TRIUMF

Ab initio nuclear reaction theory: Applications to nuclear astrophysics and the X17 boson claim

QNP2022 - The 9th International Conference on Quarks and Nuclear Physics

Florida State University, 5-9 September 2022 (online)

Petr Navratil

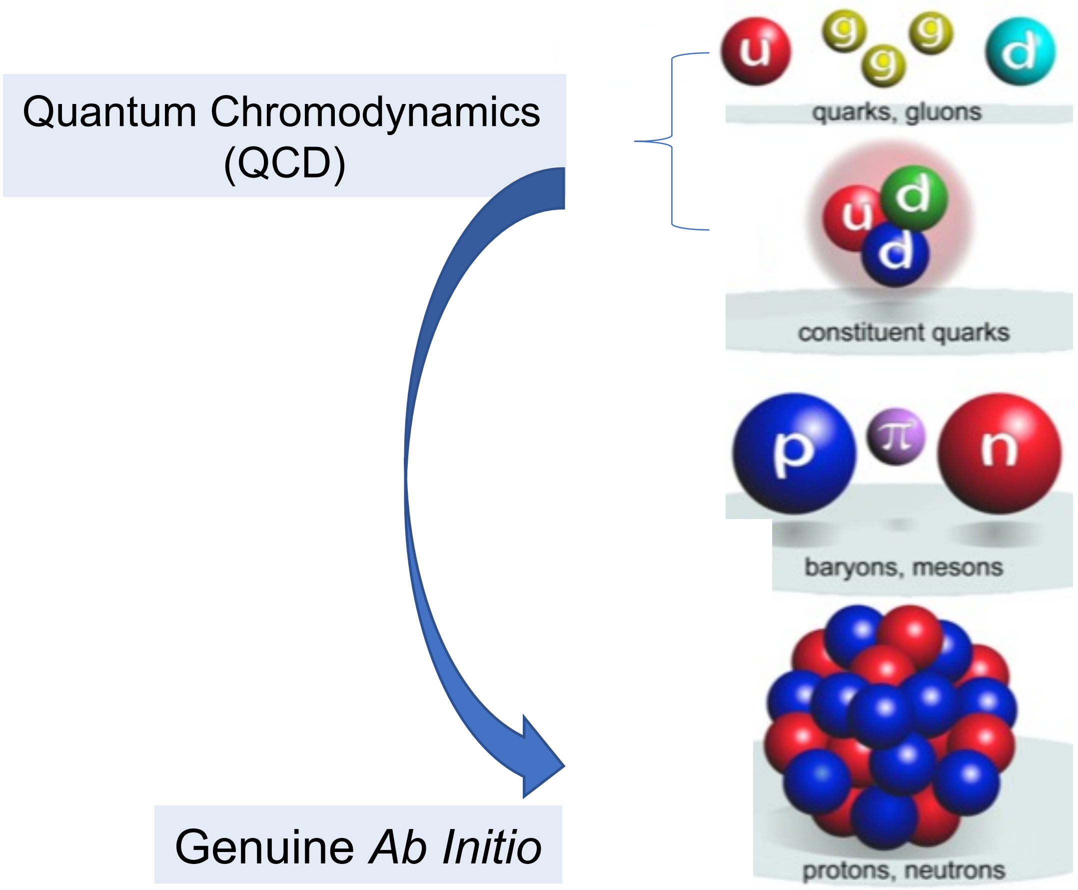
TRIUMF

Kostas Kravvaris, Sofia Quaglioni, Mack Atkinson (LLNL), Guillaume Hupin (IJCLab), Chloe Hebborn (MSU/LLNL), Peter Gysbers (UBC/TRIUMF)

2022-09-04

Discovery, accelerated

First principles or *ab initio* nuclear theory



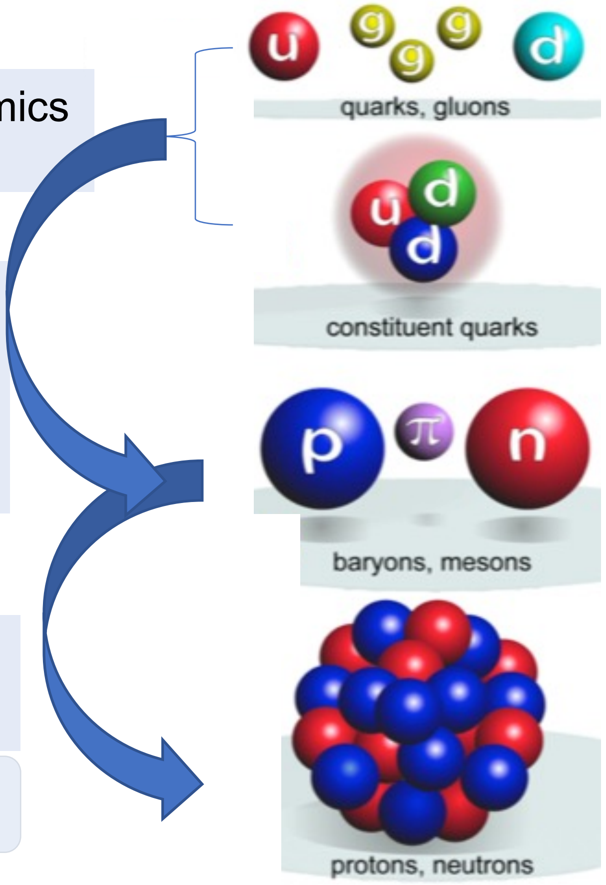
First principles or *ab initio* nuclear theory – what we do at present

Quantum Chromodynamics (QCD)

Chiral Effective Field Theory (parameters fitted to NN data)

Current *ab anitio* nuclear theory

$$H\,\Psi^{(A)} = E\,\Psi^{(A)}$$



Ab Initio Calculations of Structure, Scattering, Reactions

Unified approach to bound & continuum states

No-Core Shell Model with Continuum (NCSMC)

$$\Psi^{(A)} = \sum_{\lambda} c_{\lambda} \left| {}^{(A)}, \lambda \right\rangle + \sum_{\nu} \int d\vec{r}\; \gamma_{\nu}(\vec{r}\,)\; \hat{A}_{\nu} \left| {}_{(A-a)} \overset{\vec{r}}{\longleftarrow} (a)\,, \nu \right\rangle$$

S. Baroni, P. Navratil, and S. Quaglioni,
PRL **110**, 022505 (2013); PRC **87**, 034326 (2013).

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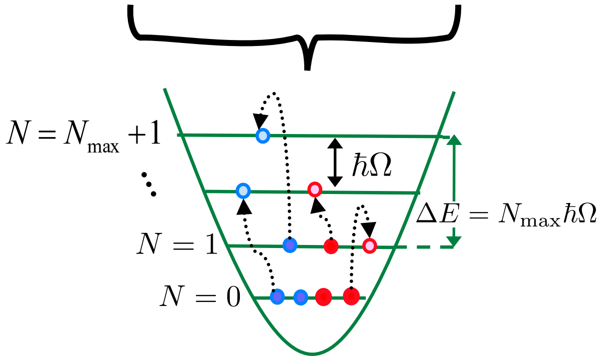

Static solutions for aggregate system,
describe all nucleons close together

S. Baroni, P. Navratil, and S. Quaglioni,
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Ab Initio Calculations of Structure, Scattering, Reactions

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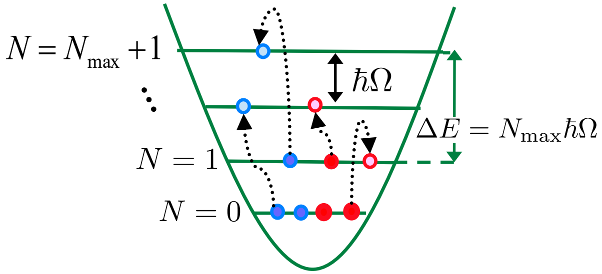


Continuous microscopic cluster states, describe long-range projectile-target

Static solutions for aggregate system, describe all nucleons close together

S. Baroni, P. Navratil, and S. Quaglioni, PRL **110**, 022505 (2013); PRC **87**, 034326 (2013).

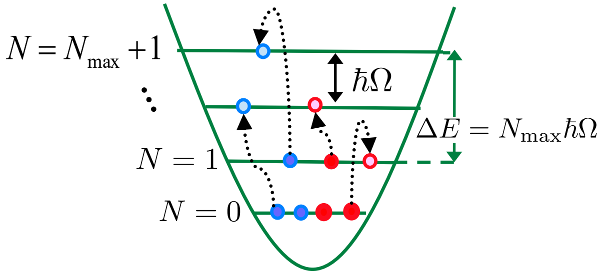
Ab Initio Calculations of Structure, Scattering, Reactions

Unified approach to bound & continuum states

No-Core Shell Model with Continuum (NCSMC)

Unknowns

$$\Psi^{(A)} = \sum_{\lambda} c_{\lambda} \left| {}^{(A)}, \lambda \right\rangle + \sum_{\nu} \int d\vec{r}\; \gamma_{\nu}(\vec{r}\,)\; \hat{A}_{\nu} \left| {}_{(A-a)} \;\vec{r}\; (a), \nu \right\rangle$$



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S. Baroni, P. Navratil, and S. Quaglioni, PRL **110**, 022505 (2013); PRC **87**, 034326 (2013).

Coupled NCSMC equations

$$H\,\Psi^{(A)} = E\,\Psi^{(A)}$$

$$\Psi^{(A)} = \sum_{\lambda} c_{\lambda} \left| (A), \lambda \right\rangle + \sum_{\nu} \int d\vec{r}\; \gamma_{\nu}(\vec{r}\,)\, \hat{A}_{\nu} \left| \vec{r}, (A-a), (a), \nu \right\rangle$$

$$E_{\lambda}^{NCSM}\,\delta_{\lambda\lambda'} \qquad \left\langle (A) \right| H \hat{A}_{\nu} \left| r, (a), (A-a) \right\rangle \qquad \delta_{\lambda\lambda'} \qquad \left\langle (A) \right| \hat{A}_{\nu} \left| r, (a), (A-a) \right\rangle$$

$$\begin{pmatrix} H_{NCSM} & h \\ h & H_{RGM} \end{pmatrix} \begin{pmatrix} c \\ \gamma \end{pmatrix} = E \begin{pmatrix} 1_{NCSM} & g \\ g & N_{RGM} \end{pmatrix} \begin{pmatrix} c \\ \gamma \end{pmatrix}$$

$$\left\langle r', (A-a), (a) \right| \hat{A}_{\nu'} H \hat{A}_{\nu} \left| r, (a), (A-a) \right\rangle \qquad \left\langle r', (A-a), (a) \right| \hat{A}_{\nu'} \hat{A}_{\nu} \left| r, (a), (A-a) \right\rangle$$

IOP Publishing | Royal Swedish Academy of Sciences Physica Scripta
Phys. Scr. 91 (2016) 053002 (38pp) doi:10.1088/0031-8949/91/5/053002

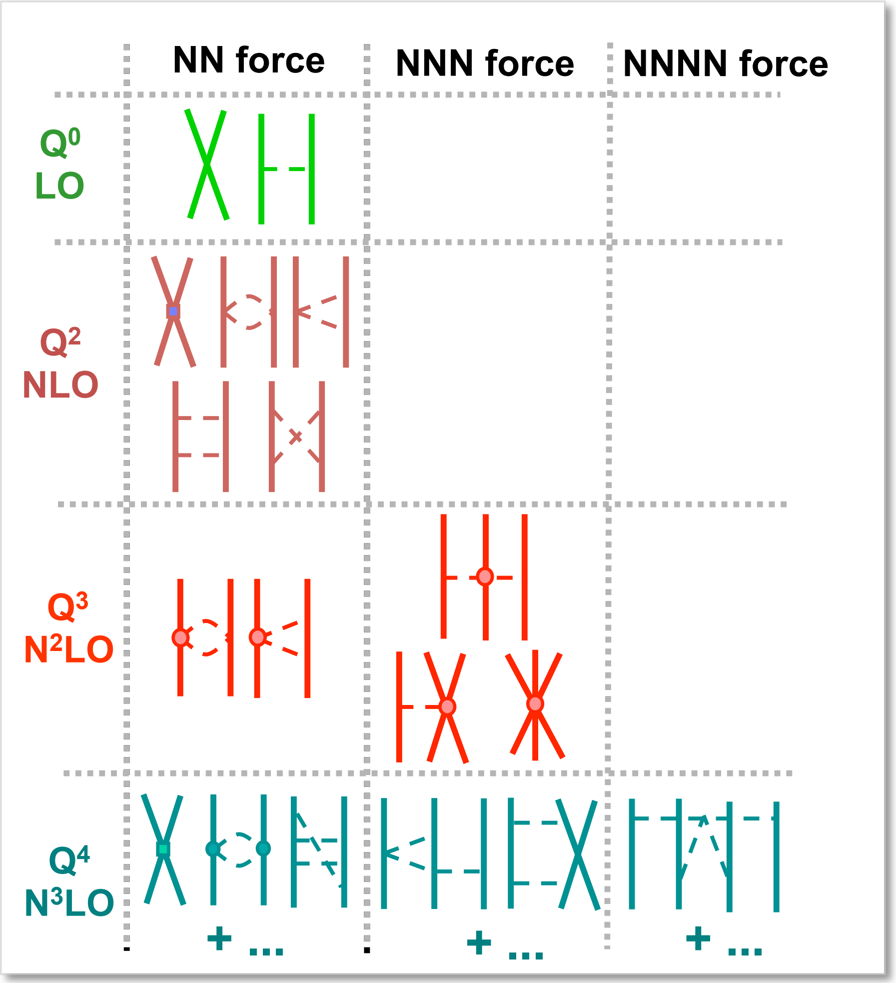
Invited Comment

Unified *ab initio* approaches to nuclear structure and reactions

Petr Navrátil[1], Sofia Quaglioni[2], Guillaume Hupin[3,4], Carolina Romero-Redondo[2] and Angelo Calci[1]

