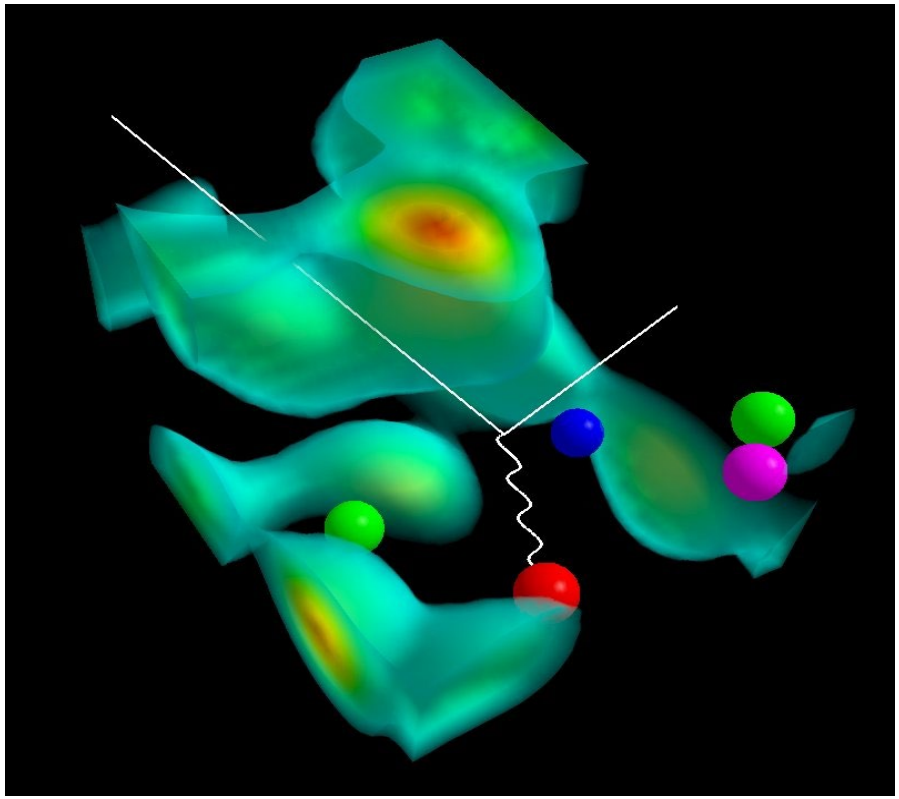
Nuclear Structure Starting at the Quark Level



Anthony W. Thomas

Fundamental Problems in Subatomic Physics
International Workshop : Cairns
27th September 2026

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SPECIAL RESEARCH CENTRE FOR THE SUBATOMIC STRUCTURE OF MATTER

Life has some bizarre twists













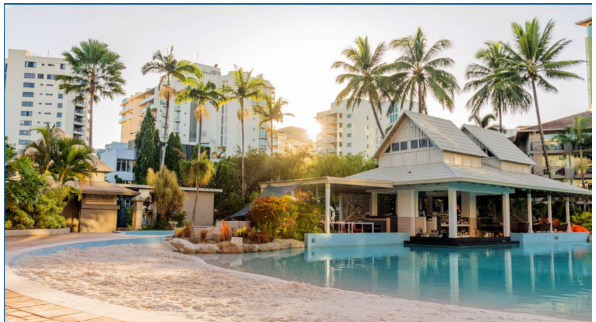
Outline

I. Nuclei from Quarks
- start from a QCD-inspired model of *hadron* structure
  - calculate change in structure in relativistic mean-fields
  - develop a quantitative theory of nuclear structure

II. Observable effect of change in hadron structure in-medium
  - EMC effect

III. Recent results for finite nuclei, including SHE (Z.ge.100)

IV. Axion field variation: effects on α decay rate



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I. Insights into nuclear structure

– what is the atomic nucleus?

There are two very different extremes….

Quark Structure matters/doesn't matter

- **Nuclear femtography: the science of mapping the quark and gluon structure of *atomic nuclei* is just beginning (EIC motivation)**

- **"Considering quarks is in contrast to our modern understanding of nuclear physics… the basic degrees of freedom of QCD (quarks and gluons) have to be considered only at higher energies. The *energies relevant for nuclear physics are only a few* MeV"**

Quark Structure matters/doesn't matter

- **Nuclear femtography: the science of mapping the quark and gluon structure of *atomic nuclei* is just beginning (EIC motivation)**

- **"Considering qu[illegible]s is in[illegible]ntrast to our modern understanding of [illegible]hysics… the basic degrees of freedo[illegible] (quarks and gluons) have to be consi[illegible]ed onl[illegible]t higher energies. The *energies relevant for nuclear physics are only a few* MeV"**

Why? What we know

- Since 1970s: Dispersion relations → intermediate range NN attraction is a strong Lorentz scalar

- In relativistic treatments (RHF, RBHF, QHD…) this leads to mean scalar field on a nucleon ~300 to 500 MeV!!

- *This is not small* – up to half the nucleon mass
  - death of "wrong energy scale" arguments

- Largely cancelled by large vector mean field BUT these have totally different dynamics: ω^0 just shifts energies, σ seriously modifies internal hadron dynamics

Suggests a different approach : QMC Model

(Guichon, Saito, Tsushima et al., Rodionov et al., Stone
- see Saito *et al*., Prog. Part. Nucl .Phys. 58 (2007) 1 and
Guichon *et al*., Prog. Part. Nucl. Phys. 100 (2018) 262 for reviews)

- Start with quark model (MIT bag/NJL...) for all hadrons

- Introduce a relativistic Lagrangian with σ, ω and ρ mesons coupling to the confined non-strange quarks

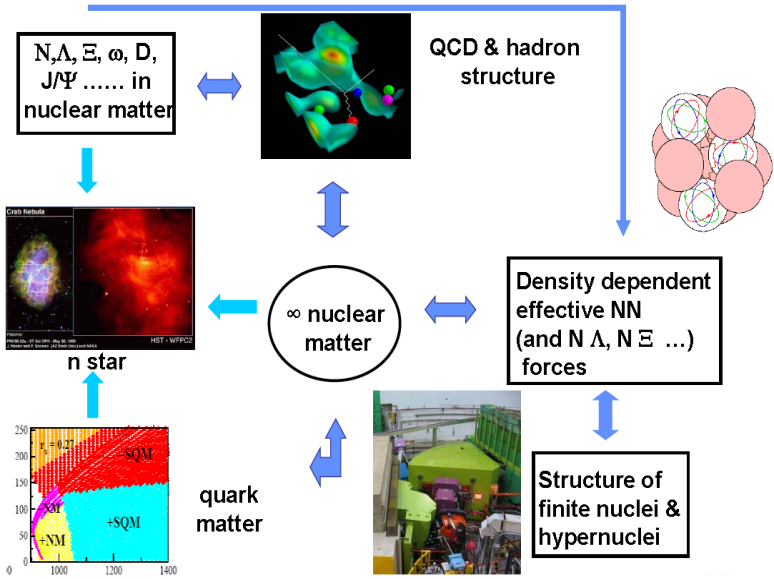
- Hence, initially only 4 parameters

  $(m_\sigma , g^{\sigma,\omega,\rho}{}_q)$

  − determine by fitting to:

  ρ_0 , E/A and symmetry energy

  − same in dense matter & finite nuclei



- Must solve self-consistently for the internal structure of baryons in-medium

Self-consistent solution for confined quarks in a hadron in nuclear matter

$$[i\gamma^{\mu}\partial_{\mu} - (m_q - g_{\sigma}{}^{q}\bar{\sigma}) - \gamma^{0}g_{\omega}{}^{q}\bar{\omega}]\psi = 0$$

Source of σ mean field changes: $\int_{Bag} d\vec{r}\bar{\psi}(\vec{r})\psi(\vec{r})$

SELF-CONSISTENCY

and hence mean scalar field changes…

and hence quark wave function changes….

THIS PROVIDES A NATURAL SATURATION MECHANISM (VERY EFFICIENT BECAUSE QUARKS ARE LIGHT)

source is suppressed as mean scalar field increases (i.e. as density increases)

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Quark-Meson Coupling Model (QMC):
Role of the Scalar Polarizability of the Nucleon

The response of the nucleon internal structure to the scalar field is of great interest… and importance

$$M^*(\mathbf{r}) = M - g_\sigma \sigma(\mathbf{r}) + \frac{d}{2}\left(g_\sigma \sigma(\mathbf{r})\right)^2$$

Non-linear dependence through the scalar polarizability

d ~ 0.22 R in original QMC (MIT bag)

At mean-field level, this is the ONLY place the response of the internal structure of the nucleon enters

≡ three-body force!

Application to nuclear structure

Derivation of Density Dependent Effective Force

Physical origin of density dependent forces of Skyrme type within the quark meson coupling model

P.A.M. Guichon [a,*], H.H. Matevosyan [b,c], N. Sandulescu [a,d,e], A.W. Thomas [b]

Nuclear Physics A 772 (2006) 1–19

- **Start with classical theory of MIT-bag nucleons with structure modified in medium to give M_{eff} (σ).**
- **Quantise nucleon motion (non-relativistic), expand in powers of derivatives**
- **Derive equivalent, local energy density functional:**

$$\langle H(\vec{r}) \rangle = \rho M + \frac{\tau}{2M} + \mathcal{H}_0 + \mathcal{H}_3 + \mathcal{H}_{\text{eff}} + \mathcal{H}_{\text{fin}} + \mathcal{H}_{\text{so}}$$

Derivation of EDF (cont.)

$$\mathcal{H}_0+\mathcal{H}_3=\rho^2\left[\frac{-3G_\rho}{32}+\frac{G_\sigma}{8(1+d\rho G_\sigma)^3}-\frac{G_\sigma}{2(1+d\rho G_\sigma)}+\frac{3G_\omega}{8}\right]$$
$$+(\rho_n-\rho_p)^2\left[\frac{5G_\rho}{32}+\frac{G_\sigma}{8(1+d\rho G_\sigma)^3}-\frac{G_\omega}{8}\right],$$

$$\mathcal{H}_{\text{eff}}=\left[\left(\frac{G_\rho}{8{m_\rho}^2}-\frac{G_\sigma}{2{m_\sigma}^2}+\frac{G_\omega}{2{m_\omega}^2}+\frac{G_\sigma}{4{M_N}^2}\right)\rho_n+\left(\frac{G_\rho}{4m_\rho^2}+\frac{G_\sigma}{2M_N^2}\right)\rho_p\right]\tau_n$$
$$+p\leftrightarrow n,$$

$$\mathcal{H}_{\text{fin}}=\left[\left(\frac{3G_\rho}{32{m_\rho}^2}-\frac{3G_\sigma}{8{m_\sigma}^2}+\frac{3G_\omega}{8{m_\omega}^2}-\frac{G_\sigma}{8{M_N}^2}\right)\rho_n\right.$$
$$\left.+\left(\frac{-3G_\rho}{16{m_\rho}^2}-\frac{G_\sigma}{2{m_\sigma}^2}+\frac{G_\omega}{2{m_\omega}^2}-\frac{G_\sigma}{4{M_N}^2}\right)\rho_p\right]\nabla^2(\rho_n)+p\leftrightarrow n,$$

$$\mathcal{H}_{\text{so}}=\nabla\cdot J_n\left[\left(\frac{-3G_\sigma}{8{M_N}^2}-\frac{3G_\omega(-1+2\mu_s)}{8{M_N}^2}-\frac{3G_\rho(-1+2\mu_v)}{32{M_N}^2}\right)\rho_n\right.$$
$$\left.+\left(\frac{-G_\sigma}{4{M_N}^2}+\frac{G_\omega(1-2\mu_s)}{4{M_N}^2}\right)\rho_p\right]+p\leftrightarrow n.$$

Spin-orbit force predicted!

Note the totally new, subtle density dependence

Overview of 106 Nuclei Studied – Across Periodic Table

J.R. Stone, P.A.M. Guichon, P. G. Reinhard & A.W. Thomas:
(Phys Rev Lett, 116 (2016) 092501)

Element	Z	N	Element	Z	N
C	6	6 -16	Pb	82	116 - 132
O	8	4 -20	Pu	94	134 - 154
Ca	20	16 – 32	Fm	100	148 - 156
Ni	28	24 – 50	No	102	152 - 154
Sr	38	36 – 64	Rf	104	152 - 154
Zr	40	44 -64	Sg	106	154 - 156
Sn	50	50 – 86	Hs	108	156 - 158
Sm	62	74 – 98	Ds	110	160
Gd	64	74 -100			

Not fit

N	Z	N	Z
20	10 – 24	64	36 - 58
28	12 – 32	82	46 - 72
40	22 – 40	126	76 - 92
50	28 – 50		

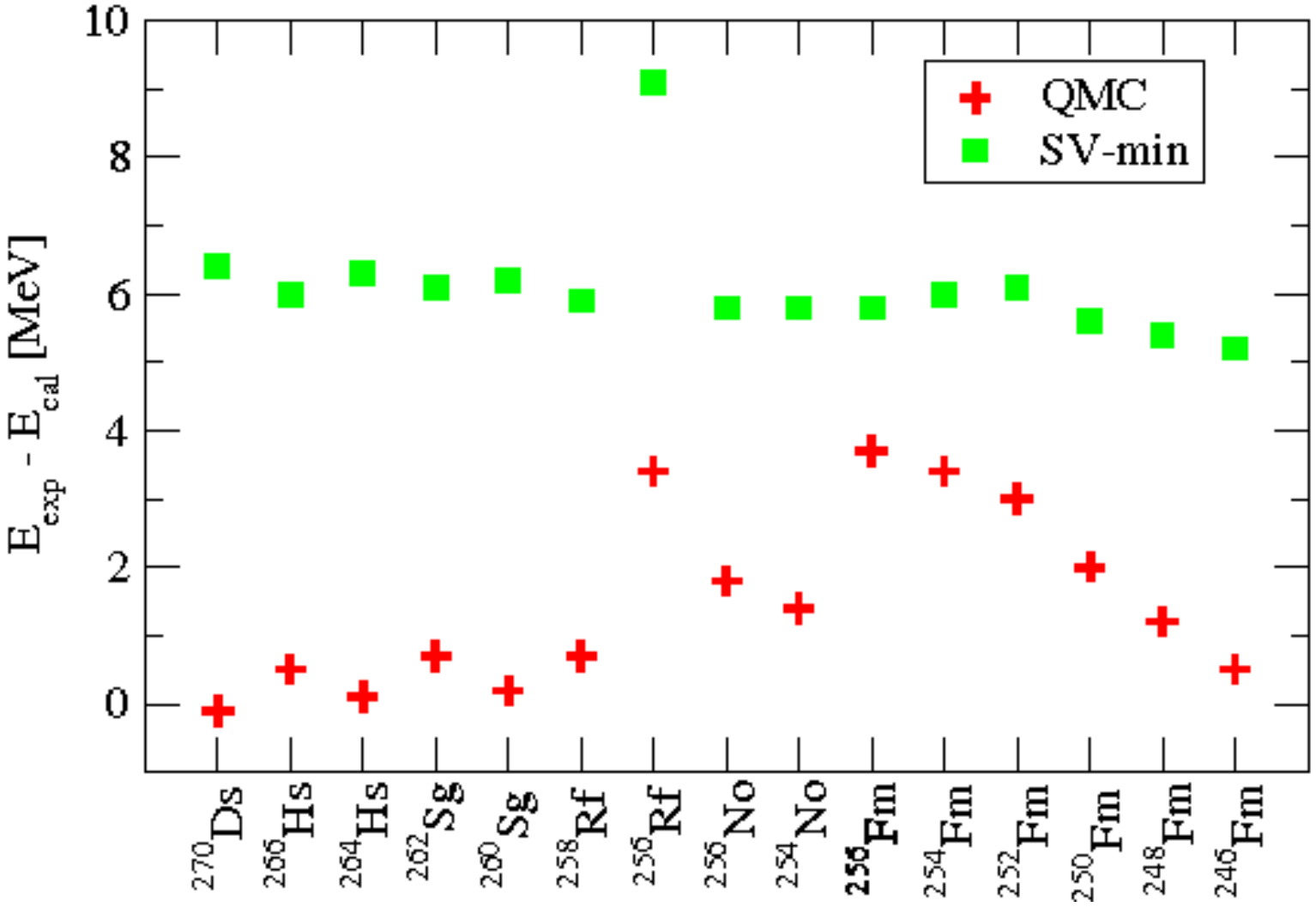
i.e. We look at most challenging cases of p- or n-rich nuclei

