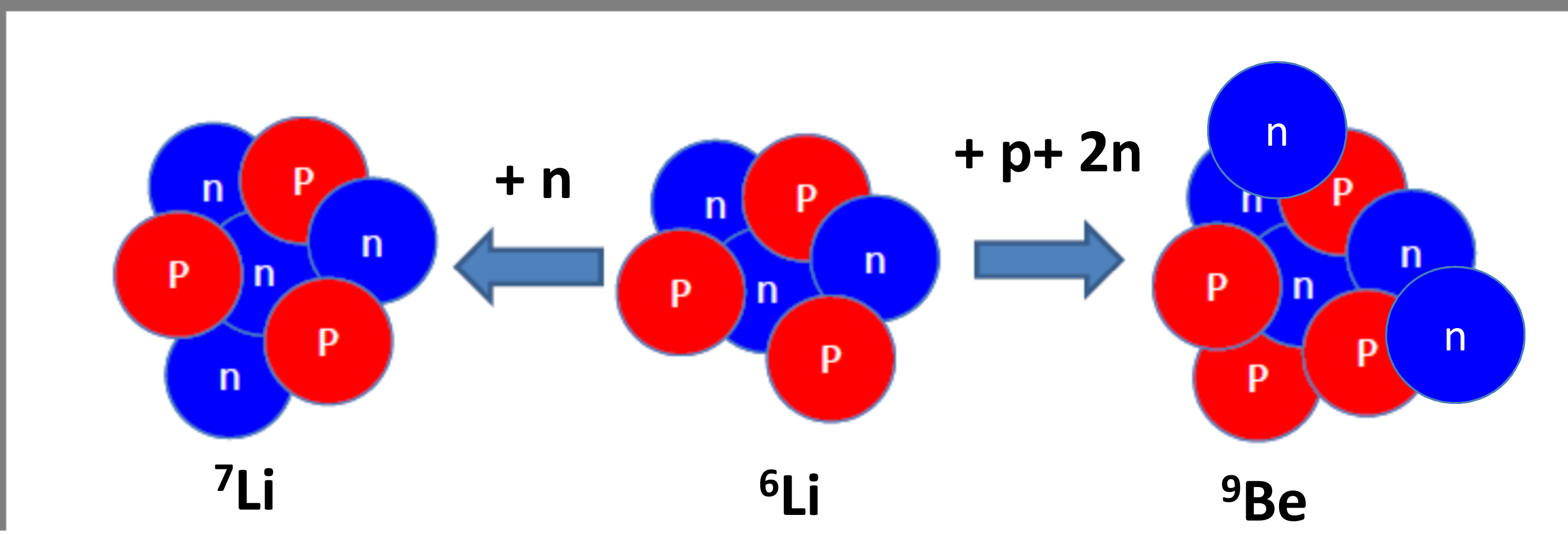


Better understanding of the nuclear physics involve in polarization transfer reactions.

$^{40}Ca(\vec{e},e'\vec{p})$

(Ar ?)

Detailed Study Short-Range Pairing Mechanisms in Nuclei



Acknowledgment

TEL AVIV UNIVERSITY

My Colleges:

Polarization-transfer measurement to a large-virtuality bound proton

A1 Collaboration: **I. Yaron** , **D. Izraeli** ,P. Achenbach, H. Arenhövel , J. Beričič , R. Böhm , D. Bosnar , T. Brecelj L. Debenjak , M., O. Distler , A. Esser , I. Friščić , R. Gilman , I. Korover , J. Lichtenstadt, H. Merkel , D. G. Middleton , M. Mihovilovič , U. Müller, S. Širca , S. Strauch J. Pochodzalla , G. Ron , B. S. Schlimme , M. Schoth , F. Schulz , C. Sfienti , M. Thiel , A. Tyukin , A. Weber .

SRC @ Mainz

A. Ashkenazi, S. Paul, E. O. Cohen, O.Hen, Y. Israel, D. Izraeli, I. Korover, A. Schmidt, B. Schmookler, R. C. Torres and the A1 collaboration.

and the organizers for the invitation.