Input for NCSMC calculations: Nuclear forces from chiral Effective Field Theory

- Approach taking advantage of the separation of scales
  - Based on the symmetries of QCD
    - Chiral symmetry of QCD ($m_u \approx m_d \approx 0$), spontaneously broken with pion as the Goldstone boson
    - Degrees of freedom: nucleons + pions
  - Systematic low-momentum expansion to a given order (Q/Λ_χ)
  - Hierarchy
  - Consistency
  - Low energy constants (LEC)
    - Fitted to data
    - Can be calculated by lattice QCD



Λ_χ~1 GeV :
Chiral symmetry breaking scale

PHYSICAL REVIEW C **101**, 014318 (2020)

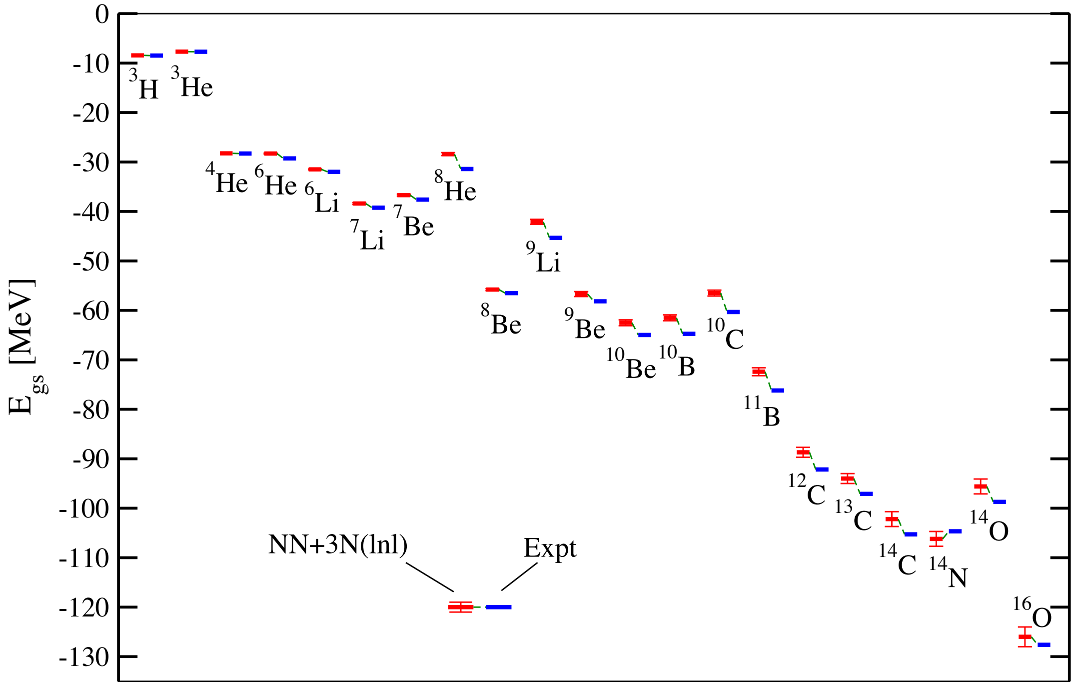
Novel chiral Hamiltonian and observables in light and medium-mass nuclei

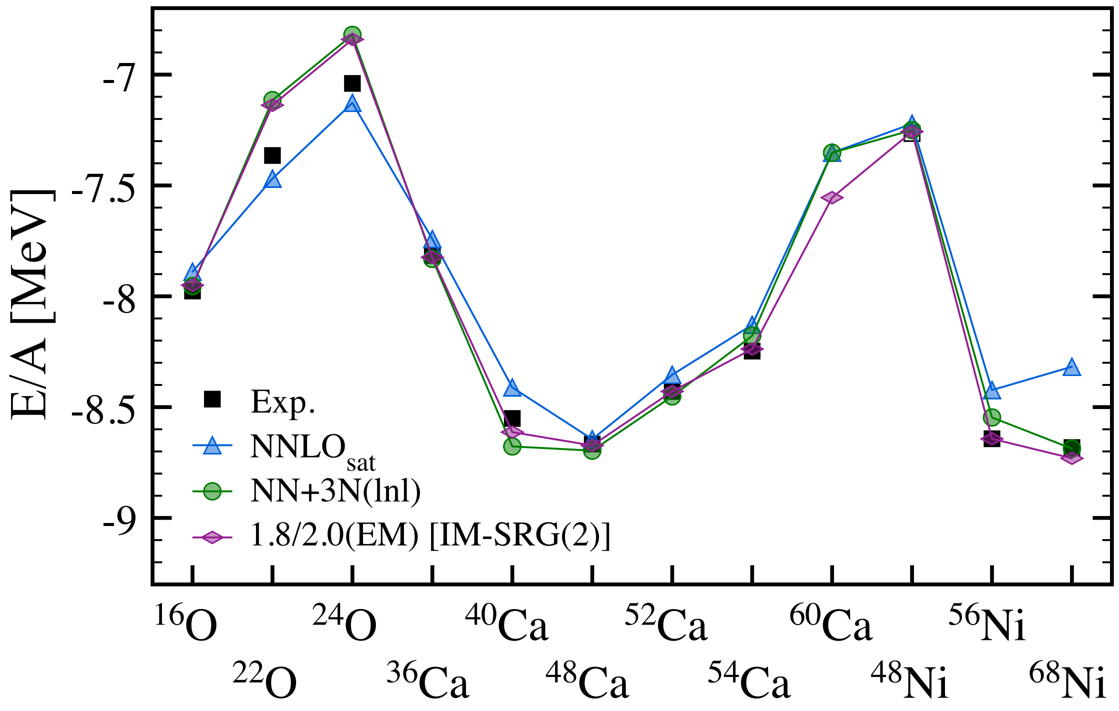
V. Somà,[1,*] P. Navrátil,[2,†] F. Raimondi,[3,4,‡] C. Barbieri,[4,§] and T. Duguet[1,5,‖]

Input for NCSMC calculations: Nuclear forces from chiral Effective Field Theory

- Quite reasonable description of binding energies across the nuclear charts becomes feasible
  - **The Hamiltonian fully determined in *A*=2 and *A*=3,4 systems**
    - Nucleon–nucleon scattering, deuteron properties, ^{3}H and ^{4}He binding energy, ^{3}H half life
  - Light nuclei – NCSM
  - Medium mass nuclei – Self-Consistent Green's Function method

NN N^{3}LO (Entem-Machleidt 2003)
3N N^{2}LO w local/non-local regulator





1.8/2.0 (EM) results: J. Simonis, S. R. Stroberg, K. Hebeler, J. D. Holt, and A. Schwenk, Phys. Rev. C 96, 014303 (2017).

PHYSICAL REVIEW C **101**, 014318 (2020)

Novel chiral Hamiltonian and observables in light and medium-mass nuclei

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    - Nucleon–nucleon scattering, deuteron properties, ^{3}H and ^{4}He binding energy, ^{3}H half life
  - Light nuclei – NCSM
  - Heavy nuclei – HF-MBPT(3)

NN N^{3}LO (Entem-Machleidt 2003)
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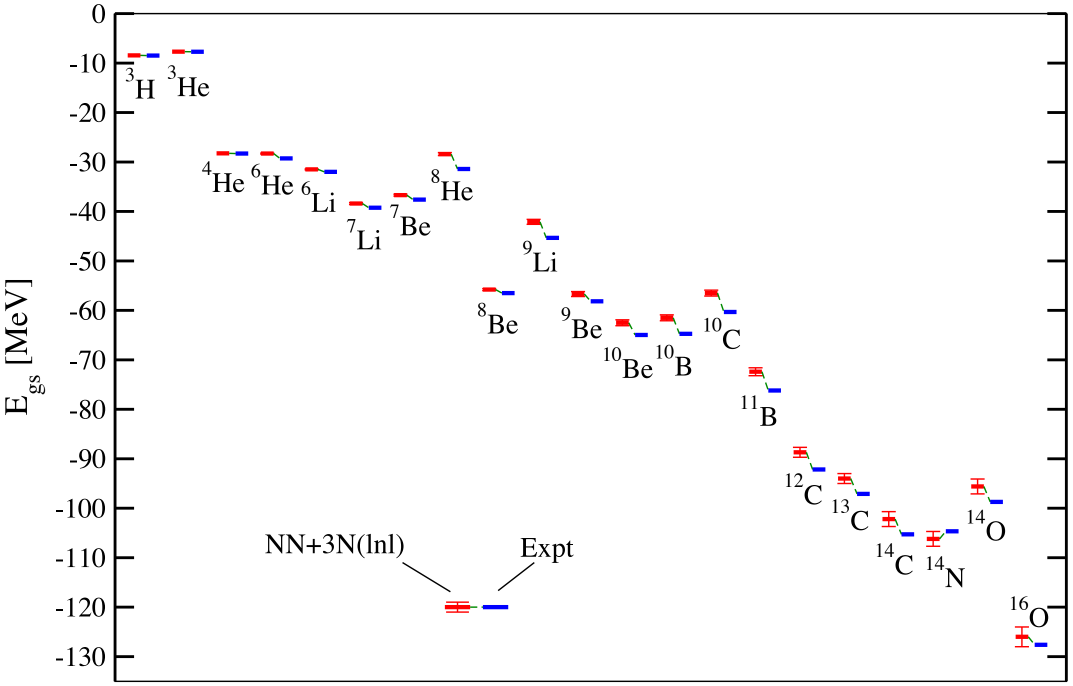

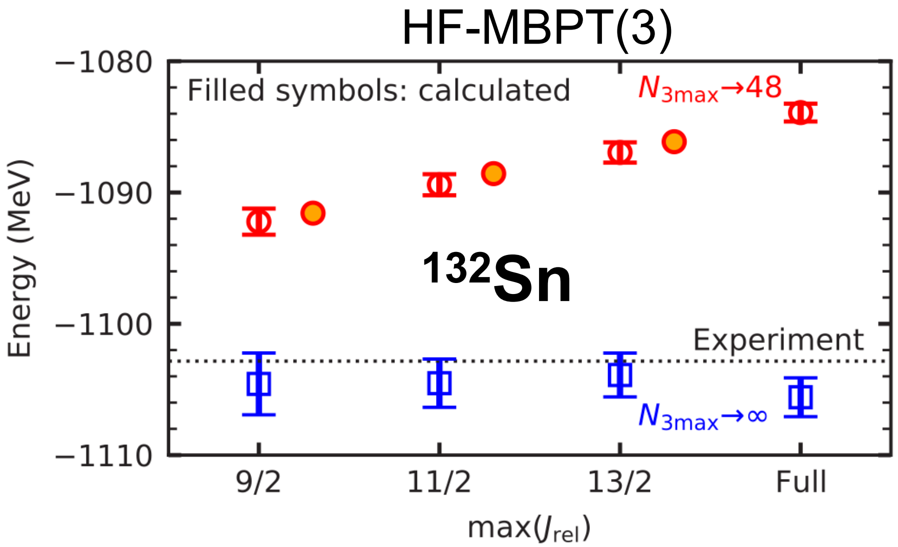

PHYSICAL REVIEW C **105**, 014302 (2022)

Converged *ab initio* calculations of heavy nuclei

T. Miyagi,[1,*] S. R. Stroberg,[2,†] P. Navrátil,[1,‡] K. Hebeler,[3,4,5,§] and J. D. Holt[1,6,‖]

β-delayed proton emission in ^{11}Be

Physics Letters B 732 (2014) 305–308

Contents lists available at ScienceDirect

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^{11}Be(βp), a quasi-free neutron decay?