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Superheavy Binding : 0.1% accuracy



Stone et al., PRL 116 (2016) 092501

For detailed study of SHE see: arXiv:1901.06064

Giant Monopole Resonances

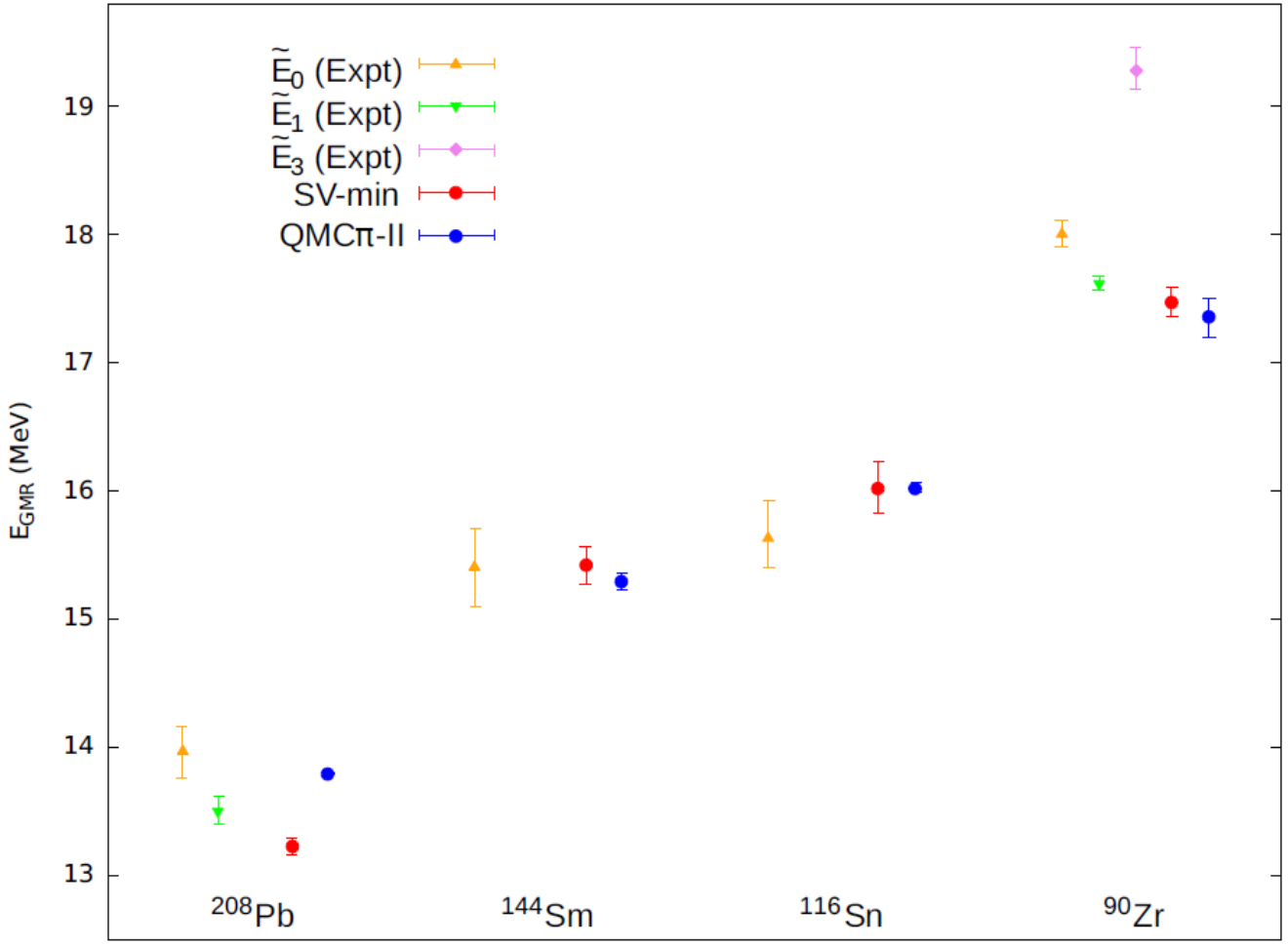
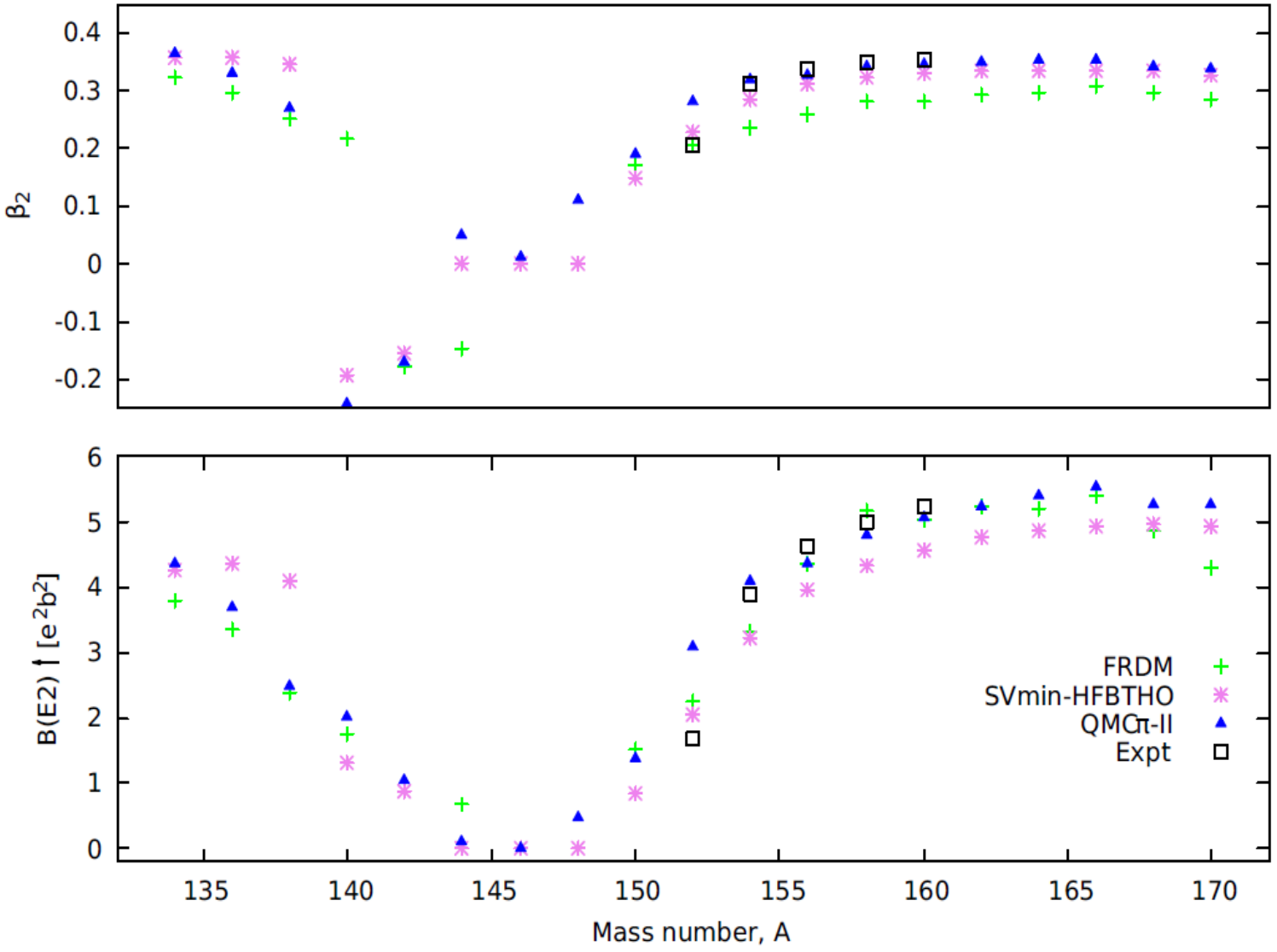


FIG. 13. GMR energies for ^{208}Pb, ^{144}Sm, ^{116}Sn, and ^{90}Zr from experiment and for the QMCπ-II and SVmin models. Experimental data are taken from Table 1 of Ref. [24].

Deformation of Gd isotopes



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Kay Martinez *et al.*, Phys Rev C100 (2019) 024333

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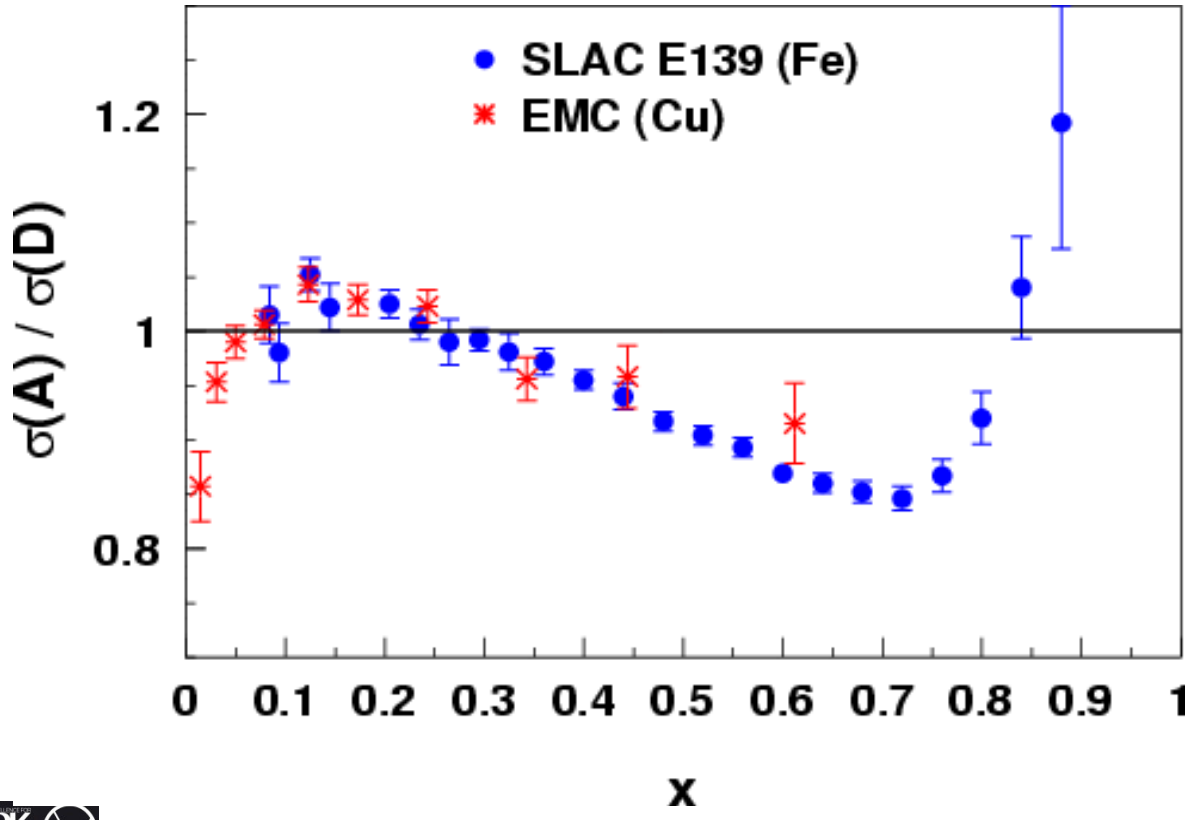
Overview of Initial Work on Finite Nuclei

- **The effective force was *derived* at the quark level *based upon the changing structure of a bound nucleon***
- **Has many less parameters but reproduces nuclear properties at a level comparable with the best phenomenological Skyrme forces**
- **Looks similar to standard nuclear forces**
- **BUT underlying theory also predicts modified internal structure and hence modified**
  - **DIS structure functions**
  - **elastic form factors.....**

The EMC Effect: Nuclear PDFs

- Observation **stunned and electrified** the HEP and Nuclear communities 40 years ago

- What is it that alters the quark momentum in the nucleus?



J. Ashman *et al.*, Z. Phys. C57, 211 (1993)

J. Gomez *et al.*, Phys. Rev. D49, 4348 (1994)

Theoretical Understanding

- Still numerous proposals but few consistent theories
- Initial studies used MIT bag[1] to estimate effect of self-consistent change of structure in-medium – but better to use a covariant theory
- For that Bentz and Thomas[2] re-derived change of nucleon structure in-medium in the NJL model
- This set the framework for sophisticated studies by Bentz, Cloët and collaborators over the last decade

[1] Thomas, Michels, Schreiber and Guichon, Phys. Lett. B233 (1989) 43
[2] Bentz and Thomas, Nucl. Phys. A696 (2001) 138

EMC Effect for Finite Nuclei

(There is also a spin dependent EMC effect - as large as unpolarized)

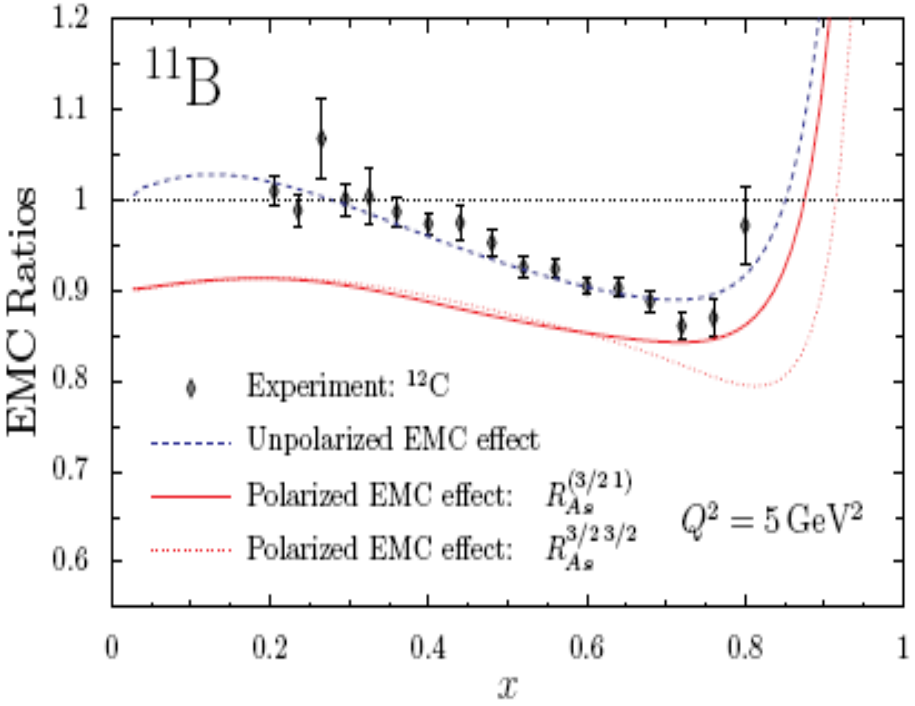


FIG. 7: The EMC and polarized EMC effect in ^{11}B. The empirical data is from Ref. [31].