K. Riisager[a,*], O. Forstner[b,c], M.J.G. Borge[d,e], J.A. Briz[e], M. Carmona-Gallardo[e], L.M. Fraile[f], H.O.U. Fynbo[a], T. Giles[g], A. Gottberg[e,g], A. Heinz[h], J.G. Johansen[a,1], B. Jonson[h], J. Kurcewicz[d], M.V. Lund[a], T. Nilsson[h], G. Nyman[h], E. Rapisarda[d], P. Steier[b], O. Tengblad[e], R. Thies[h], S.R. Winkler[b]

- Indirectly observed $^{11}\text{Be}(\beta p)^{10}\text{Be}$
- Measured an extremely high branching ratio $b_p = 8.3 \pm 0.9 \times 10^{-6}$
  - Orders of magnitude larger than theoretical predictions (*e.g.* 3.0×10^{-8})
- Two proposed explanations:
  1. The neutron decays to an unobserved $p+^{10}\text{Be}$ resonance in ^{11}B
  2. There are unobserved dark decay modes

D. Baye and E.M. Tursunov, PLB **696**, 4, 464-467 (2011)

β-delayed proton emission in ^{11}Be

PHYSICAL REVIEW LETTERS **123,** 082501 (2019)

Editors' Suggestion

Direct Observation of Proton Emission in ^{11}Be

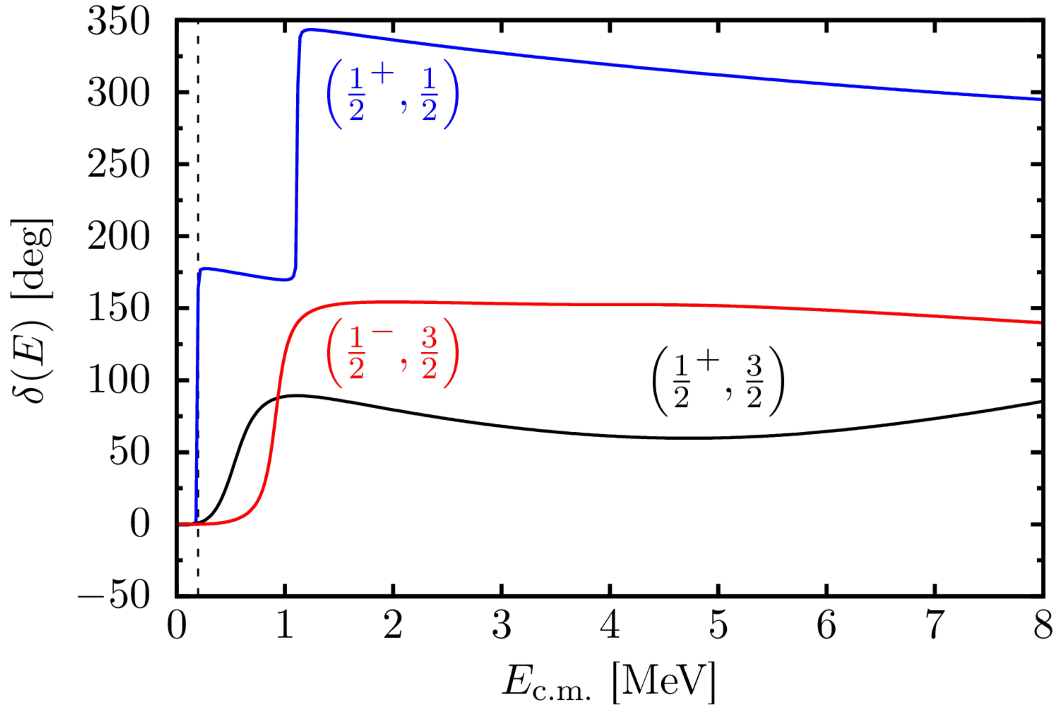
Y. Ayyad,[1,2,*] B. Olaizola,[3] W. Mittig,[2,4] G. Potel,[1] V. Zelevinsky,[1,2,4] M. Horoi,[5] S. Beceiro-Novo,[4] M. Alcorta,[3] C. Andreoiu,[6] T. Ahn,[7] M. Anholm,[3,8] L. Atar,[9] A. Babu,[3] D. Bazin,[2,4] N. Bernier,[3,10] S. S. Bhattacharjee,[3] M. Bowry,[3] R. Caballero-Folch,[3] M. Cortesi,[2] C. Dalitz,[11] E. Dunling,[3,12] A. B. Garnsworthy,[3] M. Holl,[3,13] B. Kootte,[3,8] K. G. Leach,[14] J. S. Randhawa,[2] Y. Saito,[3,10] C. Santamaria,[15] P. Šiurytė,[3,16] C. E. Svensson,[9] R. Umashankar,[3] N. Watwood,[2] and D. Yates[3,10]

- Directly observed the protons from $^{11}\text{Be}(\beta p)^{10}\text{Be}$
- Measured consistent branching ratio $b_p = 1.3(3) \times 10^{-5}$
  - Still orders of magnitude larger than theoretical predictions
- Predict the proton resonance at 11.425(20) MeV from the proton energy distribution
  - Predicted to be either $\frac{1}{2}^+$ or $\frac{3}{2}^+$
  - Corresponds to excitation energy of 197 keV

NCSMC extended to describe exotic ^{11}Be βp emission, supports large branching ratio due to narrow ½⁺ resonance

$^{11}\mathrm{Be} \rightarrow (^{10}\mathrm{Be+p}) + \beta^{-} + \bar{\nu}_e$ GT transition

p+^{10}Be Scattering Phase Shifts



PHYSICAL REVIEW C **105**, 054316 (2022)

***Ab initio* calculation of the β decay from ^{11}Be to a ^{10}Be + *p* resonance**

M. C. Atkinson,[1] P. Navrátil,[1] G. Hupin,[2] K. Kravvaris,[3] and S. Quaglioni[3]

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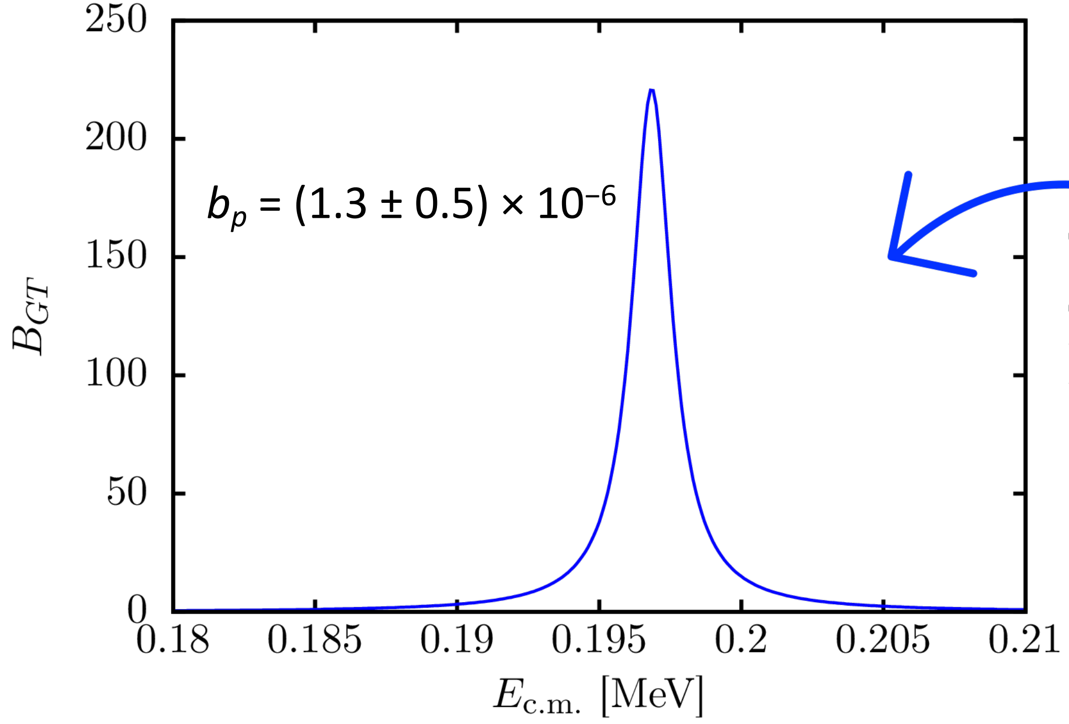
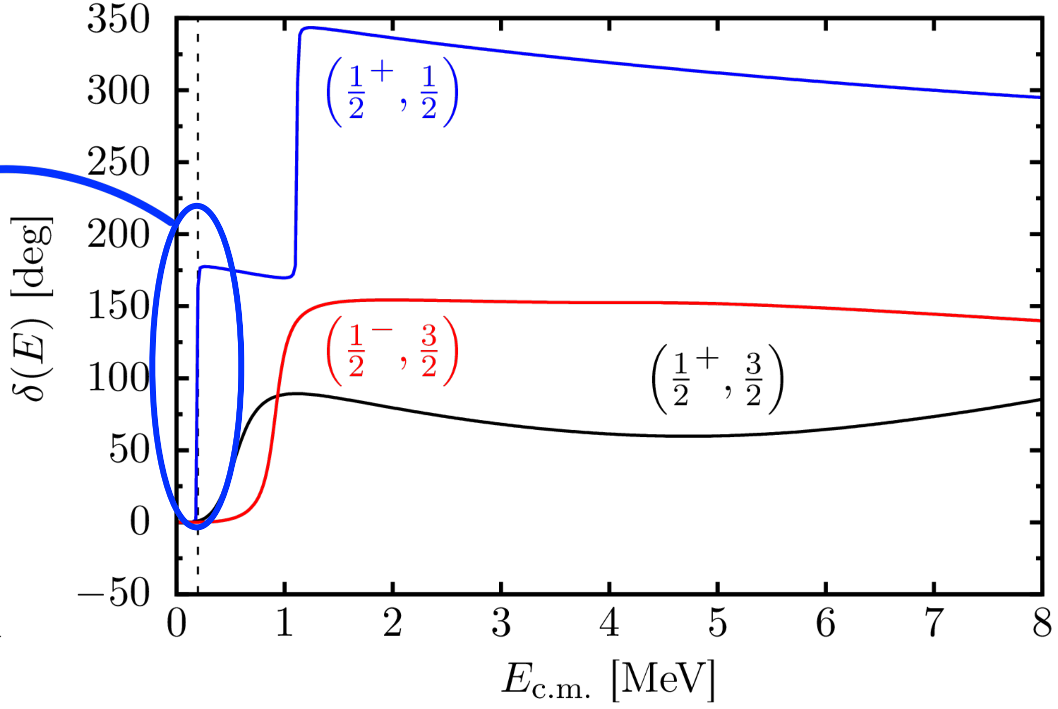
^{11}Be → (^{10}Be+p) + β^-+ $\bar{\nu}_e$ GT transition



p+^{10}Be Scattering Phase Shifts



PHYSICAL REVIEW C **105**, 054316 (2022)

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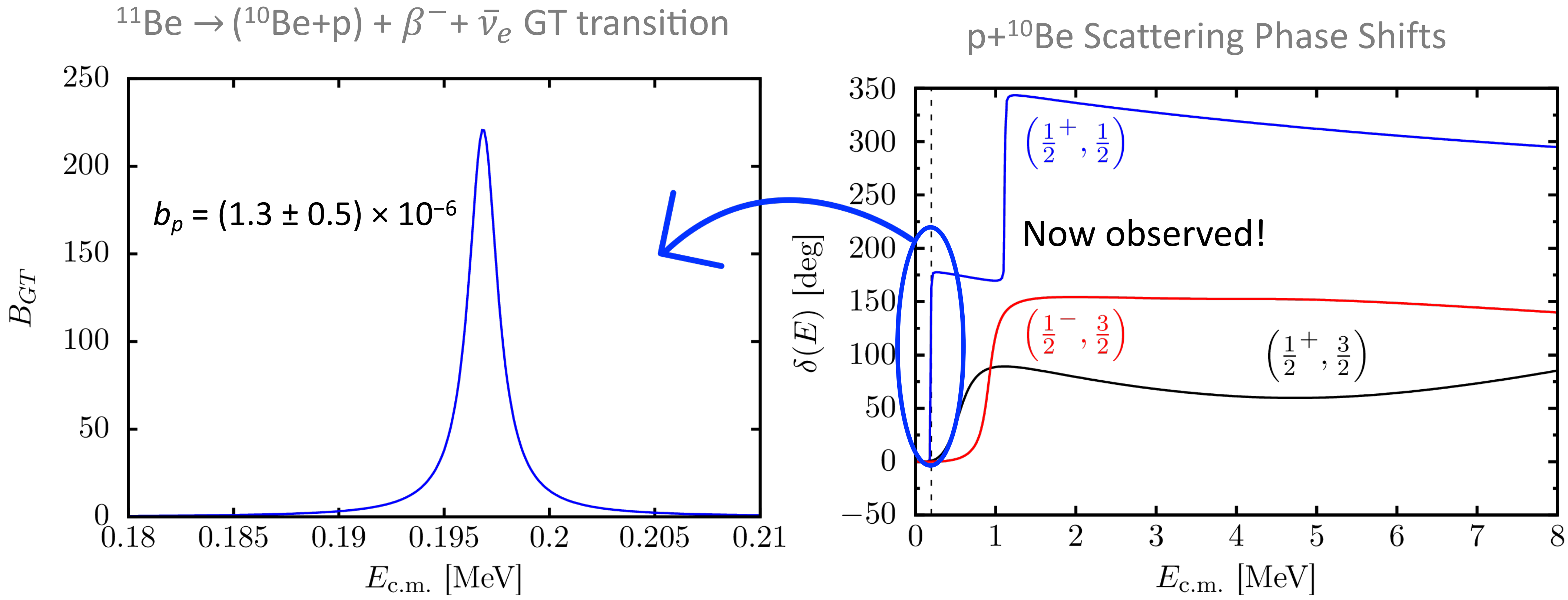


PHYSICAL REVIEW LETTERS **129,** 012502 (2022)

Observation of a Near-Threshold Proton Resonance in ^{11}B

E. Lopez-Saavedra,[1,*] S. Almaraz-Calderon,[1,†] B. W. Asher,[1] L. T. Baby,[1] N. Gerken,[1] K. Hanselman,[1] K. W. Kemper,[1] A. N. Kuchera,[2] A. B. Morelock,[1] J. F. Perello,[1] E. S. Temanson,[1] A. Volya,[1] and I. Wiedenhöver[1]

PHYSICAL REVIEW LETTERS **129,** 012501 (2022)