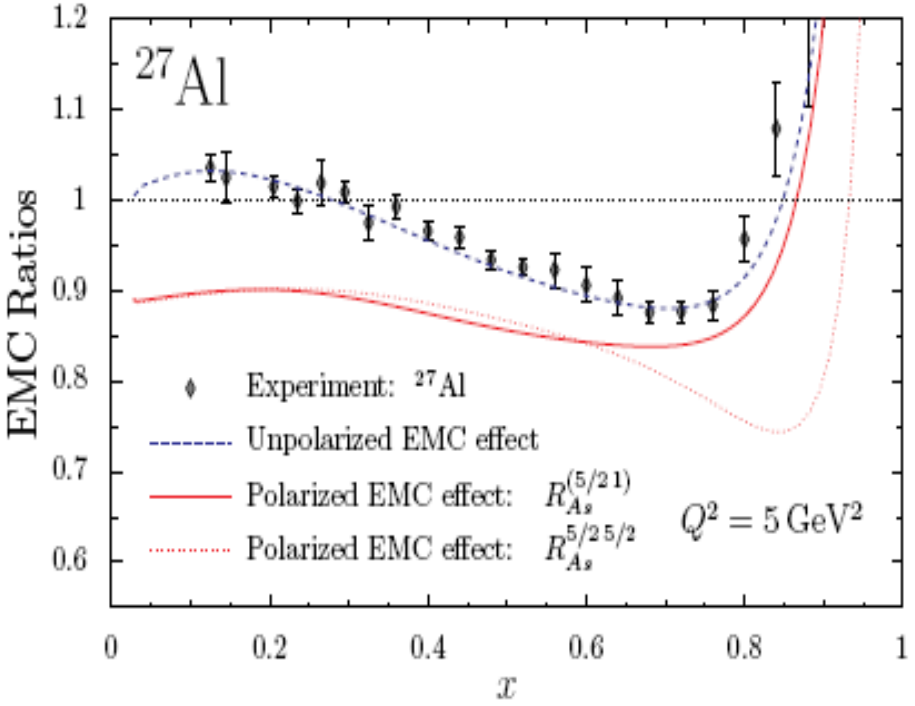
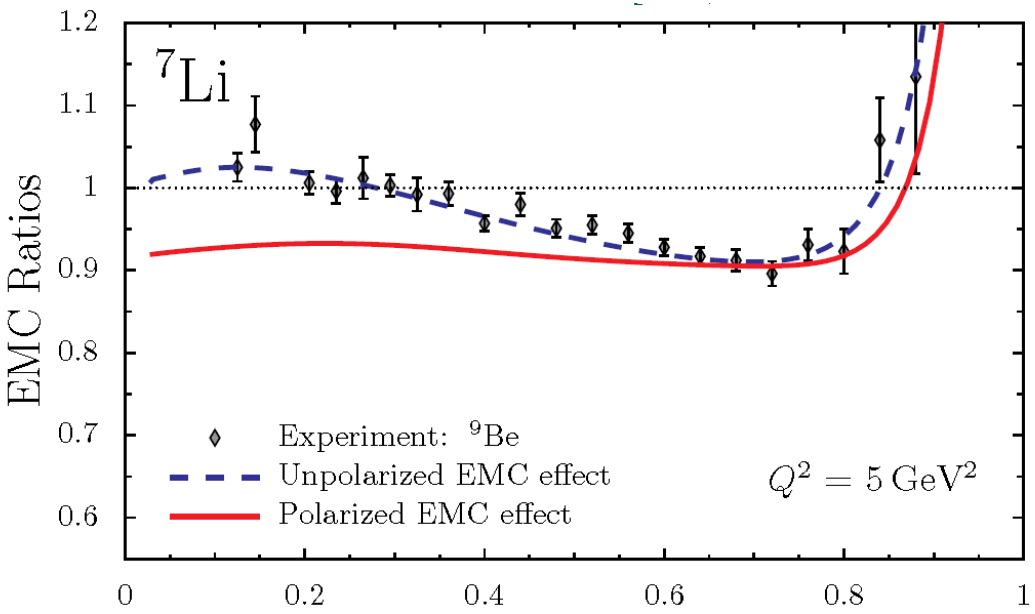


FIG. 9: The EMC and polarized EMC effect in ^{27}Al. The empirical data is from Ref. [31].

Approved JLab Experiment

- Effect in ^{7}Li is slightly suppressed because it is a light nucleus and proton does not carry all the spin (simple WF: $P_p = 13/15$ & $P_n = 2/15$)
- Experiment now approved at JLab [E12-14-001] to measure spin structure functions of ^{7}Li (GFMC: $P_p = 0.86$ & $P_n = 0.04$)



Spin EMC measurement is critical as the proposed explanation in terms of SRC through the tensor force gives NO spin EMC effect (arXiv:1809.06622)

More Nuclear Structure QMC-π3

(Publications in preparation: with Kay Martinez/Paglinawan)

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QMC π3

- More sophisticated representation of σ in terms of ρ
- **Just 5 parameters***: m_σ , quark couplings to σ, ω and ρ and λ_3 - the strength of σ^3 term
- Tensor term included:

$$H^J_{\sigma,\omega,\rho} = \left(\frac{G_\sigma(1-dv_0)^2}{4m_\sigma^2} - \frac{G_\omega}{4m_\omega^2}\right)\sum_m \vec{J}_m^2 - \frac{G_\rho}{4m_\rho^2}\sum_{m,m'} S_{m,m'}\vec{J}_m\cdot\vec{J}_{m'},$$

and $$H^J_S = -\frac{G_\sigma - G_\omega}{16M^2}\sum_m \vec{J}_m^2 + \frac{G_\rho}{16M^2}\sum_{mm'} S_{m,m'}\vec{J}_m\cdot\vec{J}_{m'}.$$

with $$\vec{J}_m = i\sum_{i\in F_m}\sum_{\sigma\sigma'}\vec{\sigma}_{\sigma'\sigma}\times[\vec{\nabla}\phi^i(\vec{r},\sigma,m)]\phi^{i*}(\vec{r},\sigma',m),\quad \vec{J}=\vec{J}_p+\vec{J}_n,$$

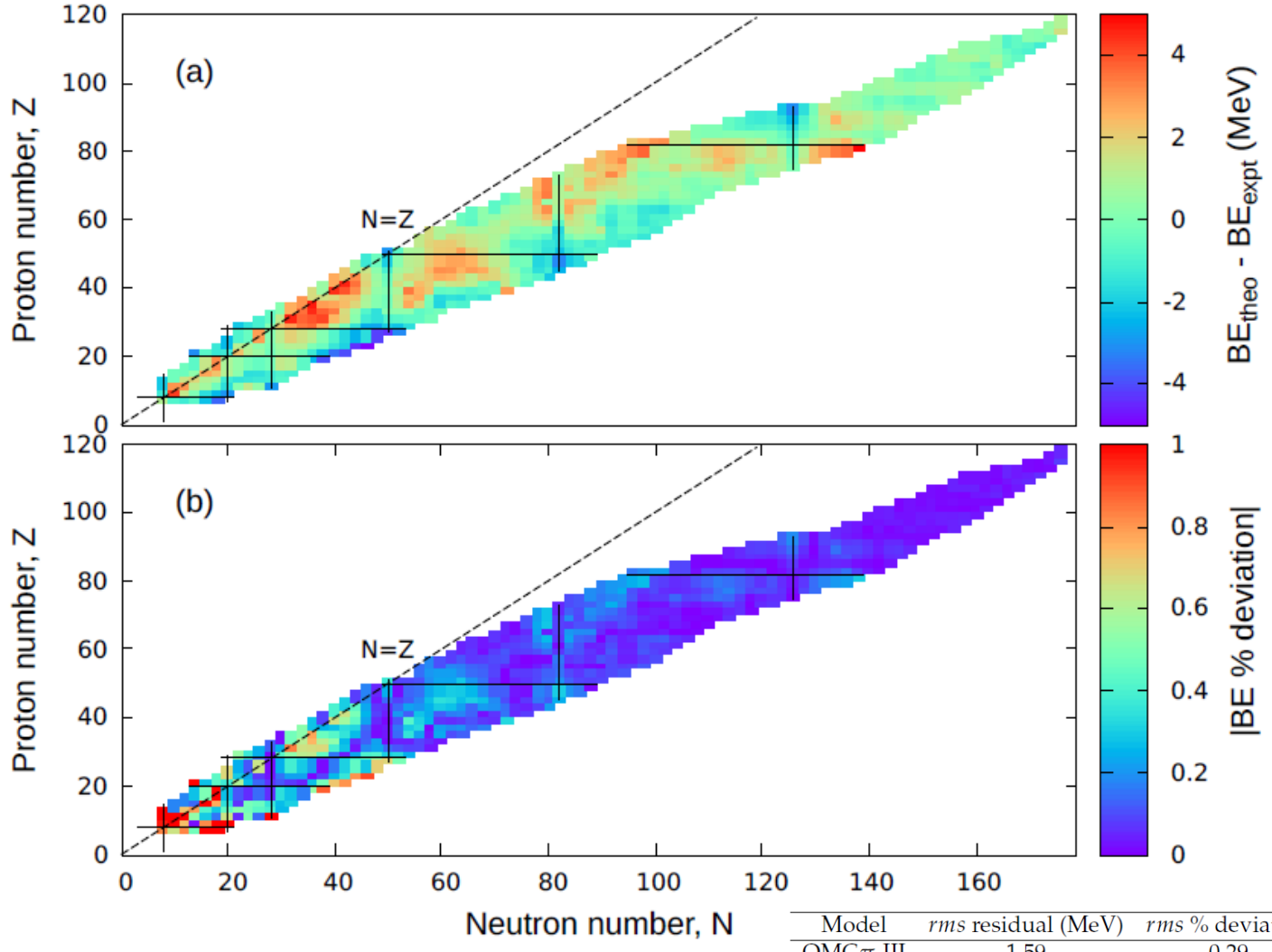
- Pairing interaction (simple BCS) derived in the model

$$V^{\rm QMC}_{\rm pair} = -\left(\frac{G_\sigma}{1+d'G_\sigma\rho(\vec{r})} - G_\omega - \frac{G_\rho}{4}\right)\delta(\vec{r}-\vec{r}')$$

$$d' = d + \tfrac{1}{3}G_\sigma\lambda_3.$$

*cf. Over 20 in FRDM and typically 16 (11+5) in Skyrme forces, χEFT and UNDEF

Binding Energies – All Known Even-Even Nuclei



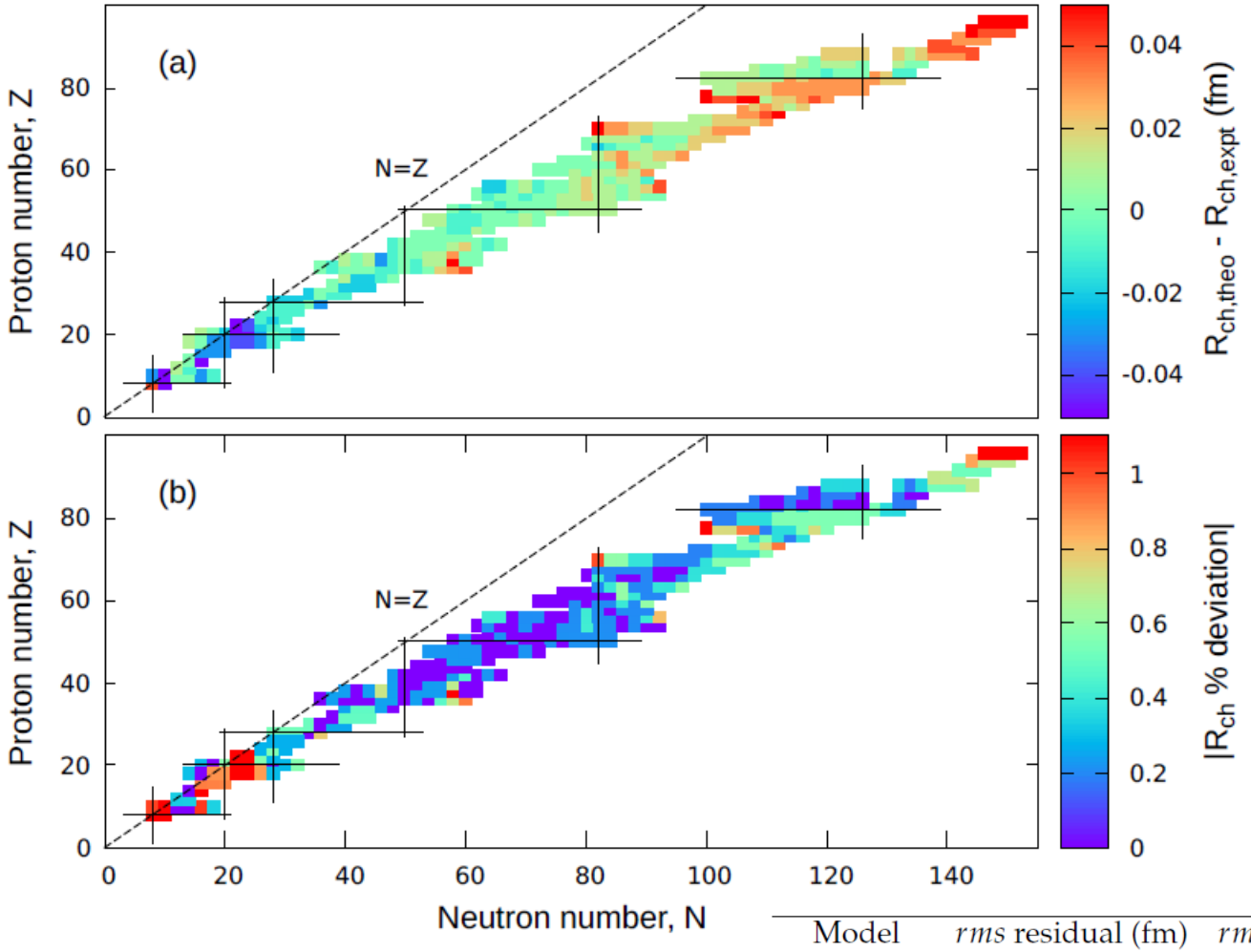
Model	*rms* residual (MeV)	*rms* % deviation
QMCπ-III	1.59	0.29
QMCπ-II	2.34	0.39
QMCπ-I	2.78	0.50
QMC-I	3.84	0.69
SV-min	3.64	0.38
UNEDF1	2.06	0.55
DD-MEδ	2.41	0.42
FRDM	0.89	0.18

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Charge Radii



Model	*rms* residual (fm)	*rms* % deviation
QMCπ-III	0.024	0.50
QMCπ-II	0.029	0.66
QMCπ-I	0.028	0.65
QMC-I	0.030	0.66
SV-min	0.024	0.61
UNEDF1	0.029	0.65
DD-MEδ	0.035	0.78

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Deformation

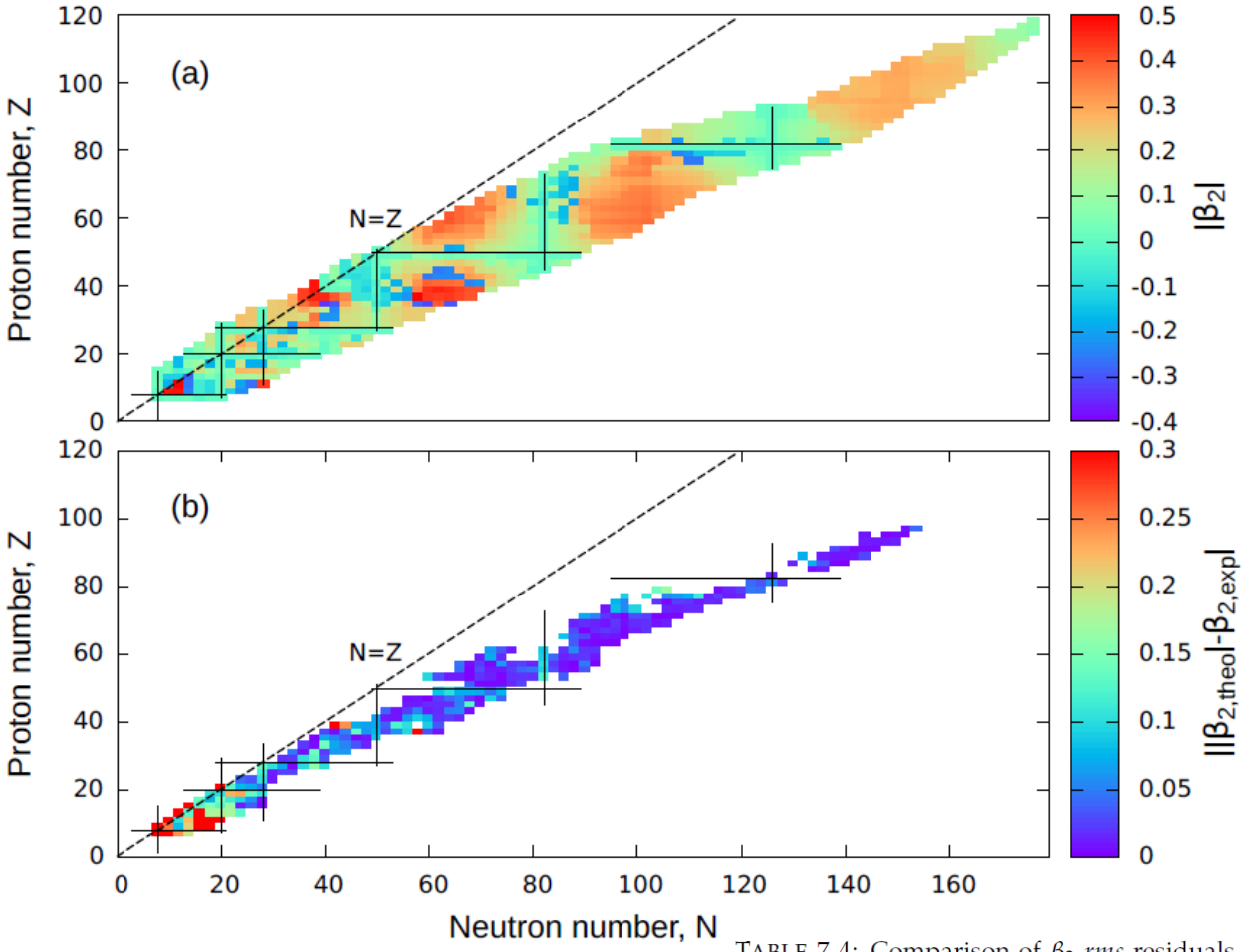
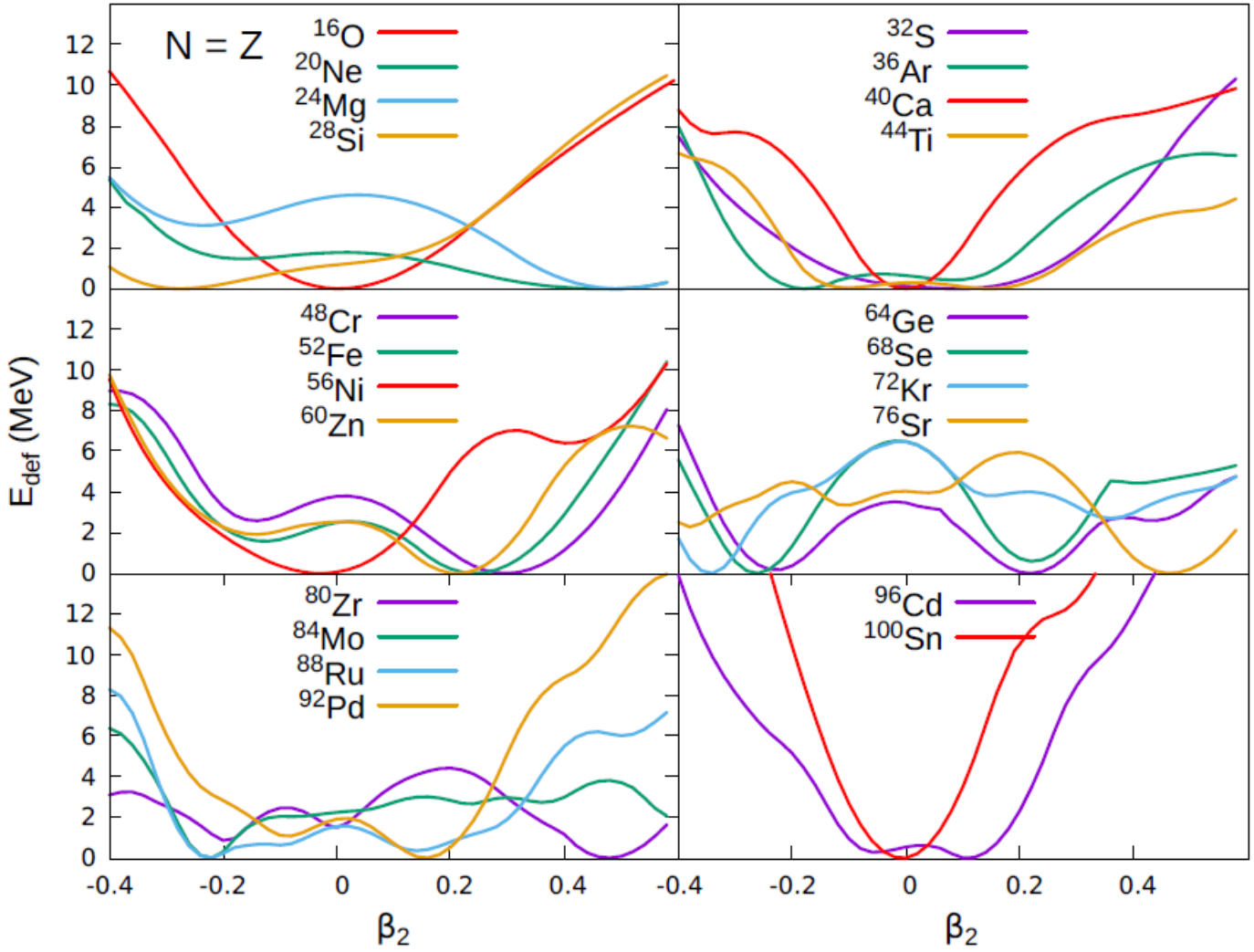


TABLE 7.4: Comparison of β_2 *rms* residuals and *rms* % deviations from QMCπ-III and from other nuclear models. There are a total of 324 even-even nuclei with available data for β_2 included for comparison.

Model	*rms* residual	*rms* % deviation
QMCπ-III	0.11	28
SV-min	0.16	59
UNEDF1	0.15	53
DD-MEδ	0.14	40
FRDM	0.11	30

Shape Co-Existence for Z=N



The Superheavy Region

First study:

PHYSICAL REVIEW C **100**, 044302 (2019)

Physics of even-even superheavy nuclei with $96 < Z < 110$ in the quark-meson-coupling model

J. R. Stone*
Department of Physics (Astro), University of Oxford, Keble Road OX1 3RH, Oxford, United Kingdom and Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA

K. Morita†
Department of Physics, Kyushu University, Nishi-ku, Fukuoka 819-0395, Japan and RIKEN Nishina Center, RIKEN, Wako-shi, Saitama 351-0198, Japan

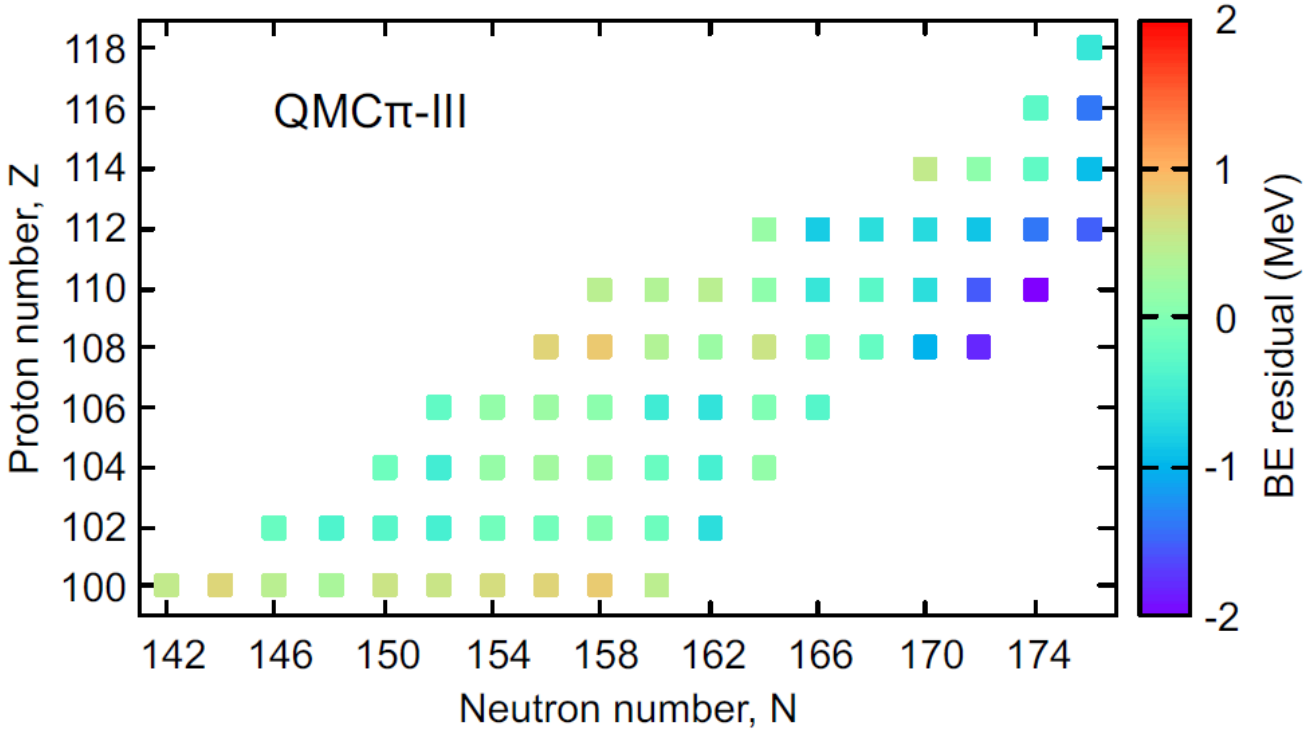
P. A. M. Guichon‡
CEA/IRFU/SPhN Saclay, F91191, France

A. W. Thomas§
CSSM and CoEPP, Department of Physics, University of Adelaide, SA 5005, Australia

Updated and expanded here (in preparation)

Deviation from total B.E.

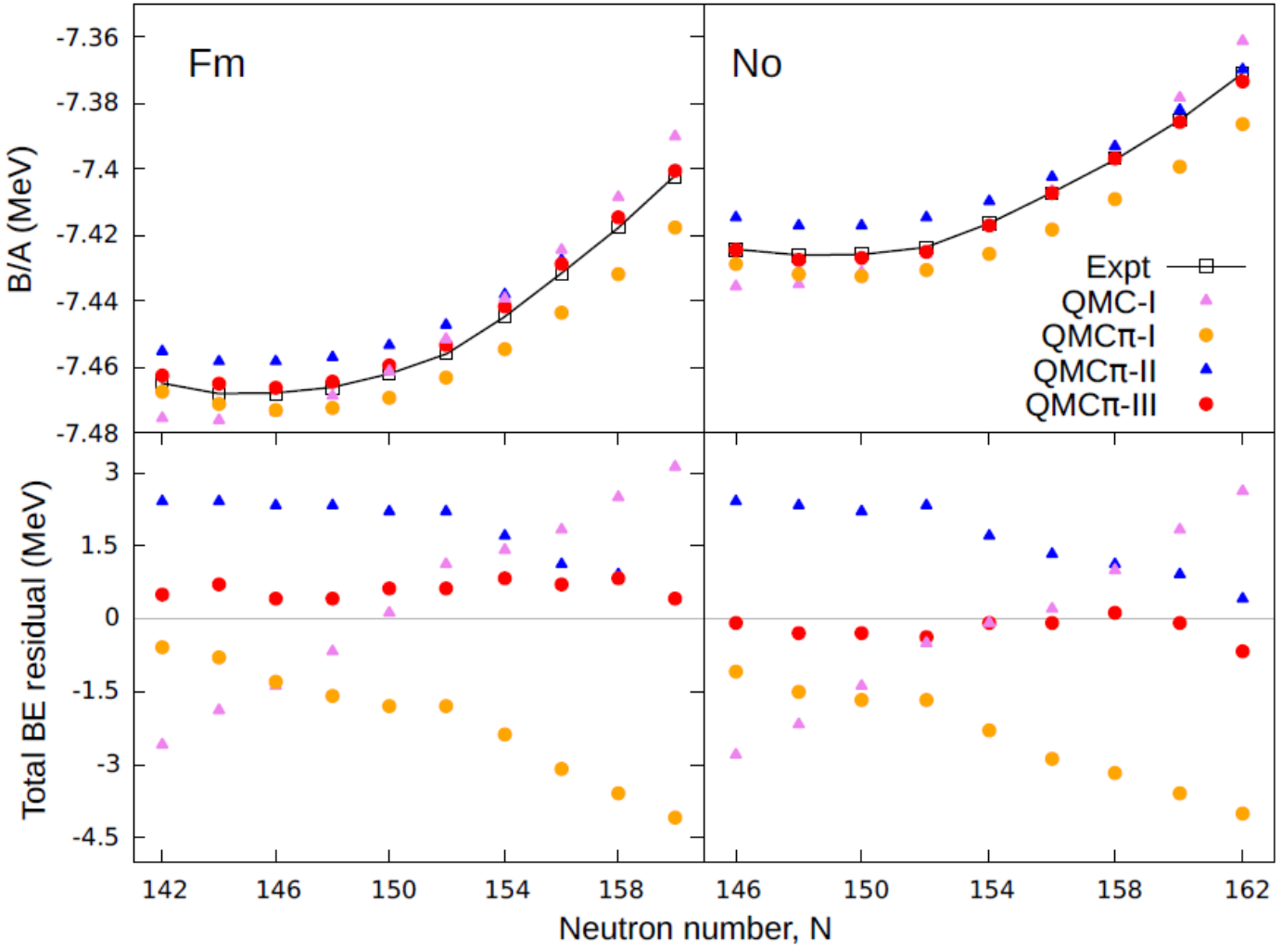
(Total binding is of order 2 GeV for Z ≥ 100)



	rms % deviation	*rms* residual (MeV)
QMCπ-III	0.03	0.52
QMCπ-II [54]	0.11	2.04
QMCπ-I [53]	0.12	2.42
QMC-I [8]	0.08	1.50
FRDM [23]	0.11	2.25
SV-min [24]	0.36	6.99
UNEDF1 [28]	0.07	1.31
DD-MEδ [66]	0.12	2.28