Evidence of a Near-Threshold Resonance in ^{11}B Relevant to the β-Delayed Proton Emission of ^{11}Be

Y. Ayyad,[1,2,*] W. Mittig,[2,3] T. Tang,[2] B. Olaizola,[4] G. Potel,[5] N. Rijal,[2] N. Watwood,[2] H. Alvarez-Pol,[1] D. Bazin,[2,3] M. Caamaño,[1] J. Chen,[6] M. Cortesi,[2] B. Fernández-Domínguez,[1] S. Giraud,[2] P. Gueye,[2,3] S. Heinitz,[7] R. Jain,[2,3] B. P. Kay,[6] E. A. Maugeri,[7] B. Monteagudo,[2] F. Ndayisabye,[2,3] S. N. Paneru,[2] J. Pereira,[2] E. Rubino,[2] C. Santamaria,[2] D. Schumann,[7] J. Surbrook,[2,3] L. Wagner,[2] J. C. Zamora,[2] and V. Zelevinsky[2,3]

PHYSICAL REVIEW C **105**, 054316 (2022)

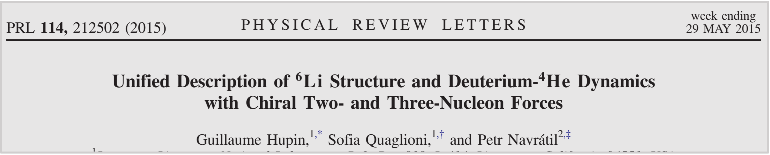
***Ab initio* calculation of the β decay from ^{11}Be to a ^{10}Be + p resonance**

M. C. Atkinson,[1] P. Navrátil,[1] G. Hupin,[2] K. Kravvaris,[3] and S. Quaglioni[3]

Radiative capture of deuterons on ^{4}He

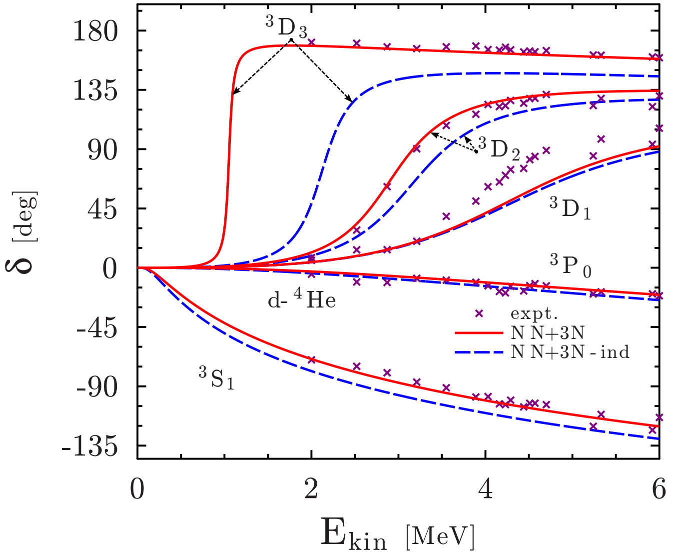
- Reaction ^{4}He(d,γ)^{6}Li responsible for ^{6}Li production in BBN
- Three orders of magnitude discrepancy between BBN predictions and observations
  - Problem with astronomical observations?
  - Problem with our understanding of the reaction rate?
  - New physics?

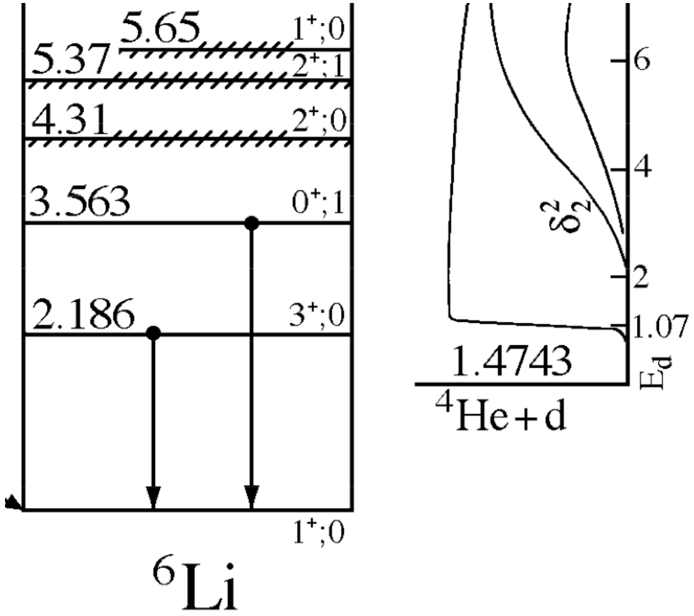
^{6}Li ↔ ^{4}He+d investigated within NCSMC in the past


PRL **114,** 212502 (2015) PHYSICAL REVIEW LETTERS week ending 29 MAY 2015

Unified Description of ^{6}Li Structure and Deuterium-^{4}He Dynamics with Chiral Two- and Three-Nucleon Forces

Guillaume Hupin,[1,*] Sofia Quaglioni,[1,†] and Petr Navrátil[2,‡]





PHYSICAL REVIEW LETTERS **129**, 042503 (2022)

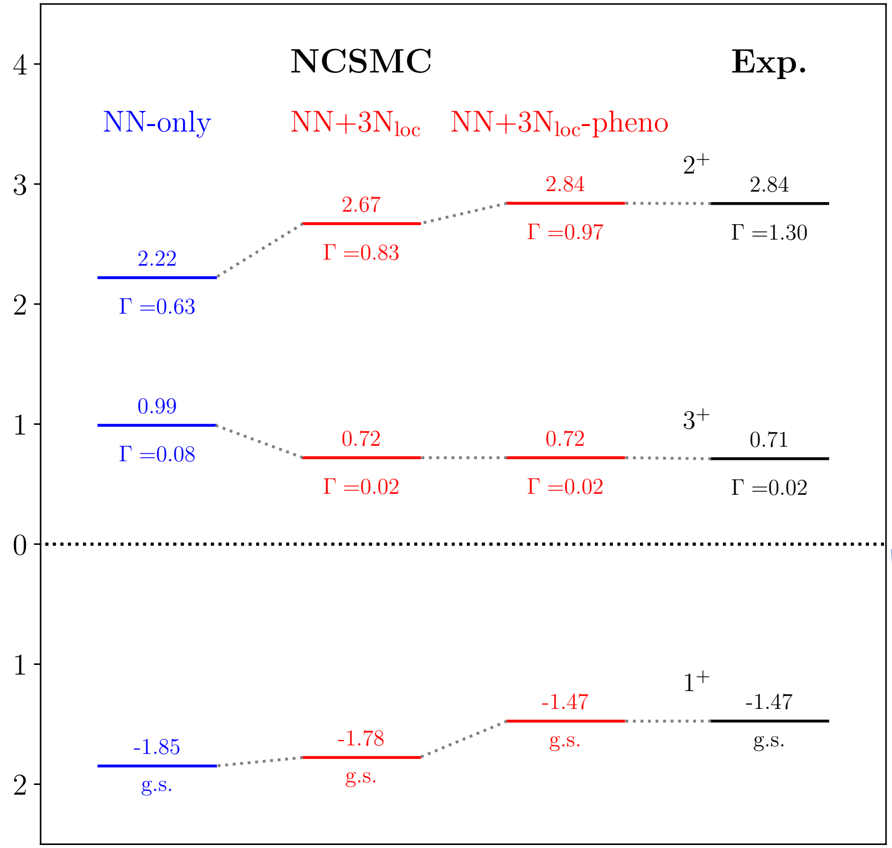
***Ab Initio* Prediction of the ^{4}He(d,γ)^{6}Li Big Bang Radiative Capture**

C. Hebborn,[1,2,*] G. Hupin,[3] K. Kravvaris,[2] S. Quaglioni,[2] P. Navrátil,[4] and P. Gysbers[4,5]

Radiative capture of deuterons on ^{4}He

- NCSMC calculations with chiral NN+3N interaction

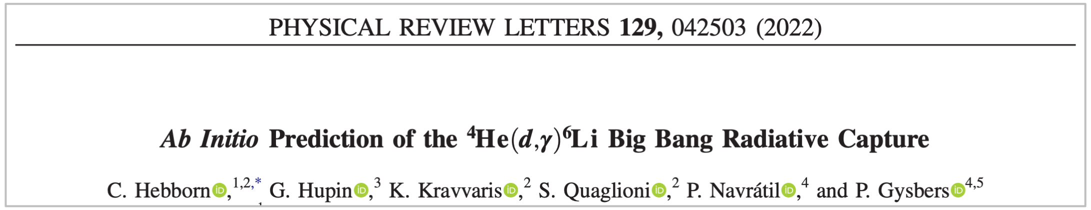
Structure of ^{6}Li



^{4}He+d threshold

Ground state properties:
Energy
Asymptotic normalization constants
Magnetic moment

	NN-only	3N$_{loc}$	3N$_{loc}$-pheno	Exp. or Eval.
$E_{g.s.}$	-1.848	-1.778	-1.474	-1.4743
$\mathcal{C}_0$	2.95	2.89	2.62(4)	2.28(7) 2.29(12)
$\mathcal{C}_2$	-0.0369	-0.0642	-0.0554(305)	-0.077(18)
$\mathcal{C}_2/\mathcal{C}_0$	-0.013	-0.022	-0.021(11)	-0.025(6)(10)
μ	0.85	0.84	0.84(1)	0.8220473(6)


PHYSICAL REVIEW LETTERS **129,** 042503 (2022)

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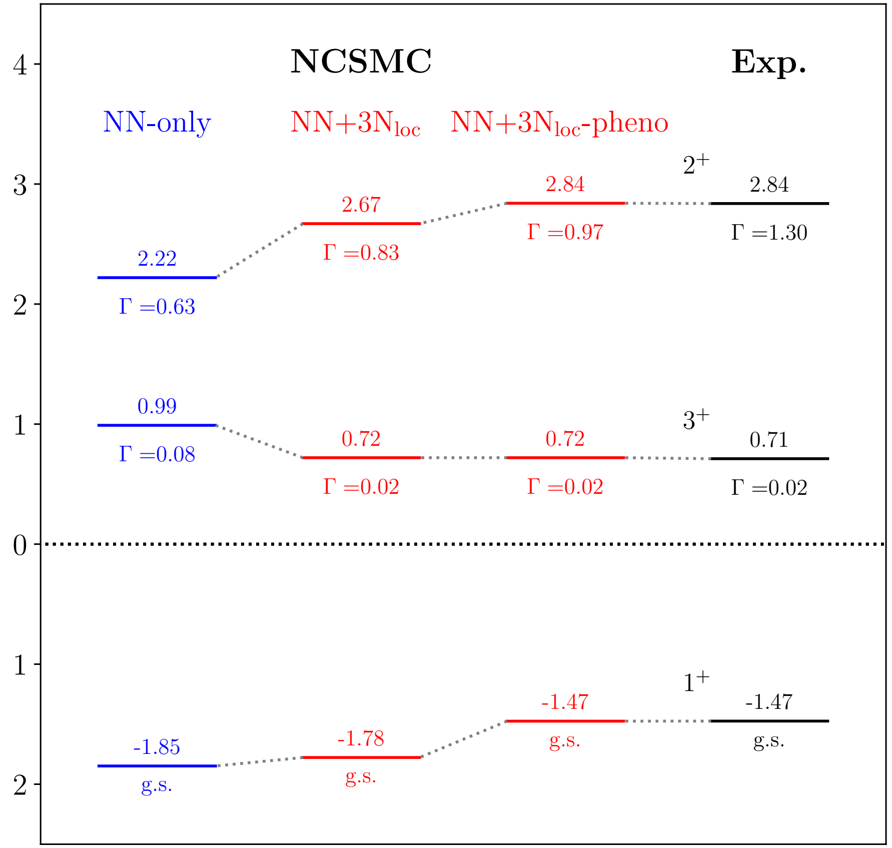
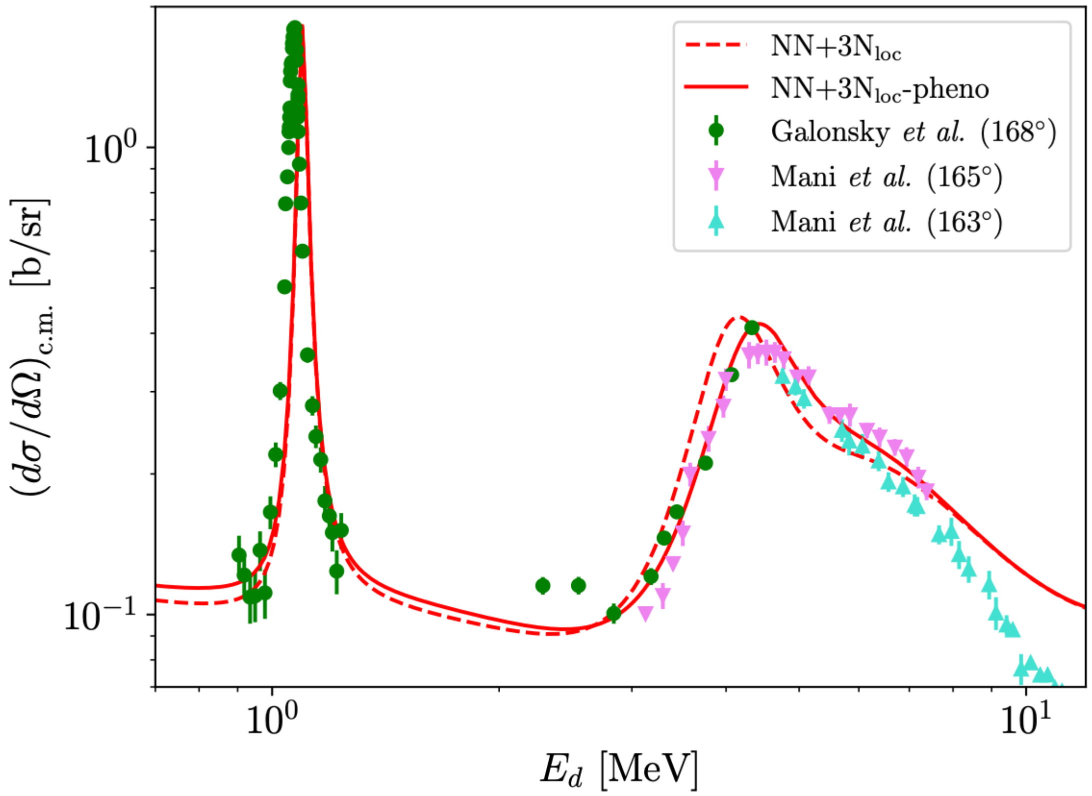