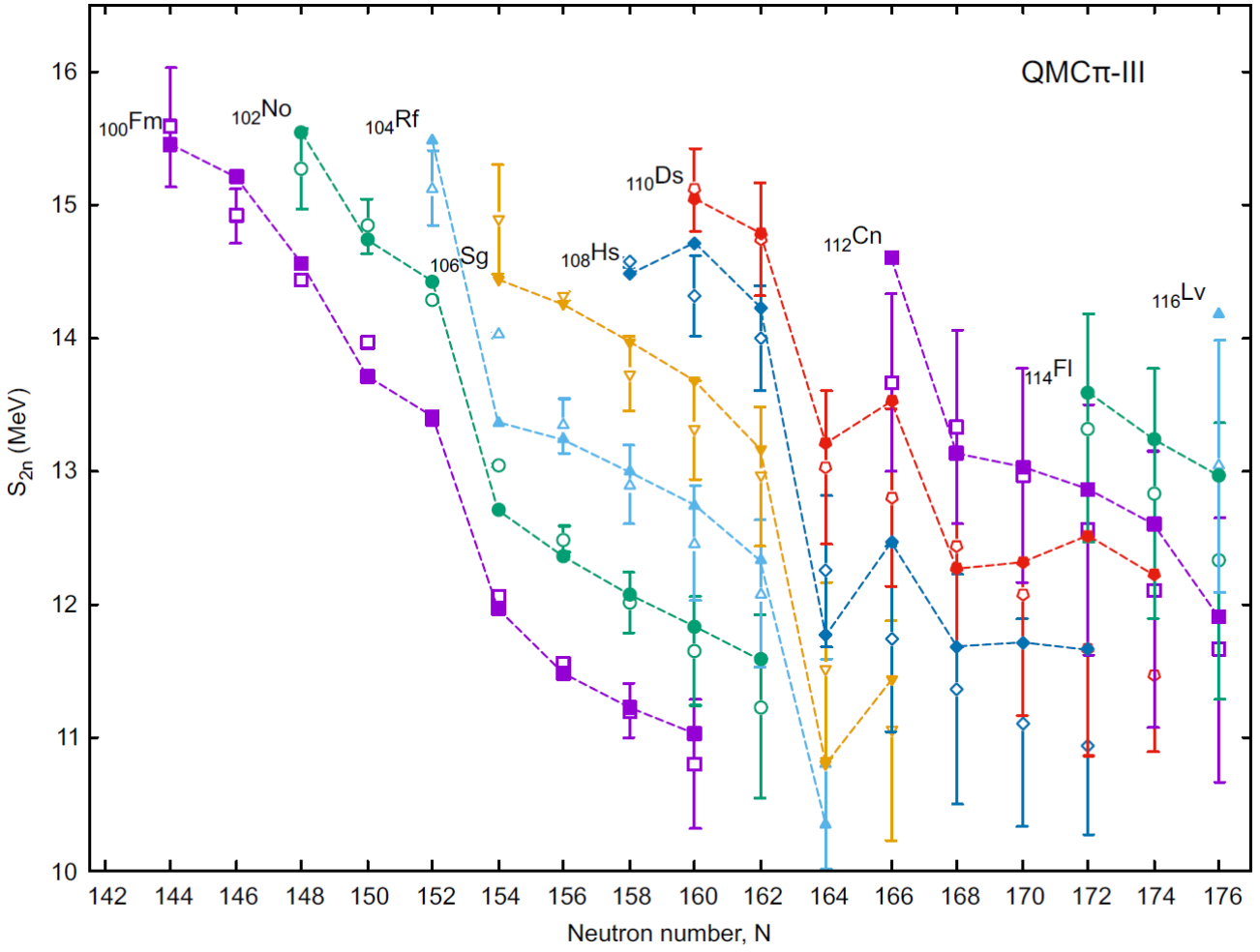
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Trends Along Chains: ^{100} Fermium and ^{102} Nobelium



Two neutron separation energies

Shows shell closures at N=152 and 162



Solid symbols QMC-π3 and open Experiment

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Shape co-existence – e.g. Flerovium

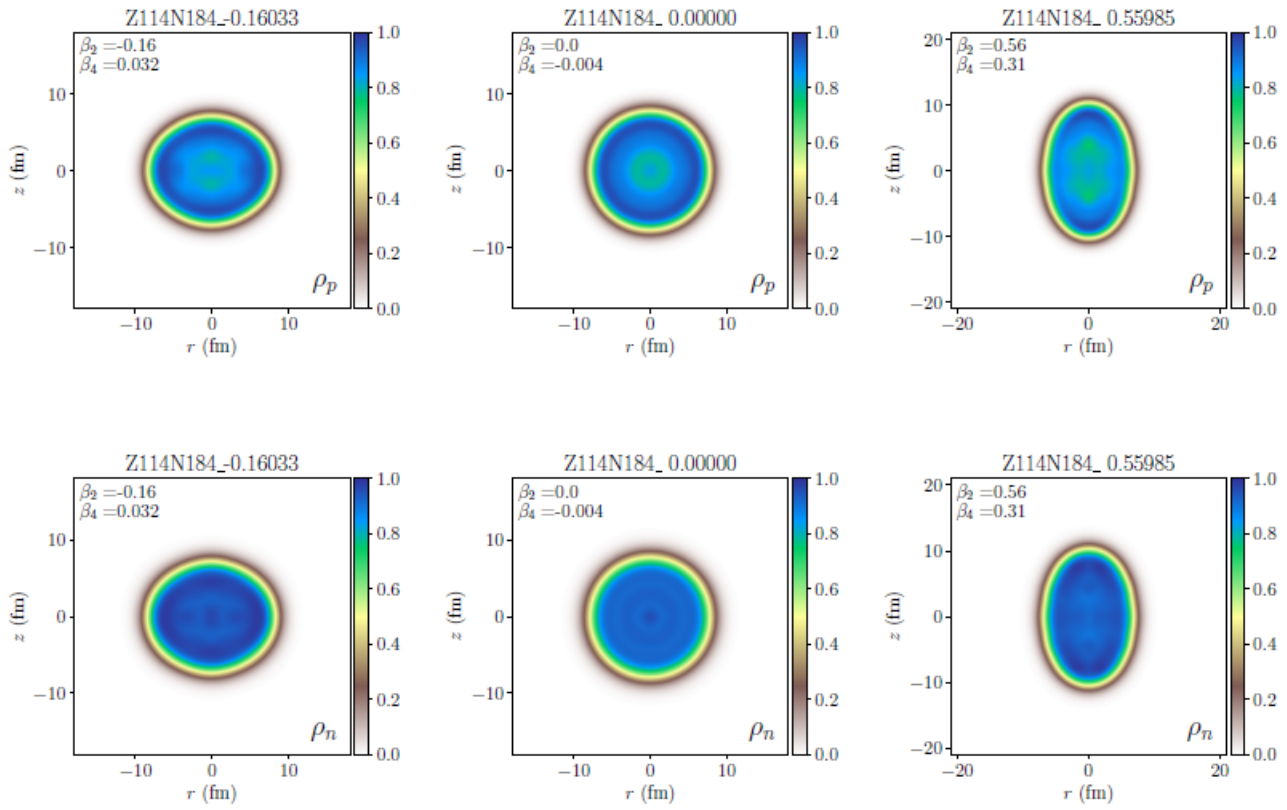


Figure 12. Proton (top panels) and neutron (bottom panels) density distributions at the oblate (left), spherical (middle), and highly prolate (right) energy minima of $^{298}_{114}\mathrm{Fl}_{184}$. Densities are normalized to their maximum value.

α Decay: Oganesson

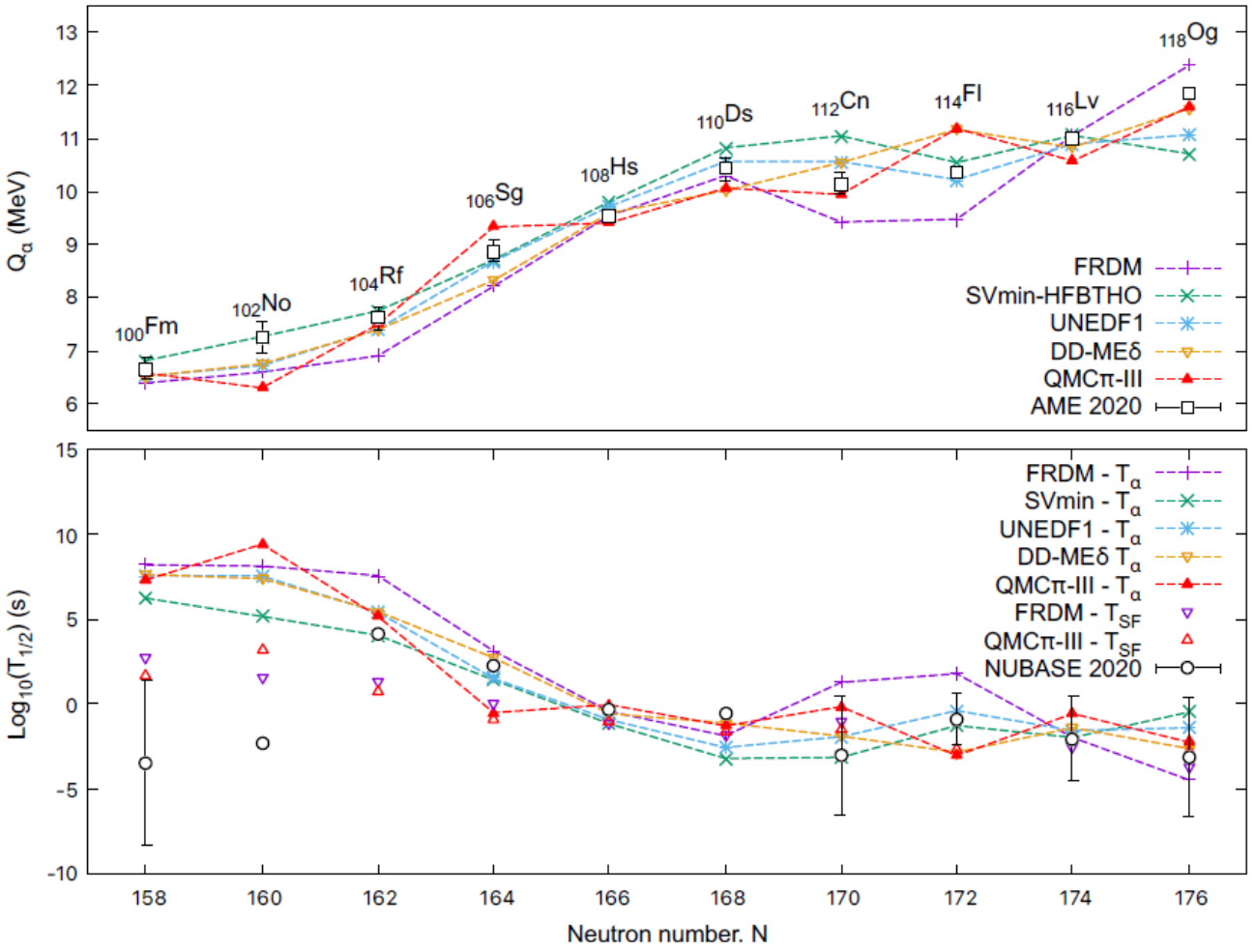


Figure 14. Q_α energies (upper panel) and α decay and spontaneous fission half-lives (lower panel) plotted against neutron number N along the α decay chain of $^{294}_{118}\mathrm{Og}_{176}$.

Axions and nuclear binding

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RadioAxion Experiment at Gran Sasso

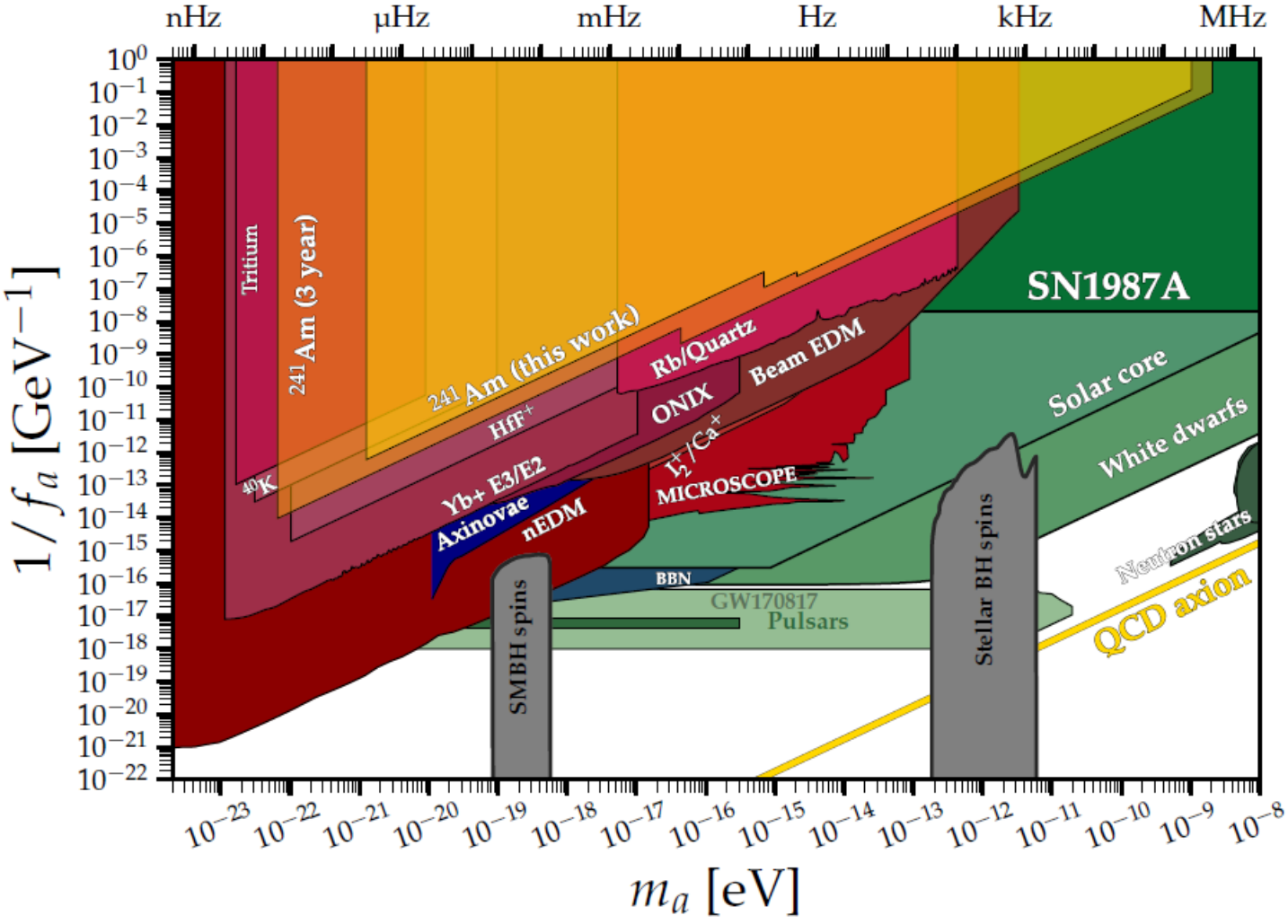


FIG. 5. Constraints on the axion decay constant as a function of the axion mass. The exclusion limits derived in this work are shown in the yellow region, together with the projected sensitivity of a 3-year data taking (orange

Broggini et al., 2602.18392

Assuming Misalignment θ varies with time

$$\theta(t) \approx \theta_0 \cos(m_a t)$$

Then the pion mass varies: $M_\pi^2(\theta) = M_\pi^2 \cos\frac{\theta}{2}\left[\sqrt{1+\varepsilon^2 \tan^2\frac{\theta}{2}}\right]$

and so does the σ coupling: (Donoghue 2006) $G_\sigma(\theta) = G_\sigma(0)\left(1.4 - 0.4\frac{M_\pi^2(\theta)}{M_\pi^2}\right)$

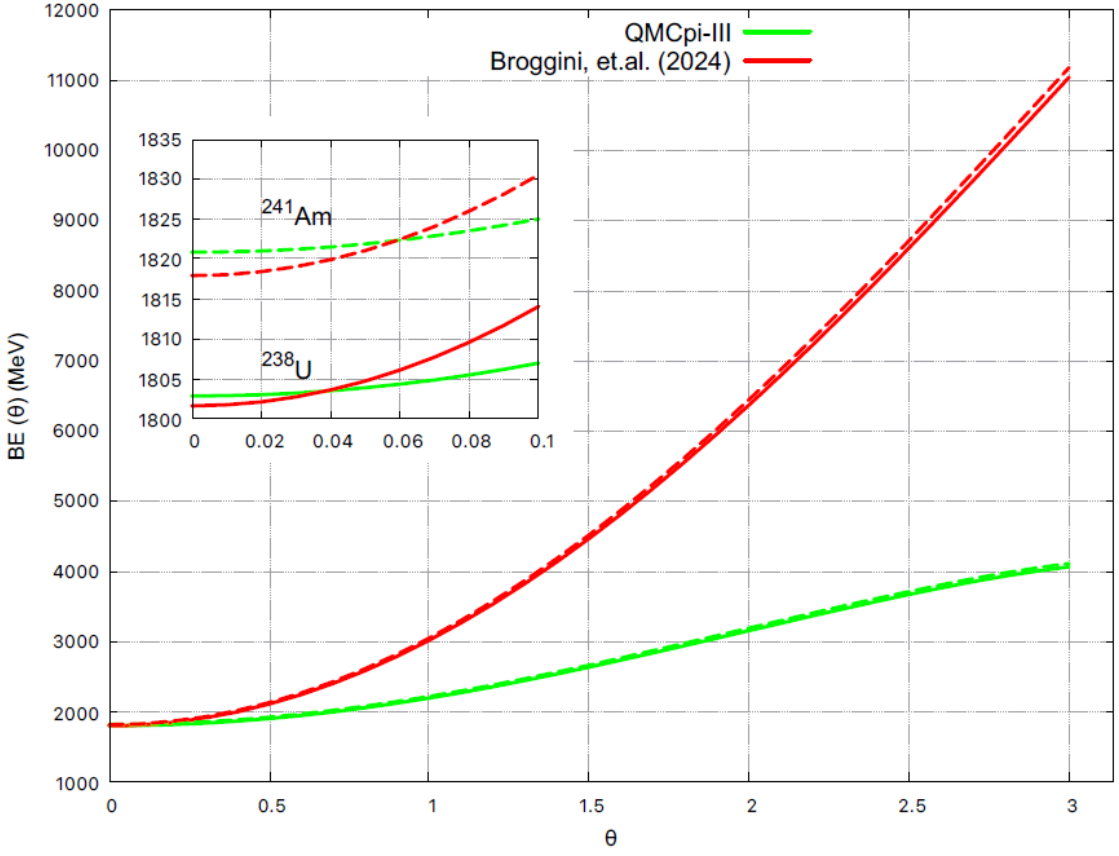
Then many authors employ crude ideas of nuclear structure to estimate changes in nuclear binding

Radio Axion put limits on change in Am α-Decay Rate: 2602.18392
And hence on axion properties

QMC is ideal for this task

This is because it is built explicitly on a physical picture employing the relativistic scalar and vector mean fields

The predictions are verv different:



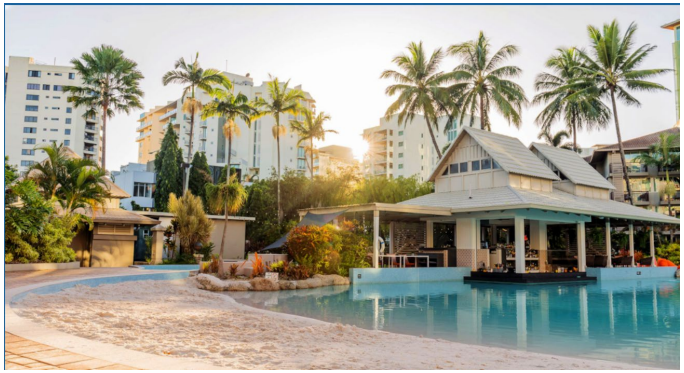
We can improve the quoted RadioAxion limits

Summary

- Intermediate range NN attraction is STRONG Lorentz scalar

- This modifies the intrinsic structure of the bound nucleon
  - profound change in shell model :
    what occupies shell model states are NOT free nucleons

- Scalar polarizability is a natural source of three-body forces (NNN, HNN, HHN…)
  - clear physical interpretation



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SPECIAL RESEARCH CENTRE FOR THE SUBATOMIC STRUCTURE OF MATTER

Summary

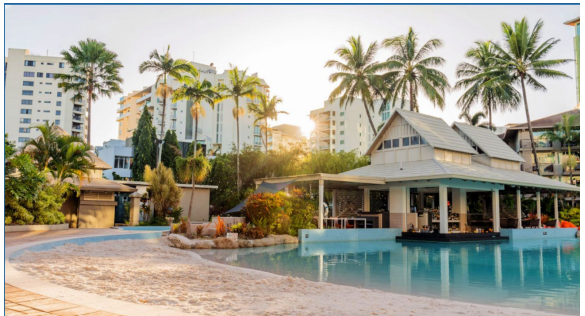
- **Need empirical confirmation of changing baryon structure:**
  - Response Functions & Coulomb sum rule
  - EMC effect; spin EMC (not too long…)
  - Change in Λ decay rate in nuclei?

- **Initial systematic study of finite nuclei very promising**

  With just 5 parameters:

  - Binding energies typically within 0.29% across periodic table
  - Super-heavies (Z > 100) especially good: 0.03%
  - Systematics of charge radii, deformations, shell and subshell closures pretty good

- **QMC ideally suited to explore nuclear limits on axion properties**



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Special Mentions……



Guichon



Tsushima



Saito



Stone



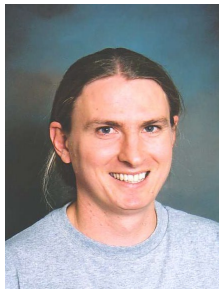
Krein



Leong



Matevosyan



Cloët



Whittenbury



Simenel



Bentz



Husain



Martinez



Motta



Antic



Kalaitzis



Wang

Adelaide University

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Latest papers

- **QMC π3;**
  Martinez et al., Phys Rev C102 (2020) 034304

- **Review:**
  Guichon *et al.*, PPNP 100 (2018) 262

- **SHE:**
  Stone *et al.*, arXiv: 1901.06064

- **Systematic application to finite nuclei:**
  Stone *et al.*, Phys Rev Lett 116 (2016) 092501

Key papers on QMC

- **Many-body forces:**

  1. Guichon, Matevosyan, Sandulescu, Thomas, Nucl. Phys. A772 (2006) 1.
  2. Guichon and Thomas, Phys. Rev. Lett. 93 (2004) 132502

- **Built on earlier work on QMC: e.g.**

  3. Guichon, Phys. Lett. B200 (1988) 235
  4. Guichon, Saito, Rodionov, Thomas, Nucl. Phys. A601 (1996) 349

- **Major review of applications of QMC to many nuclear systems:**

  5. Saito, Tsushima, Thomas, Prog. Part. Nucl. Phys. 58 (2007) 1-167 (hep-ph/0506314)
  6. Guichon et al., Prog. Part. Nucl. Phys. 100 (2018) 262

References to: Covariant Version of QMC

- **Basic Model: (Covariant, chiral, confining version of NJL)**

- **Bentz & Thomas, Nucl. Phys. A696 (2001) 138**
- **Bentz, Horikawa, Ishii, Thomas, Nucl. Phys. A720 (2003) 95**

- **Applications to DIS:**

- **Cloet, Bentz, Thomas, Phys. Rev. Lett. 95 (2005) 052302**
- **Cloet, Bentz, Thomas, Phys. Lett. B642 (2006) 210**

- **Applications to neutron stars – including SQM:**

- **Lawley, Bentz, Thomas, Phys. Lett. B632 (2006) 495**
- **Lawley, Bentz, Thomas, J. Phys. G32 (2006) 667**

Heaviest Nuclei

TABLE 6.2: Comparison of total *BE* residuals for $Z \geq 112$ from different QMC versions.

Element	Z	N	QMC-I	QMCπ-I	QMCπ-II	QMCπ-III
Cn	112	164	-1.8	-1.2	2.7	0.2
	112	166	-1.7	-1.9	2.5	-0.8
	112	168	-1.4	-2.5	1.5	-0.6
	112	170	-0.8	-2.8	1.0	-0.6
	112	172	-0.4	-3.4	0.4	-1.1
Fl	114	170	-1.2	-1.7	1.6	0.3
	114	172	-0.5	-2.0	1.4	0.2
	114	174	0.1	-2.4	1.0	-0.6
Lv	116	174	-0.4	-1.2	2.4	-0.3
	116	176	0.3	-1.6	2.1	-1.3
Og	118	176	-0.7	-0.8	3.5	-0.8

Subshell Closures: Neutron Shell Gaps

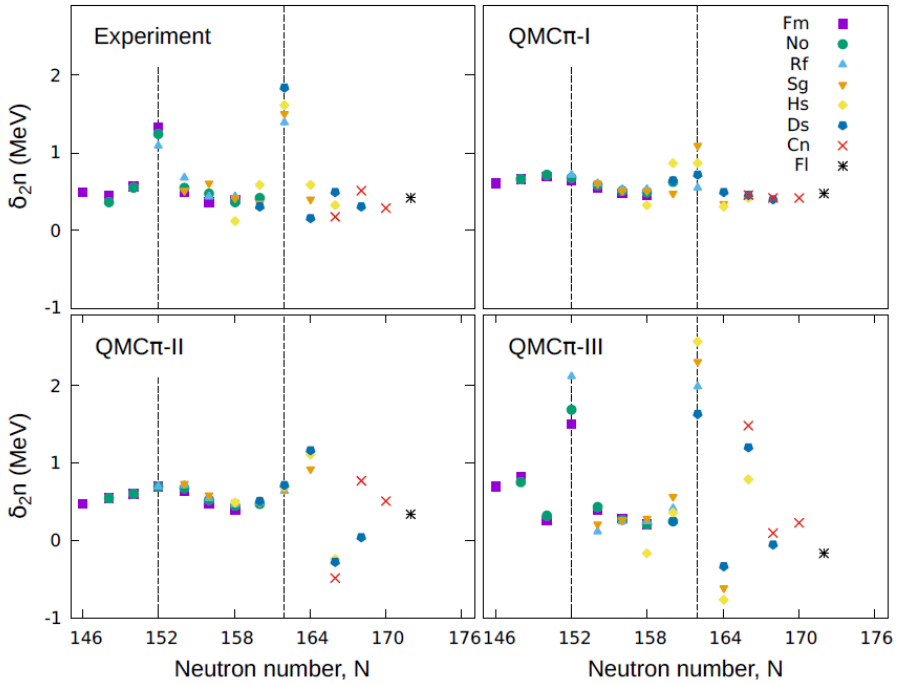
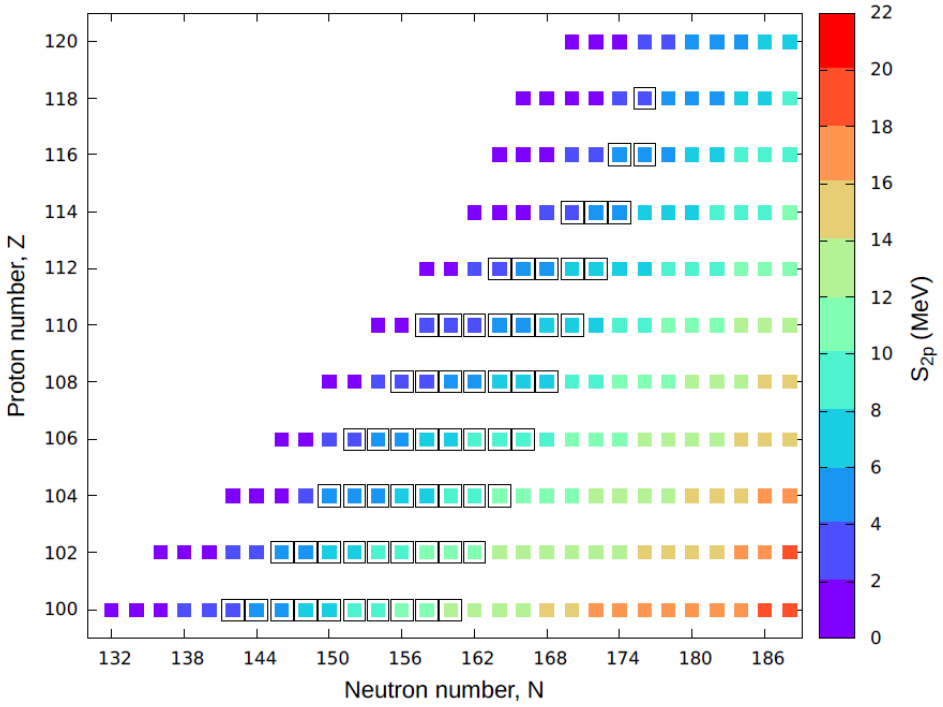