Elastic scattering ^{4}He$(d,d)^4$He cross section at the deuteron back scattered angle 164°



PHYSICAL REVIEW LETTERS 129, 042503 (2022)

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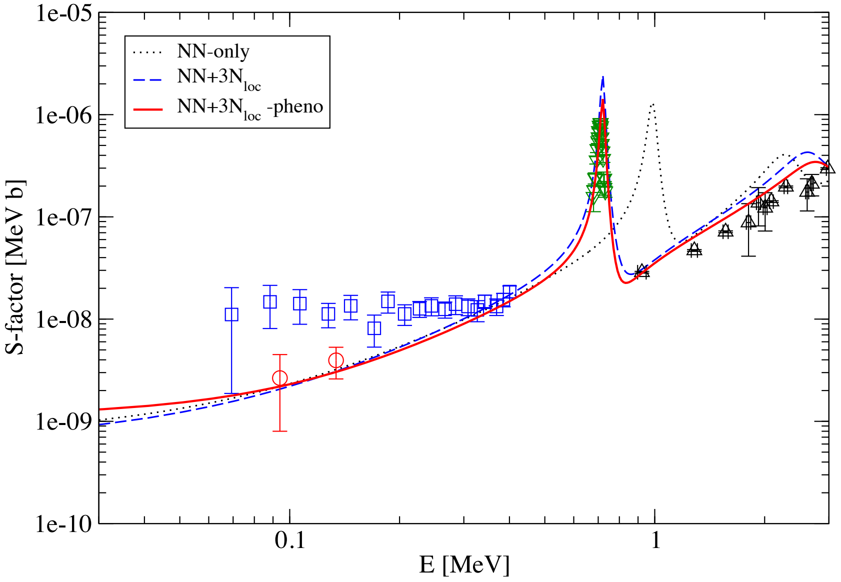
Radiative capture of deuterons on ^{4}He

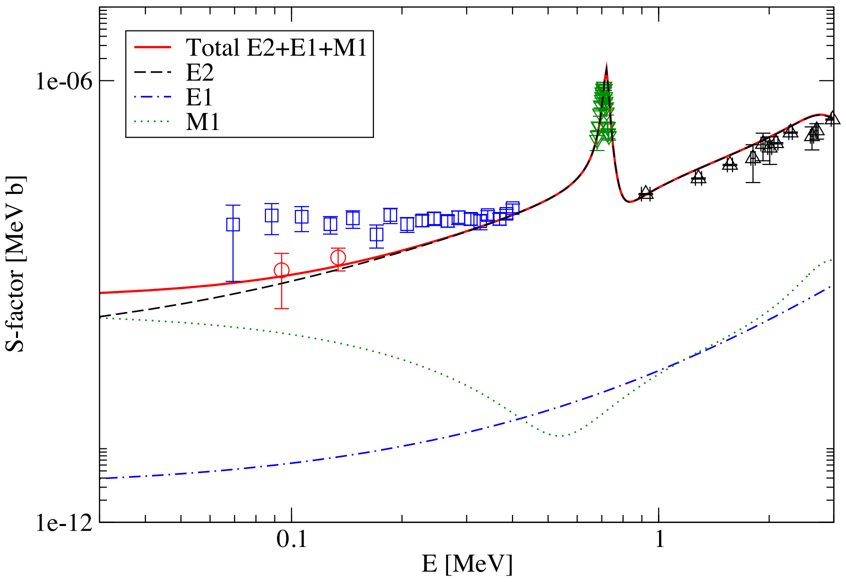
- NCSMC calculations with chiral NN+3N interaction
  - Capture S-factor

Dominated by E2
M1 significant at low energy
E1 negligible – isospin supressed (T=0 → T=0)

$$\mathcal{M}^{E\lambda} = e\sum_{j=1}^{A}\frac{1+\tau_{jz}}{2}[\boldsymbol{r}_j - \boldsymbol{R}_{cm}^{(A)}]^\lambda$$

$$\mathcal{M}^{M1} = \frac{\mu_N}{\hbar c}\sqrt{\frac{3}{4\pi}}\sum_{j=1}^{A}(g_{lj}L_j + g_{sj}S_j)$$





Low energy S-factor consistent with LUNA data, below the ^{6}Li Coulomb breakup data

PHYSICAL REVIEW LETTERS **129,** 042503 (2022)

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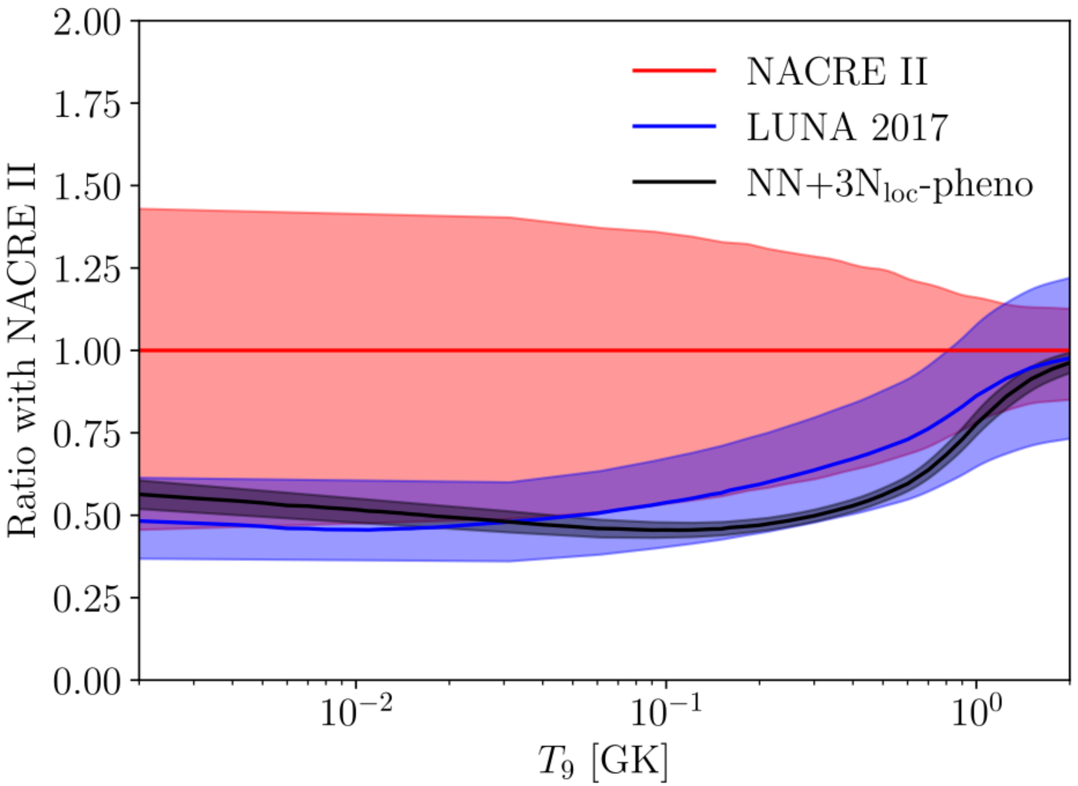
C. Hebborn,[1,2,*] G. Hupin,[3] K. Kravvaris,[2] S. Quaglioni,[2] P. Navrátil,[4] and P. Gysbers[4,5]

Radiative capture of deuterons on ^{4}He

- NCSMC calculations with chiral NN+3N interaction
  - Thermonuclear reaction rate



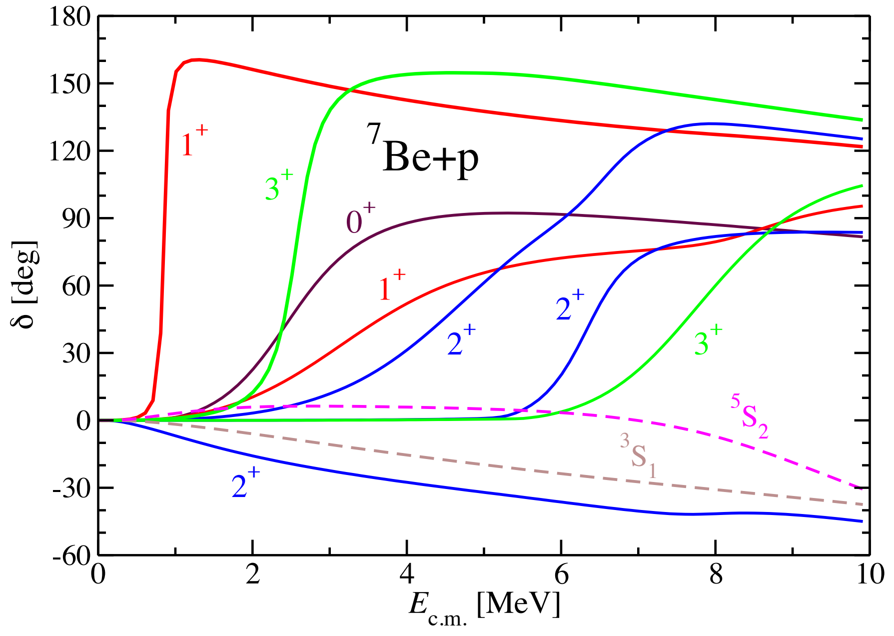
Thermonuclear reaction rate smaller than NACRE II evaluation, agreement with LUNA result with less uncertainty

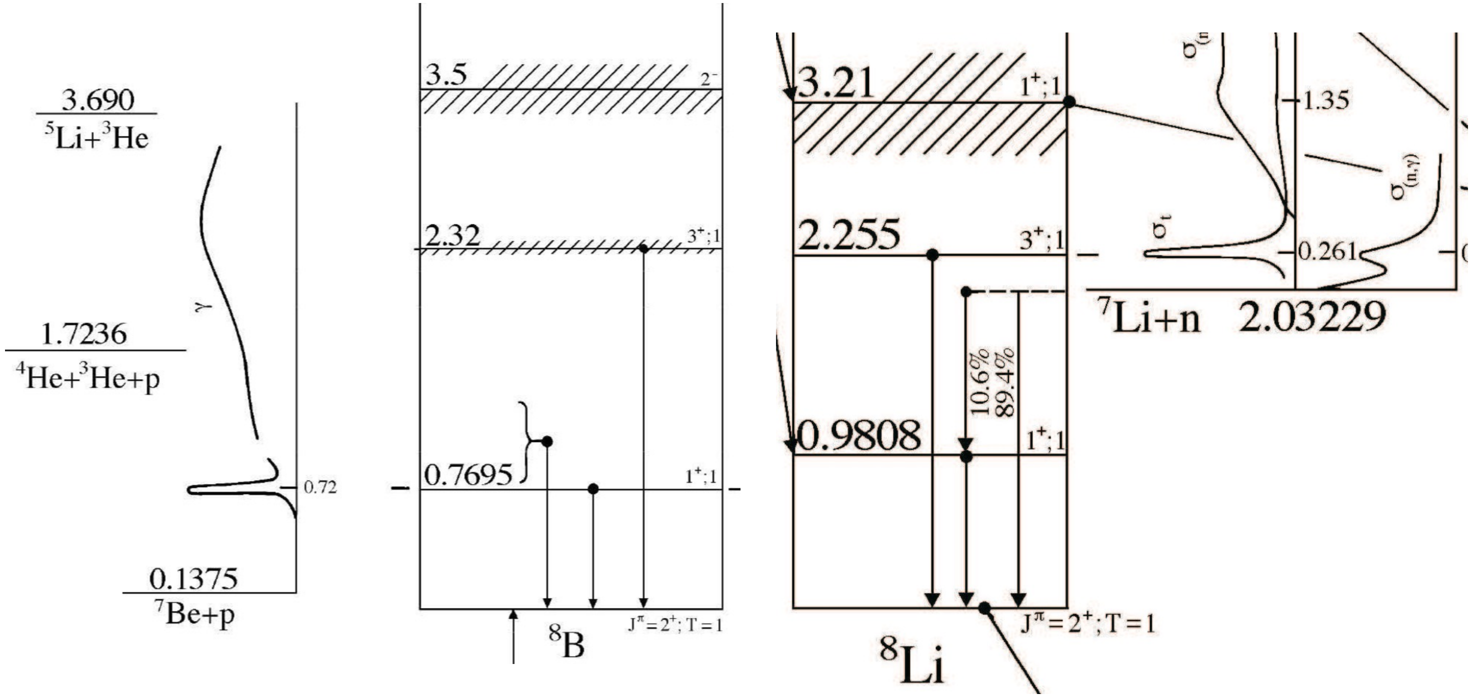
Ab initio prediction for the radiative capture of protons on ^{7}Be
K. Kravvaris,[1] P. Navrátil,[2] S. Quaglioni,[1] C. Hebborn,[3,1] and G. Hupin[4]
arXiv: 2202.11759

Radiative capture of protons on ^{7}Be

- Solar pp chain reaction, solar ^{8}B neutrinos
- NCSMC calculations with a set of chiral NN+3N interactions as input

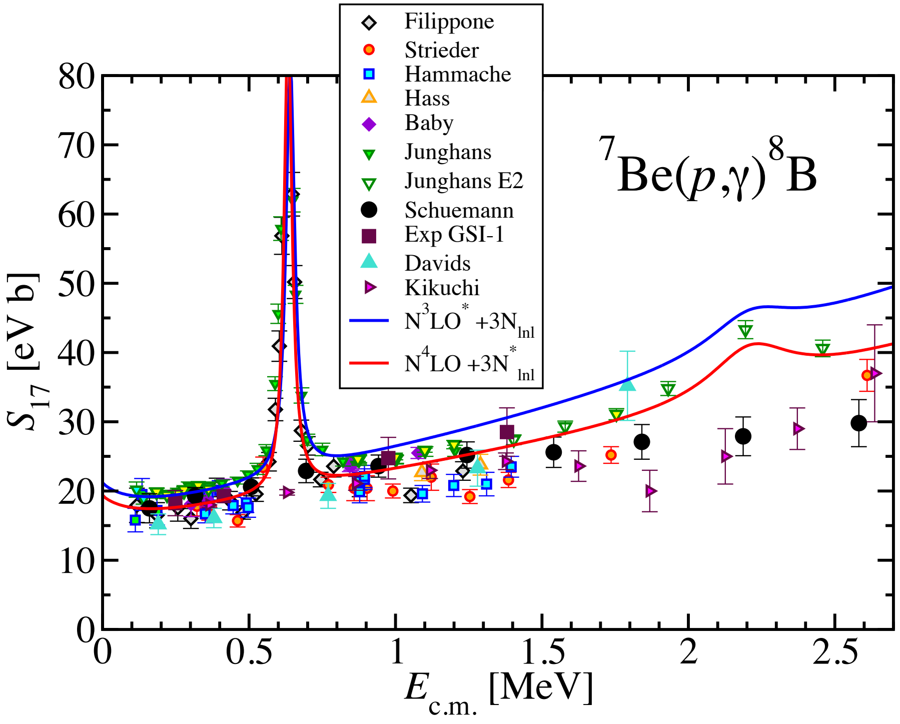
- Example of ^{8}B structure results



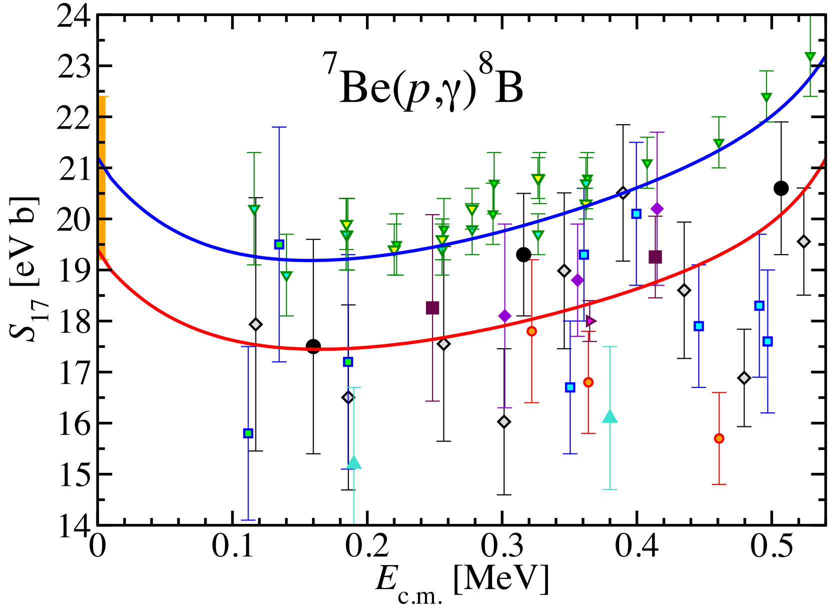


Radiative capture of protons on ^{7}Be

- NCSMC S-factor results



	$C_{p_{1/2}}$	$C_{p_{3/2}}$	a_1	a_2	$S_{17}(0)$
N^{2}LO+3N$_{\rm lnl}$	0.384	0.691	4.4(1)	-0.5(1)	23.9
N^{3}LO+3N$_{\rm lnl}$	0.390	0.678	1.3(1)	-4.7(1)	23.5
N^{4}LO+3N$_{\rm lnl}$	0.354	0.669	1.6(1)	-4.4(1)	22.0
N^{4}LO+3N$^*_{\rm lnl}$	0.343	0.621	1.3(1)	-5.0(1)	19.3
N^{3}LO*+3N$_{\rm lnl}$	0.334	0.663	0.1(1)	-7.7(1)	21.1
N^{3}LO*+3N$_{\rm loc}$	0.308	0.584	2.5(1)	-3.6(2)	16.8
Ref. [41]	0.315(9)	0.66(2)	$17.34^{+1.11}_{-1.33}$	$-3.18^{+0.55}_{-0.50}$	



E1 non-resonant, M1/E2 at 1$^+$ and 3$^+$ resonances

Ab initio prediction for the radiative capture of protons on ^{7}Be

K. Kravvaris,[1] P. Navrátil,[2] S. Quaglioni,[1] C. Hebborn,[3,1] and G. Hupin[4]

arXiv: 2202.11759

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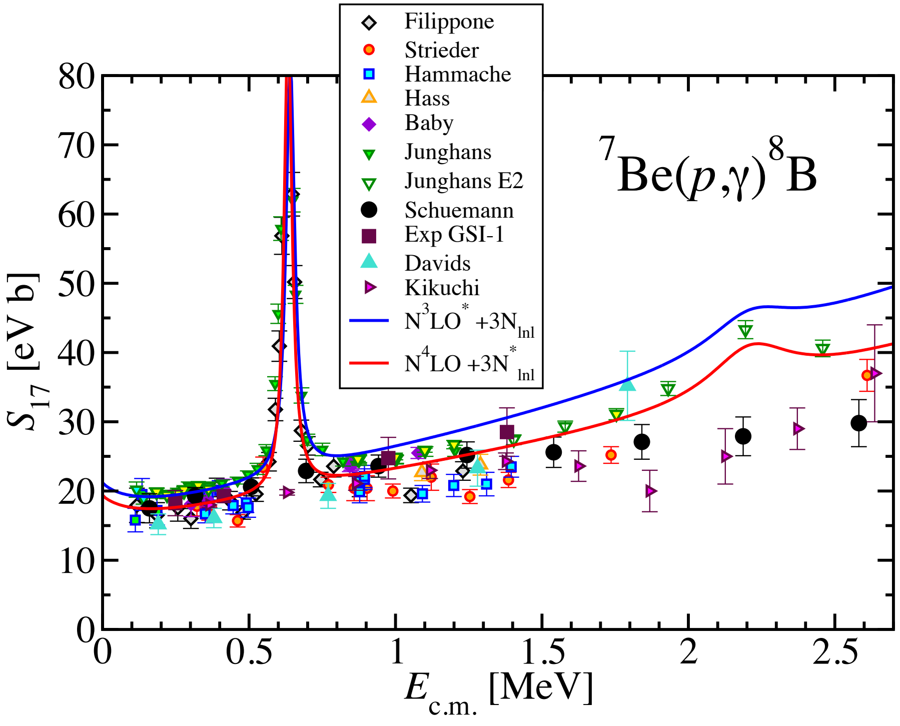