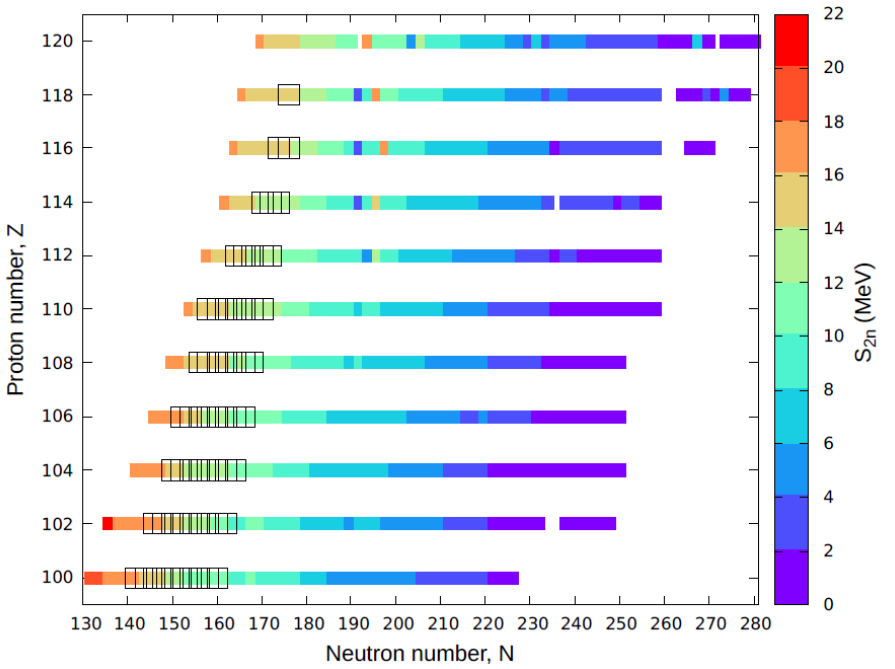
FIGURE 6.5: Two-neutron shell gaps plotted against neutron number from various QMC versions. Experimental data are taken from the differences of S_{2n} in Ref. [38]. Subshell closures at $N = 152$ and $N = 162$ are indicated with dashed lines. Plot legend is located in the top right panel.

	S_{2n} *rms* residual (MeV)	δ_{2n} *rms* residual (MeV)
QMCπ-III [55]	0.39	0.51
QMCπ-II [54]	0.46	0.44
QMCπ-I [53]	0.51	0.34
QMC-I [8]	0.62	0.37
FRDM [23]	0.44	0.36
SV-min [24]	0.24	0.29
UNEDF1 [28]	0.31	0.26

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Proton and Neutron Drip Lines





α Decay Half-Lives

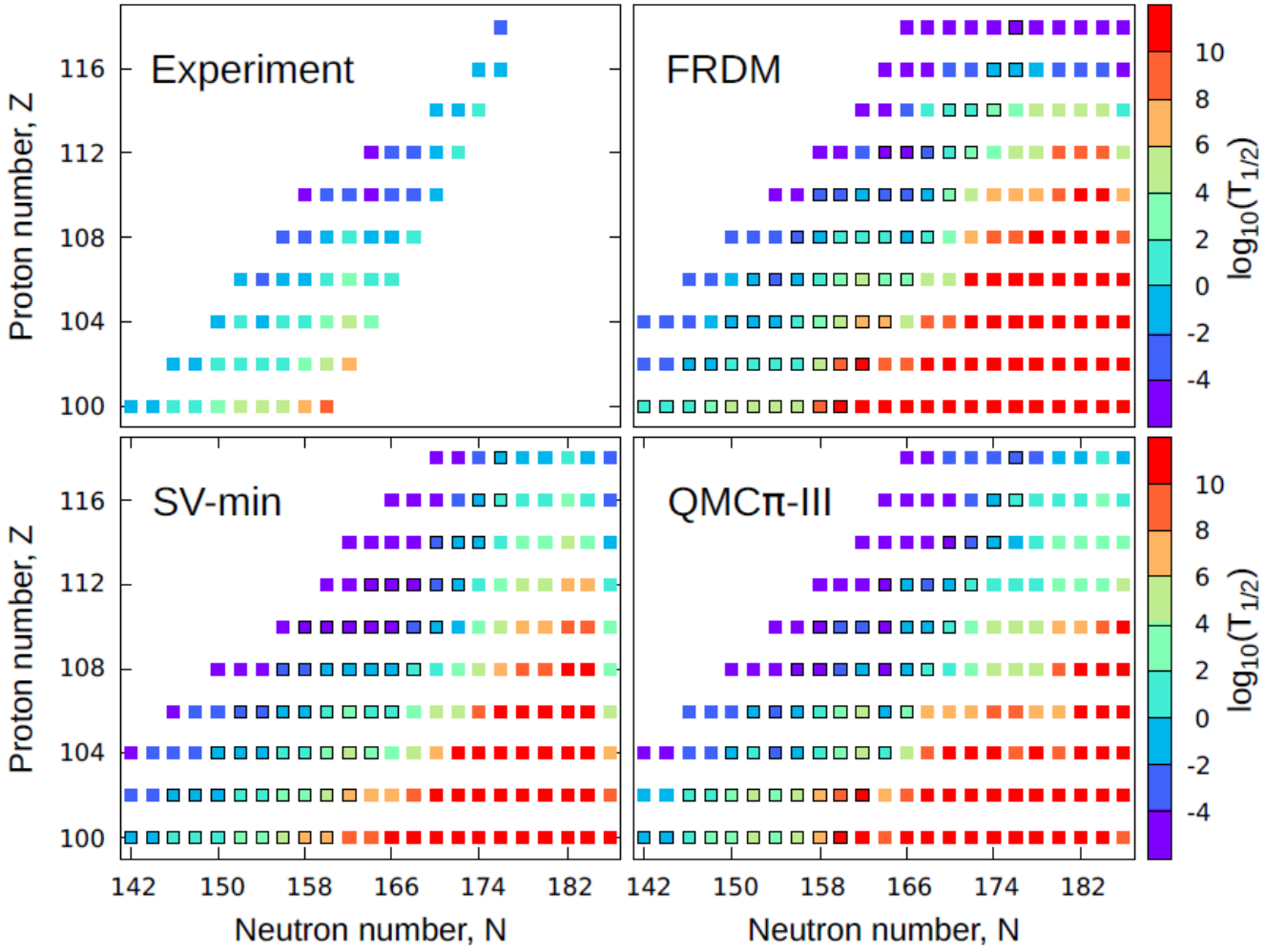


FIGURE 6.10: Comparison of $\log_{10}(T_{1/2})$ predictions from FRDM, SV-min and QMCπ-III along with values obtained from available data.

Not as good as UNDEF1 and SV-min comparable to FRDM

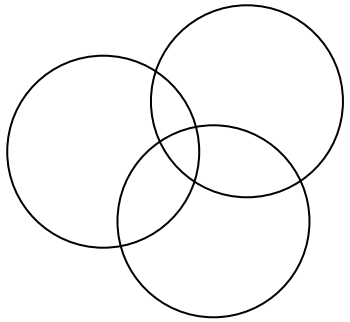
Very large scalar mean-fields are a fact

TABLE II. Results of a relativistic Dirac-Brueckner calculation in comparison to the tential B. As a function of the Fermi momentum k_F, it is listed: the energy per nucleon vector potentials U_S and U_V, and the wound integral κ.

			Relativistic		
k_F (fm^{-1})	$\mathcal{E}/A$ (MeV)	$\tilde{M}/M$	U_S (MeV)	U_V (MeV)	κ (%)
0.8	−7.02	0.855	−136.2	104.0	23.1
0.9	−8.58	0.814	−174.2	134.1	18.8
1.0	−10.06	0.774	−212.2	164.2	16.1
1.1	−11.18	0.732	−251.3	195.5	12.7
1.2	−12.35	0.691	−290.4	225.8	11.9
1.3	−13.35	0.646	−332.7	259.3	12.5
1.35	−13.55	0.621	−355.9	278.4	13.0
1.4	−13.53	0.601	−374.3	293.4	13.8
1.5	−12.15	0.559	−413.6	328.4	14.4
1.6	−8.46	0.515	−455.2	371.0	15.8

Summary : Scalar Polarizability

- **Consequence of polarizability in atomic physics is many-body forces:**



$$V = V_{12} + V_{23} + V_{13} + V_{123}$$

  - **same is true in nuclear physics**

- **Three-body forces (NNN, HNN, HHN…) generated with NO new parameters**
  - **critical in neutron stars**

Systematic approach to finite nuclei

J.R. Stone, P.A.M. Guichon, P. G. Reinhard & A.W. Thomas:
(Phys Rev Lett, 116 (2016) 092501)

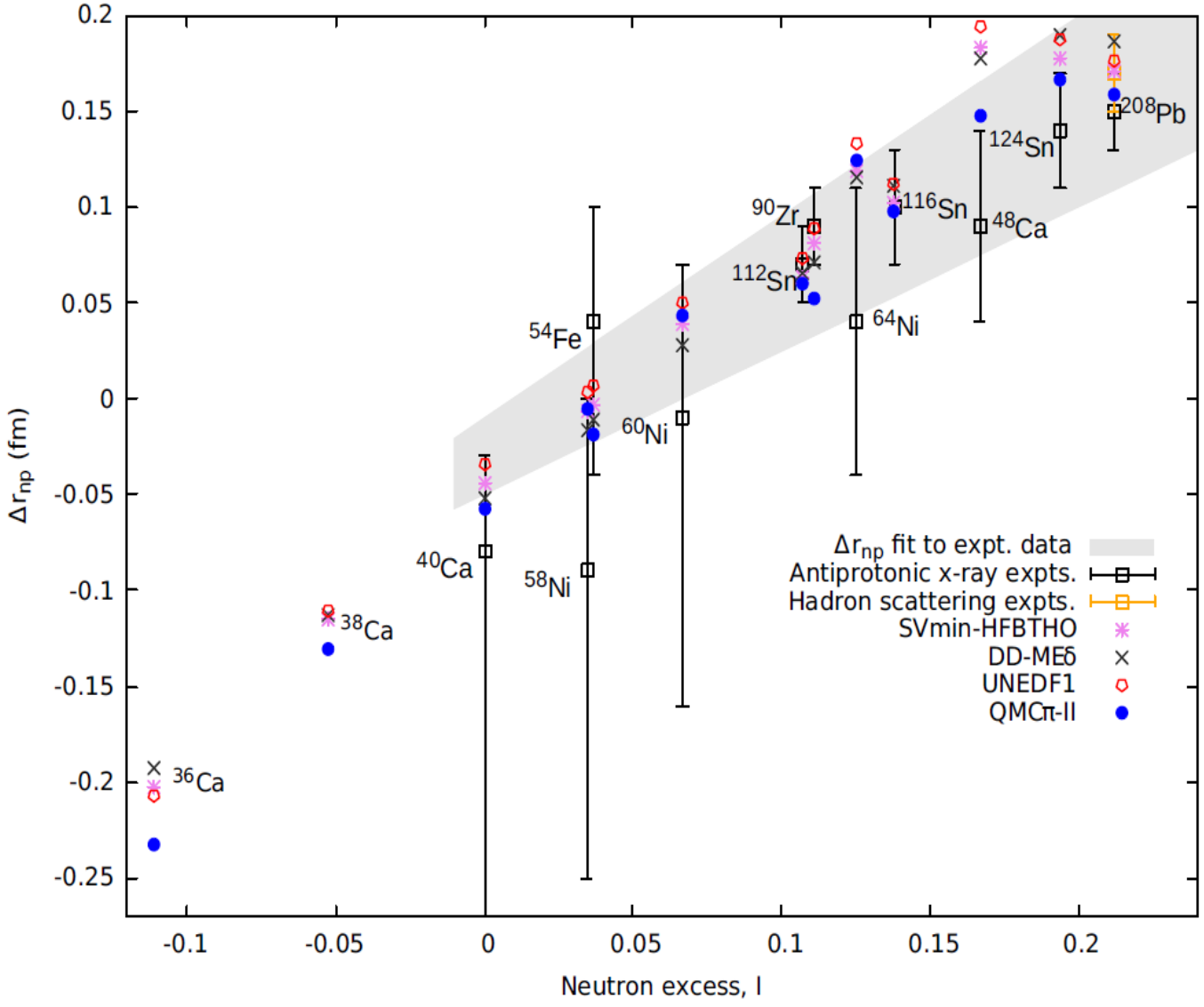
- Constrain 3 basic quark-meson couplings (g_σ^q, g_ω^q, g_ρ^q) so that nuclear matter properties are reproduced within errors

$-17 < E/A < -15$ MeV
$0.14 < \rho_0 < 0.18$ fm^{-3}
$28 < S_0 < 34$ MeV
$L > 20$ MeV
$250 < K_0 < 350$ MeV

- Fix at overall best description of finite nuclei with 5 parameters (3 for the EDF +2 pairing pars)

- Benchmark comparison: SV-min 16 parameters (11+5 pairing)

Neutron distributions



Kay Martinez *et al.*, Phys Rev C100 (2019) 024333

For the EIC: Polarized Gluon EMC Effect

Xuangong Wang et al.