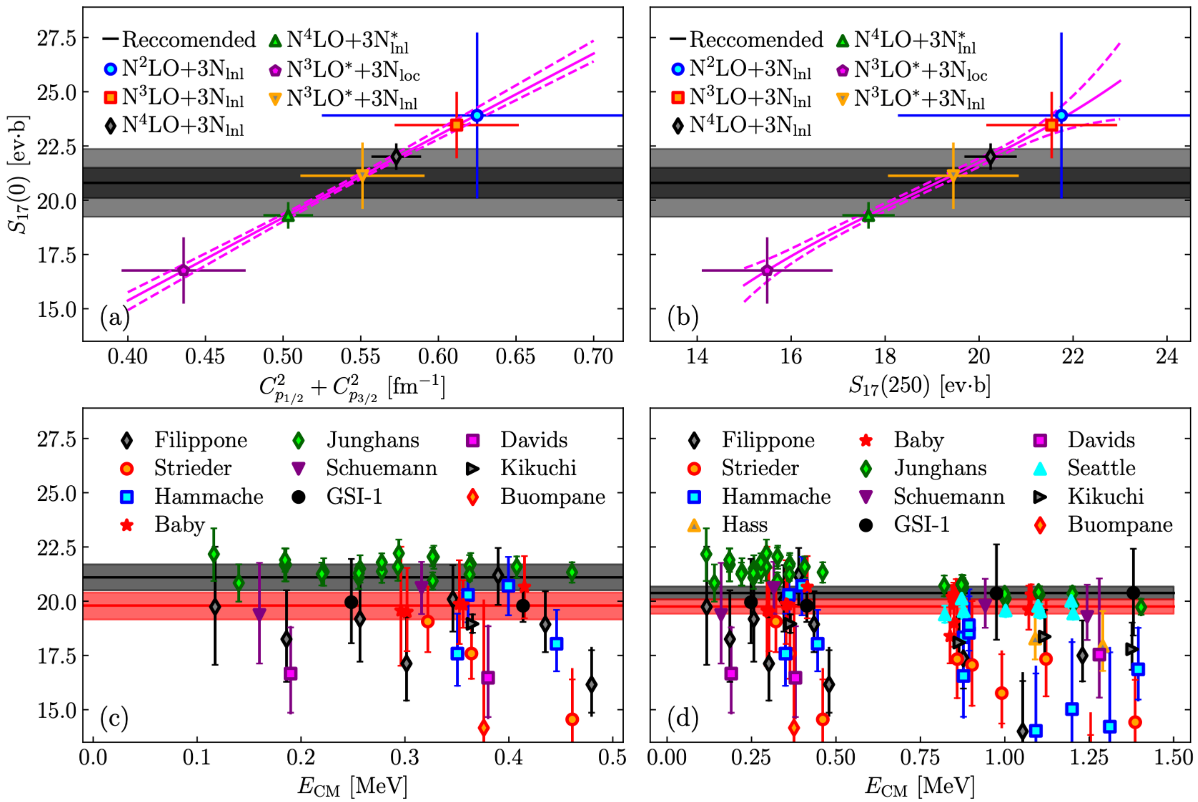

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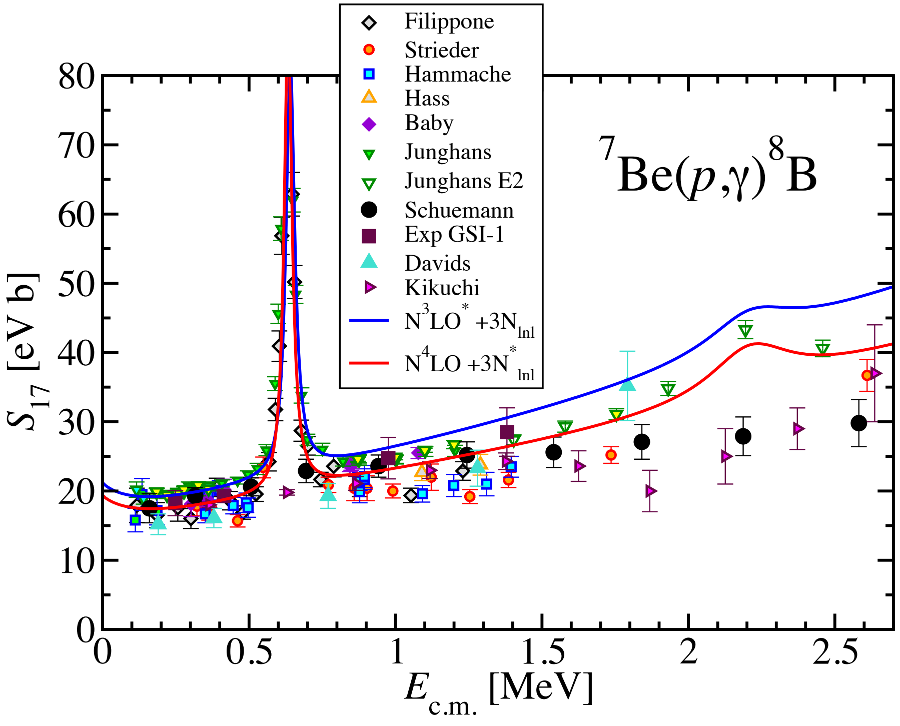
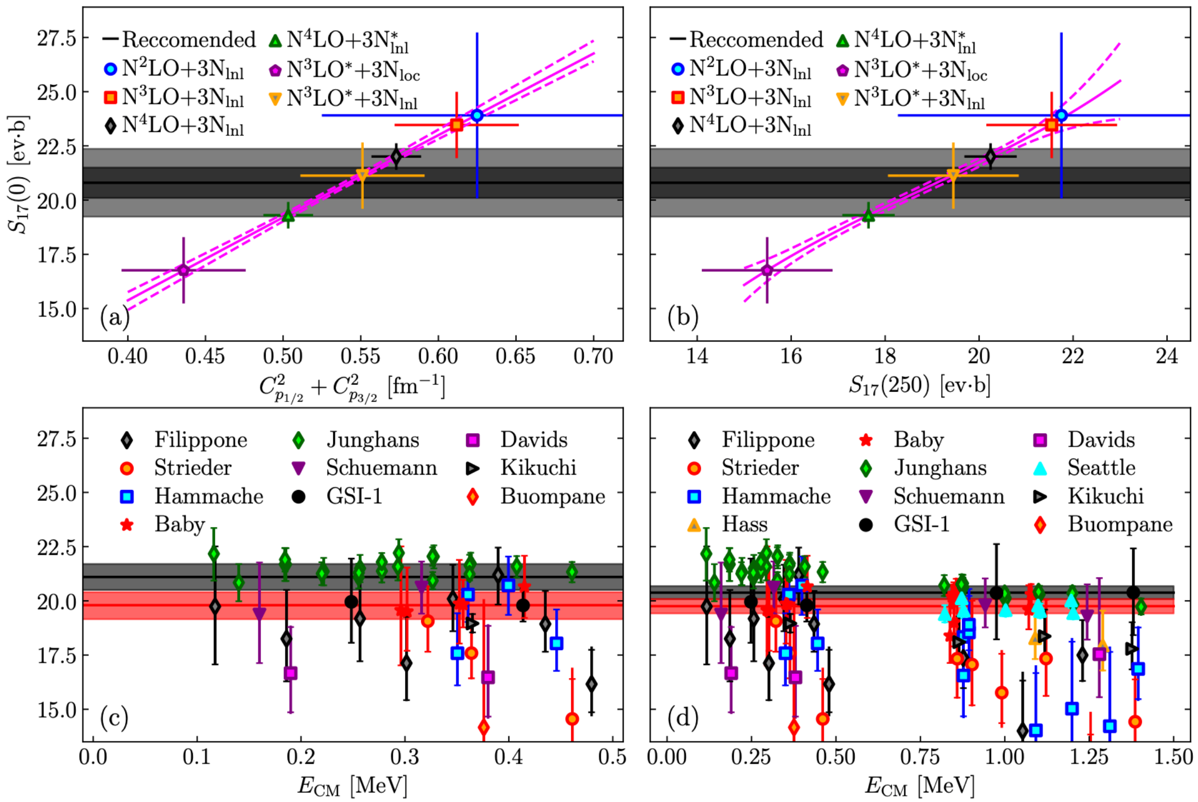
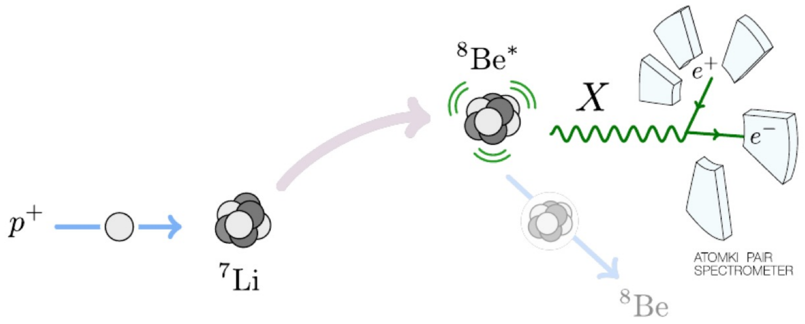




Recommended value $S_{17}(0)$ ~ 19.8(3) eV b

Latest evaluation in *Rev. Mod. Phys.* **83**,195–245 (2011):
$S_{17}(0)$ = 20.8 ± 0.7(expt) ± 1.4(theory) eV b

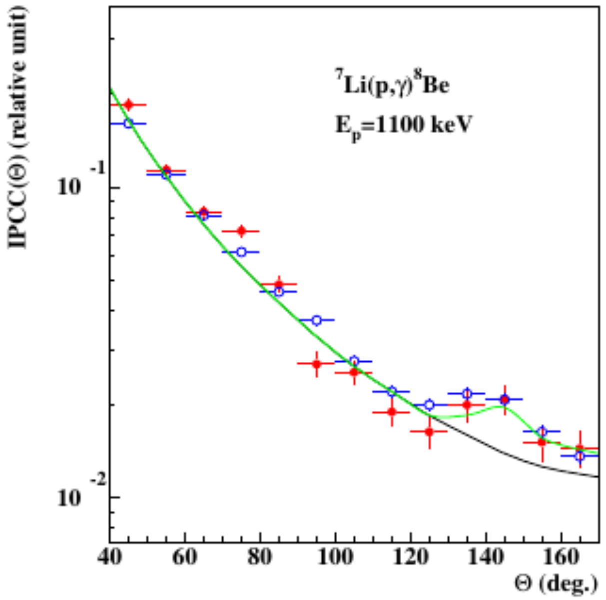
X17 Anomaly

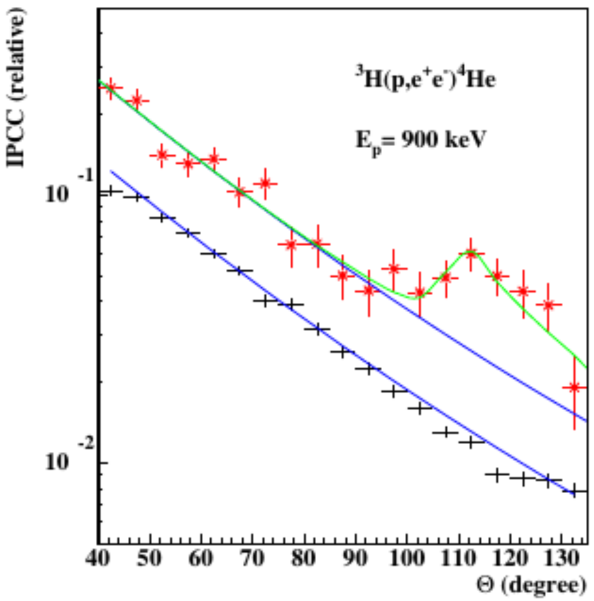


Feng PRD **95**, 035017 (2017)

"An anomaly in the internal pair creation on the M1 transition depopulating the 18.15 MeV isoscalar 1^+ state on $^8\mathrm{Be}$ was observed. This could be explained by the creation and subsequent decay of a new boson .. mass 17.01(16) MeV"

Firak, Krasznahorkay, et al
EPJ Web of Conferences **232 04005 (2020)**





Angle between e⁻ and e⁺

IPCC:
Internal Pair Creation
Angular Correlation

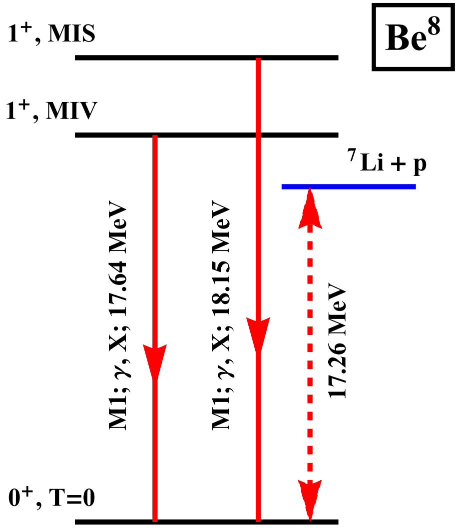


Fig. from PLB 813, 136061 (2021)

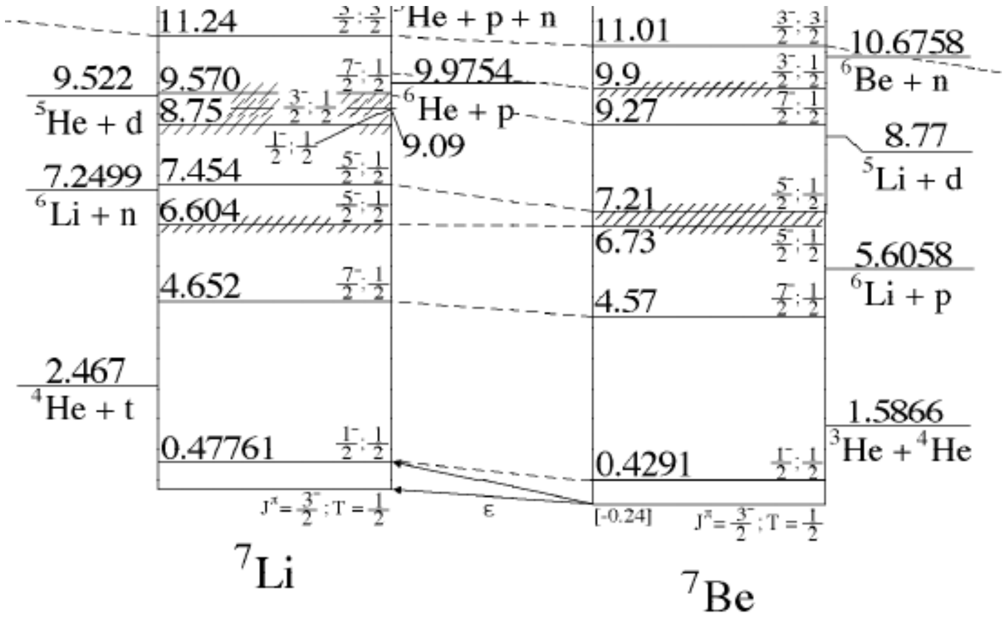
Can *ab initio* nuclear theory help interpret the anomaly?

NCSMC calculations of ^{8}Be structure and ^{7}Li+p scattering and capture

- Wave function ansatz

$$\Psi^{(8)}_{\text{NCSMC}} = \sum_{\lambda} c_{\lambda} \left|{}^{8}\text{Be}, \lambda\right\rangle + \sum_{\nu} \int dr \gamma_{\nu}(r) \hat{A}_{\nu} \left|{}^{7}\text{Li} + p, \nu\right\rangle + \sum_{\mu} \int dr \gamma_{\mu}(r) \hat{A}_{\mu} \left|{}^{7}\text{Be} + n, \mu\right\rangle$$

- $3/2^-$, $1/2^-$, $7/2^-$, $5/2^-$, $5/2^-$ ^{7}Li and ^{7}Be states in cluster basis
- 15 positive and 15 negative parity states in ^{8}Be composite state basis