J. Phys. G: Nucl. Part. Phys. **49** (2022) 03LT01

Letters

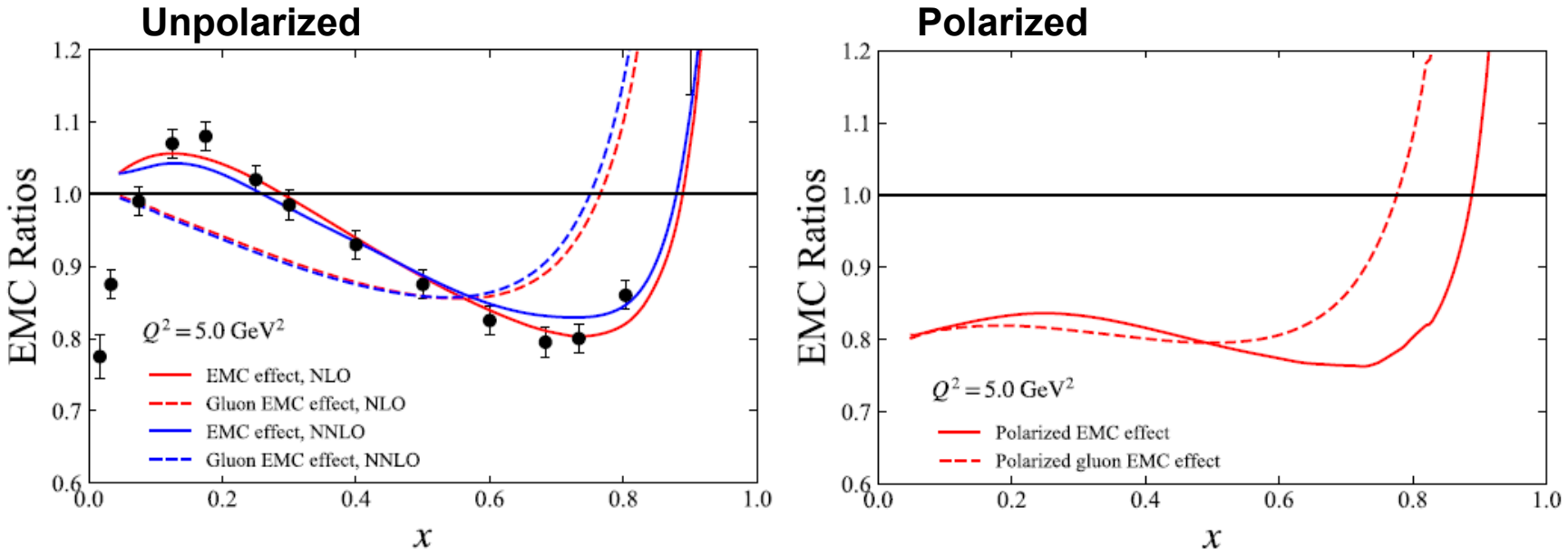
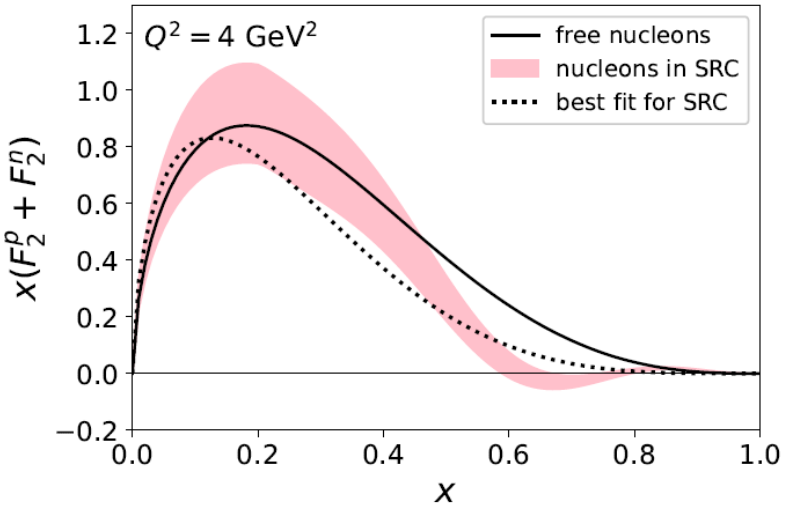


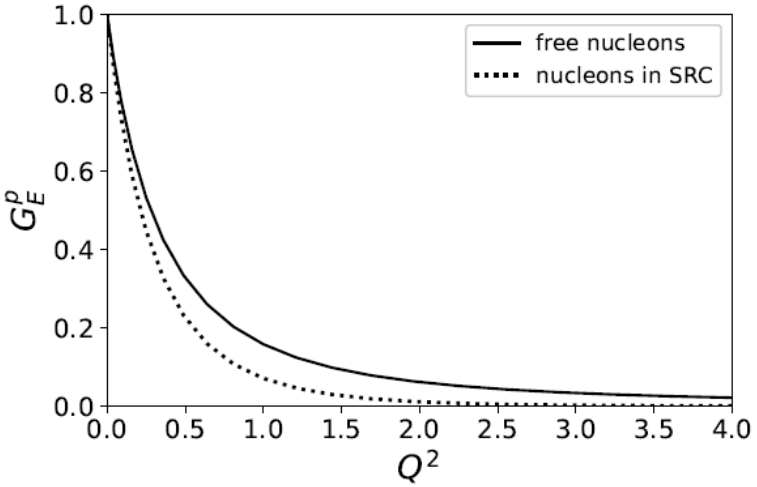
Figure 3. (Left panel) Unpolarized EMC ratios for the structure functions $F_{2A}(x)/F_{2N}(x)$ (solid) and the unpolarized gluon distributions $g_A(x)/g_p(x)$ (dashed). (Right panel) Polarized EMC ratios for the structure functions $g_{1A}(x)/g_{1p}(x)$ (solid) and polarized gluon distributions $\Delta g_A(x)/\Delta g_p(x)$ (dashed). The empirical data points are the unpolarized nuclear matter results for the EMC ratio from reference [53].

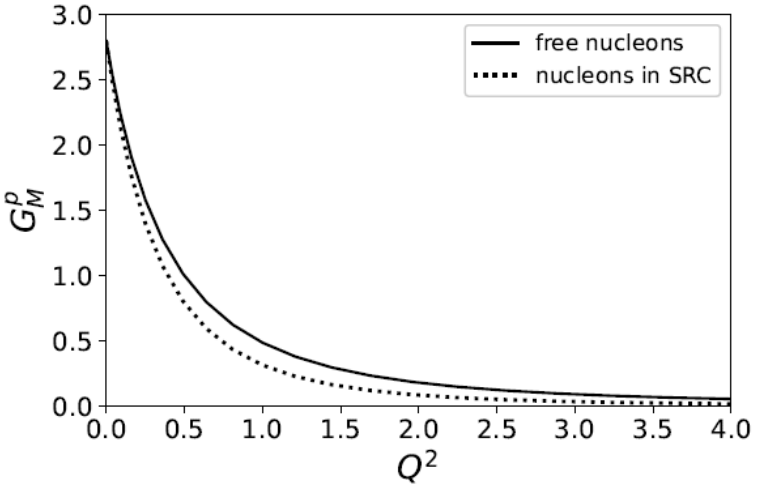
New Observation on SRC and EMC Effect

Use simple AdS/QCD model of Maji and Chakrabati PRD 94 (2016)



Fit SRC-modified F_2 and then calculate modified elastic form factors





Refs: Wang *et al.*, PRL 125 (2020) 262002 and Wanli Xing *et al.*, to be published

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Shape Co-Existence

TABLE 7.5: β_2 values corresponding to the locations of the first and second deformed minima for symmetric nuclei obtained from QMCπ-III. Also added for comparison are experimental data which are only available in absolute values [52], as well as FRDM results [23].

Z or N	Expt.	QMCπ-III		FRDM	Z or N	Expt.	QMCπ-III		FRDM
		1st	2nd				1st	2nd	
8	0.36	0.00	-	-0.01	30	-	0.22	-0.14	0.16
10	0.73	0.46	-0.16	0.36	32	-	0.22	-0.22	0.21
12	0.61	0.50	-0.24	0.39	34	-	-0.26	0.22	0.23
14	0.41	-0.28	-	-0.36	36	-	-0.34	-	-0.37
16	0.31	0.10	-	0.22	38	-	0.46	-	0.40
18	0.26	-0.18	0.08	-0.26	40	-	0.48	-0.20	0.43
20	0.12	0.00	-	0.00	42	-	-0.22	-	-0.23
22	0.27	0.14	-	0.00	44	-	-0.22	0.14	-0.24
24	0.34	0.30	-0.14	0.23	46	-	0.16	-0.16	0.00
26	-	0.24	-0.12	0.12	48	-	0.10	-0.06	-0.02
28	0.17	-0.02	-	0.00	50	-	0.00	-	0.00

Separation energies: Drip Lines

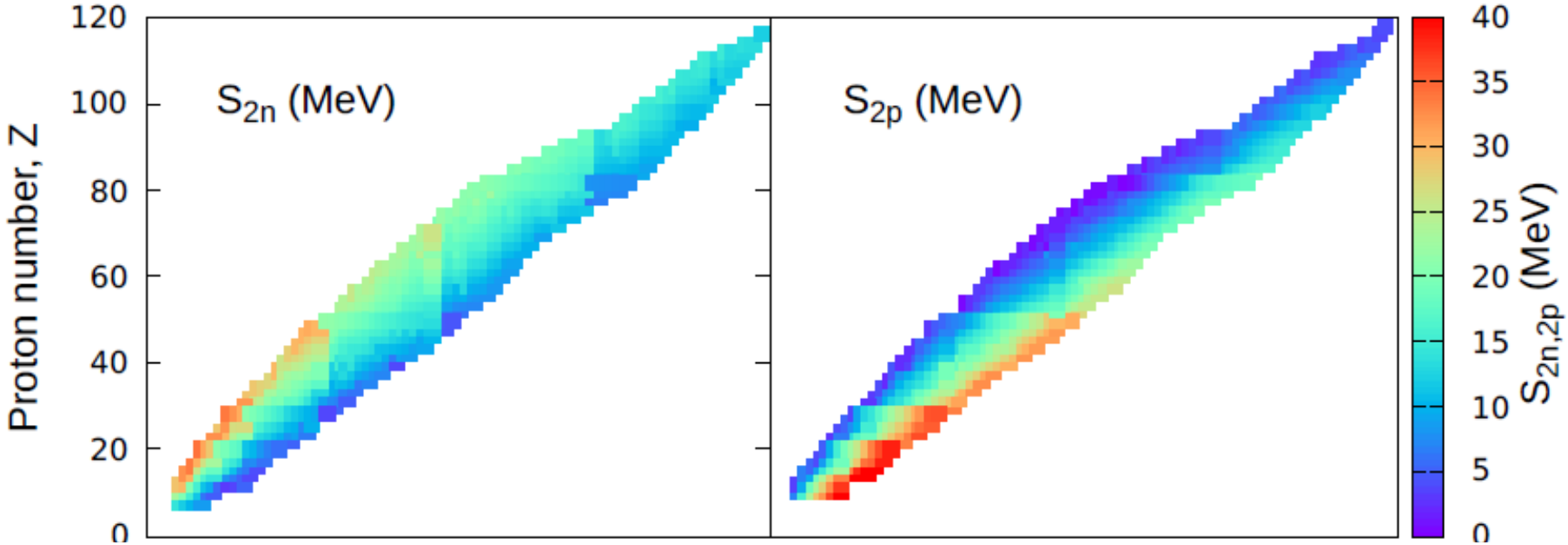


TABLE 7.3: Comparison of *rms* residuals for separation energies (in MeV) from QMC and from other nuclear models.

Model	S_{2n}	S_{2p}	δ_{2n}	δ_{2p}	Q_α
QMCπ-III	0.97	0.95	1.24	1.28	1.07
QMCπ-II	1.03	1.08	1.20	1.25	1.19
SV-min	0.77	0.82	0.87	1.00	0.79
UNEDF1	0.74	0.82	0.85	0.90	0.80
DD-MEδ	1.01	1.05	1.12	1.11	1.30
FRDM	0.50	0.55	0.61	0.75	0.61

Binding Energies

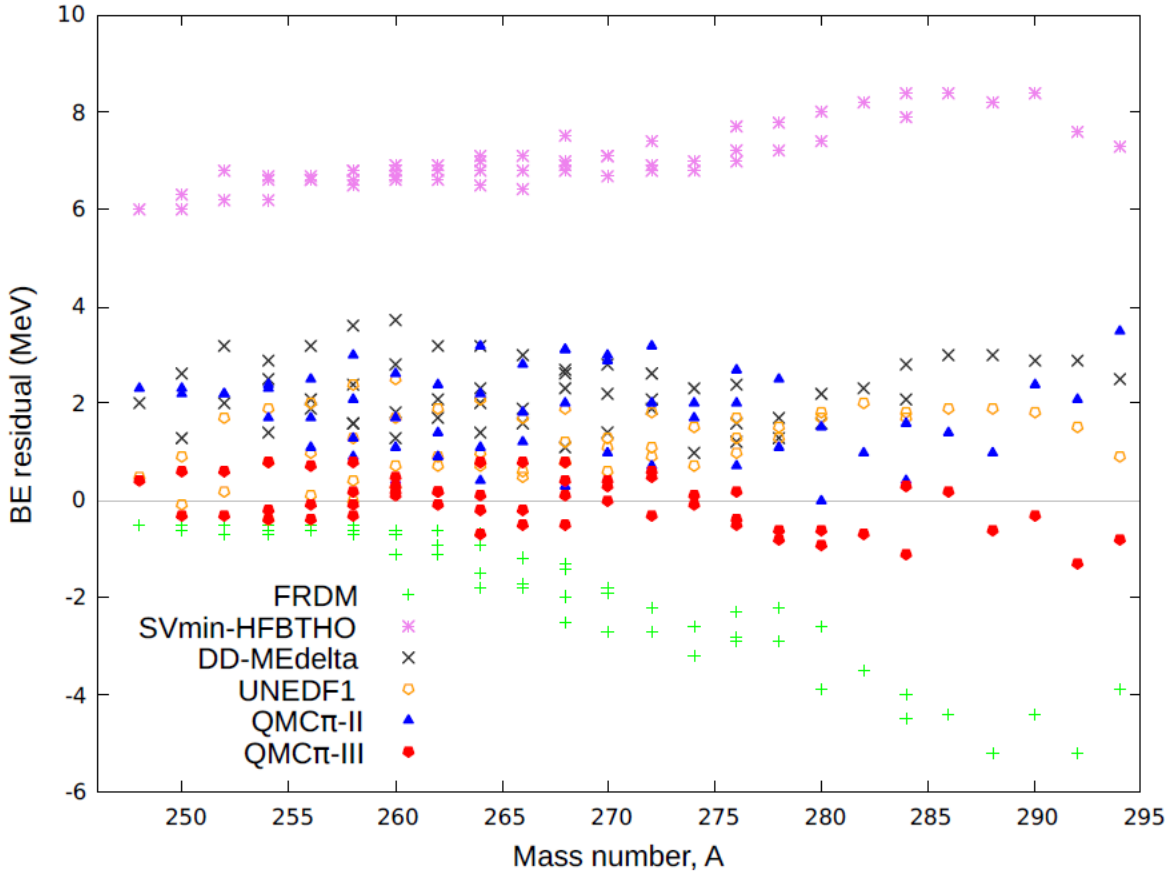


TABLE 6.1: Comparison of *rms* percent deviations and *rms* residuals from QMC and from other nuclear models for SHE with available data.

	rms % deviation	*rms* residual (MeV)
QMCπ-III	0.03	0.52
QMCπ-II [54]	0.11	2.04
QMCπ-I [53]	0.12	2.42
QMC-I [8]	0.08	1.50
FRDM [23]	0.11	2.25
SV-min [24]	0.36	6.99
UNEDF1 [28]	0.07	1.31
DD-MEδ [66]	0.12	2.28

Outstanding agreement