In collaboration with UBC/TRIUMF PhD student Peter Gysbers

TUNL Nuclear Data Evaluation Project

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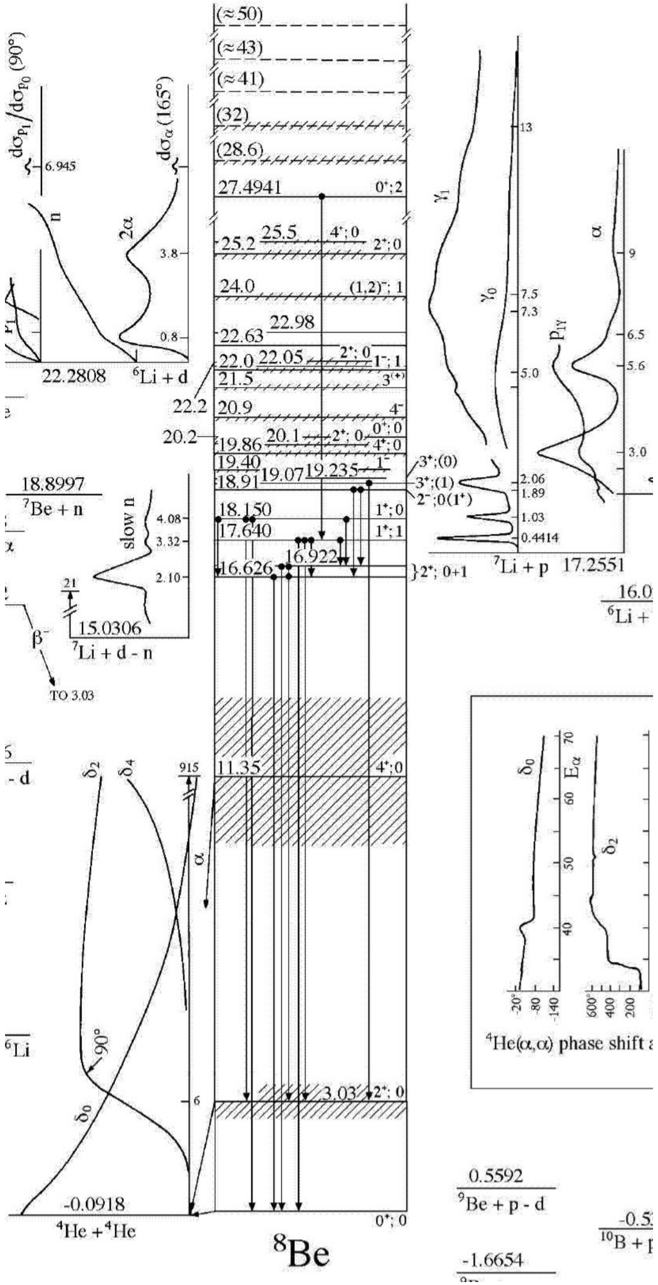
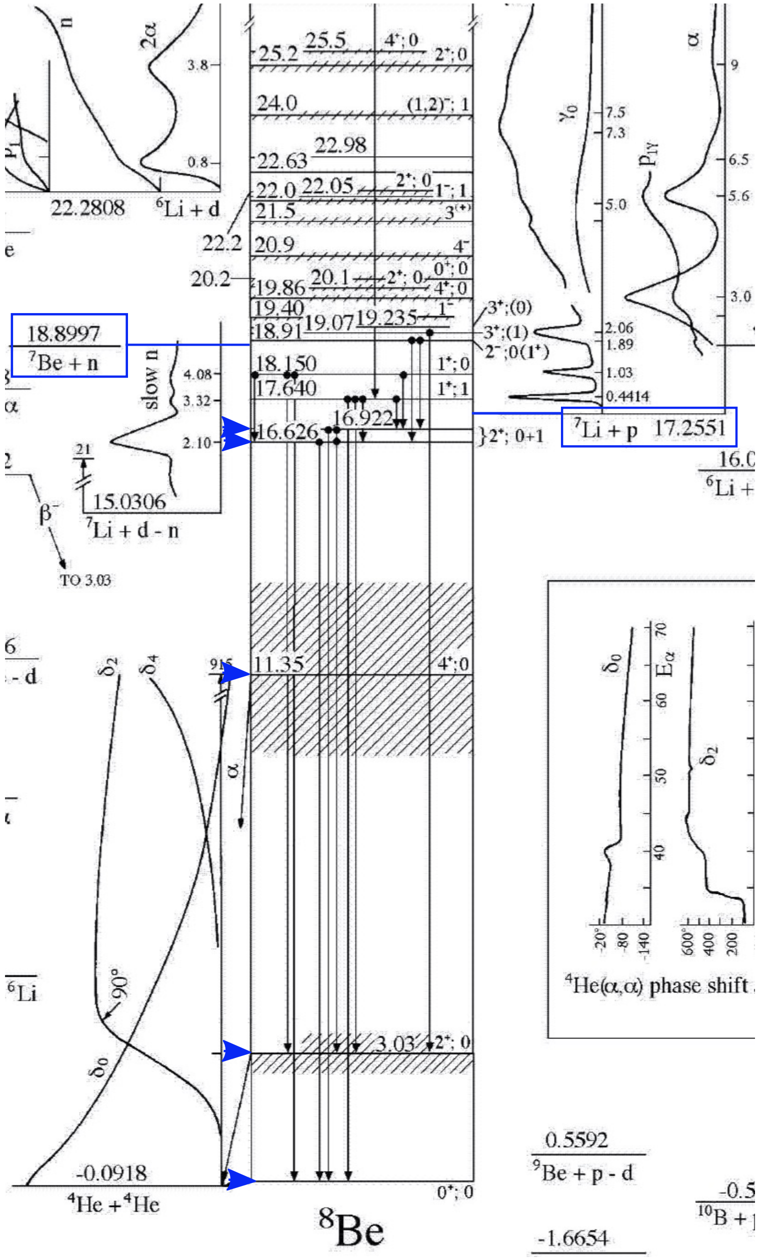


^{8}Be structure

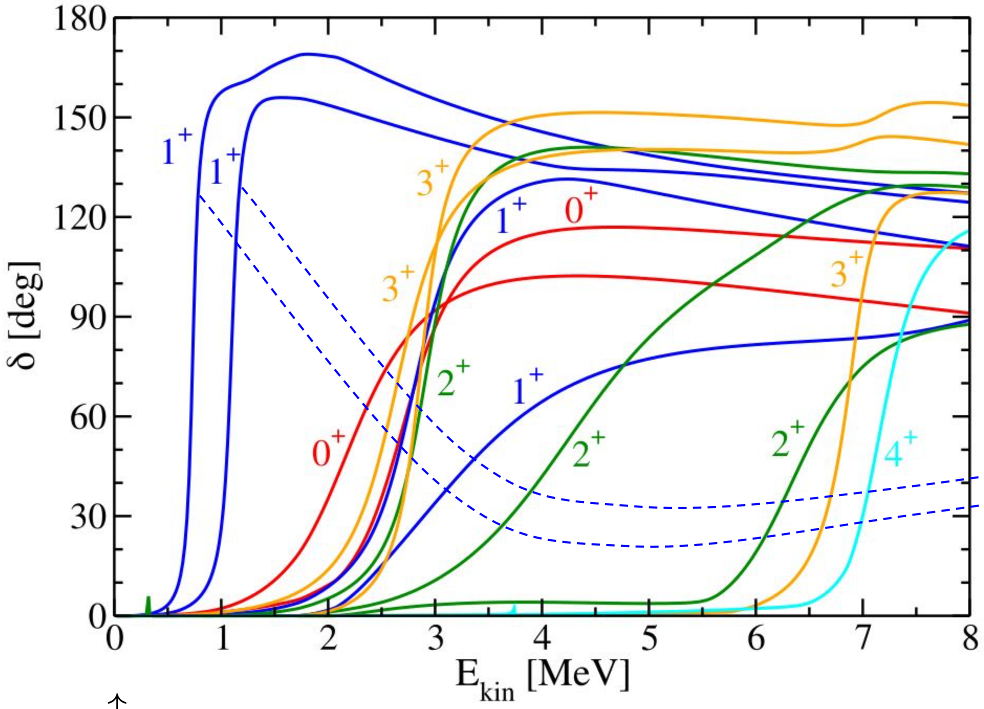
Calculated $^{8}\mathrm{Be}$ bound states w.r.t. $^{7}\mathrm{Li}+p$ threshold ($N_{max}=8/9$)

State	Energy [MeV]		Excitation Energy [MeV]	
	NCSMC	Expt.	NCSMC	Expt.
0^+	-16.13	-17.25	0.00	0.00
2^+	-12.72	-14.23	3.41	3.03
4^+	-4.31	-5.91	11.82	11.35
2^+	-0.10	-0.63	16.03	16.63
2^+	+0.31	-0.33	16.44	16.92

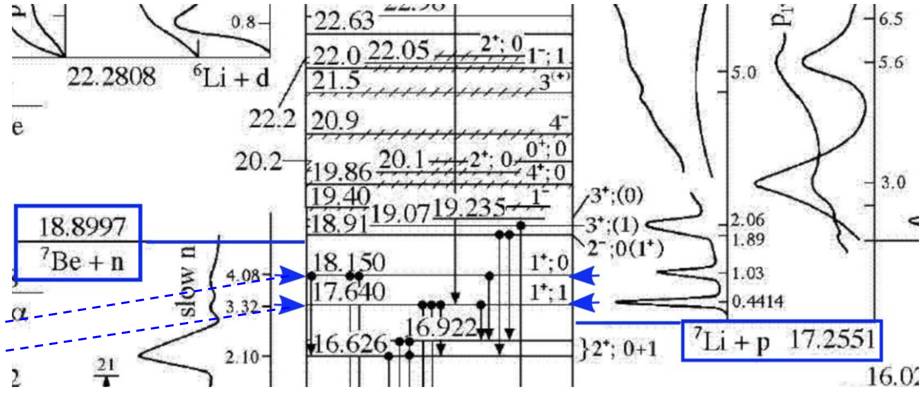
Matches experiment well, except the 3rd 2^+ is slightly above the $^{7}\mathrm{Li}+p$ threshold.



^{8}Be structure – calculated positive-parity eigenphase shifts



↑
$p + {}^{7}\mathrm{Li}$ threshold



Additional resonances are seen compared to TUNL data

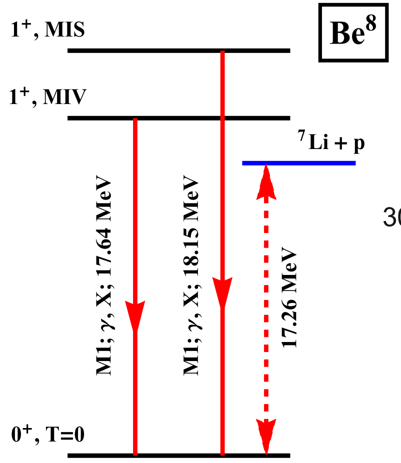


Fig. from PLB 813, 136061 (2021)

Ab initio calculations of ^{7}Li(p,γ)^{8}Be radiative capture, ^{7}Li(p,e$^+$e$^-$)^{8}Be pair production & X17 boson

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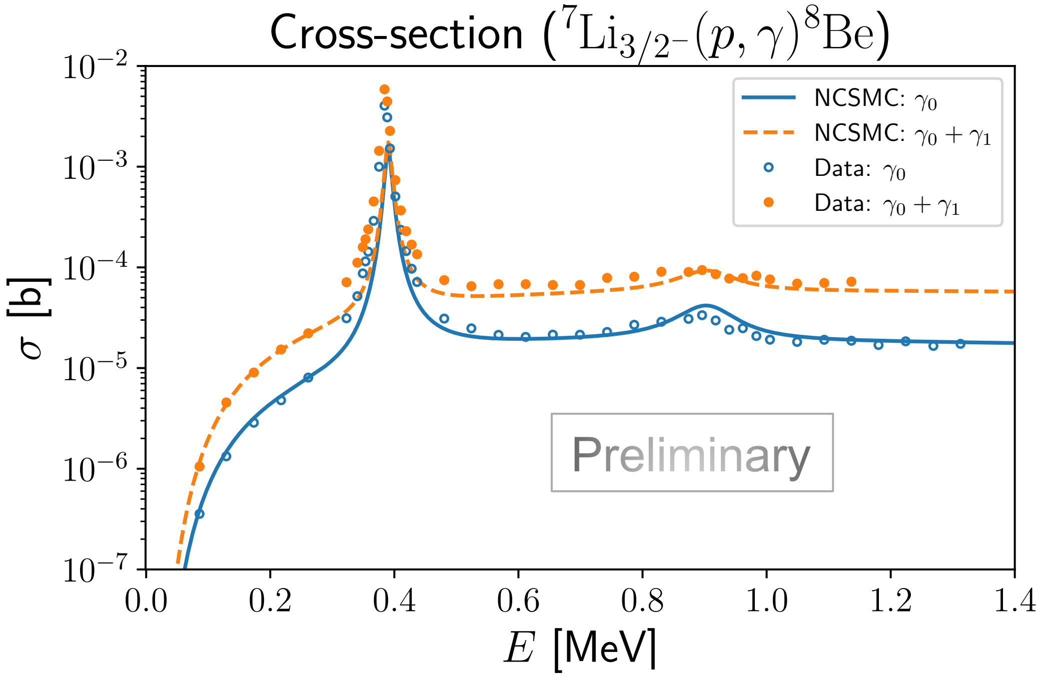

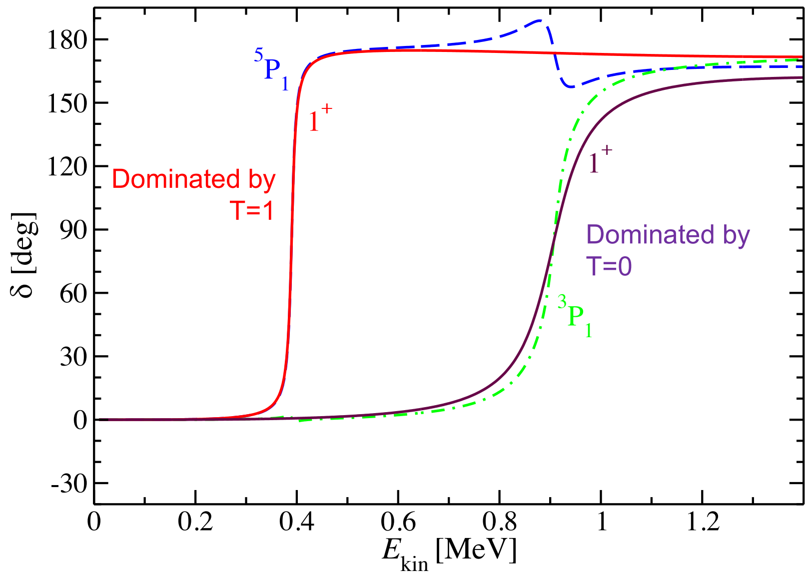

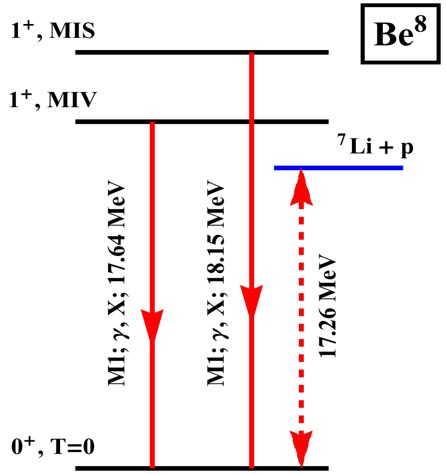

Data: Zahnow *et al.*
Z.Phys.A **351** 229-236 (1995)

γ_0: decay to ground state (0^+)
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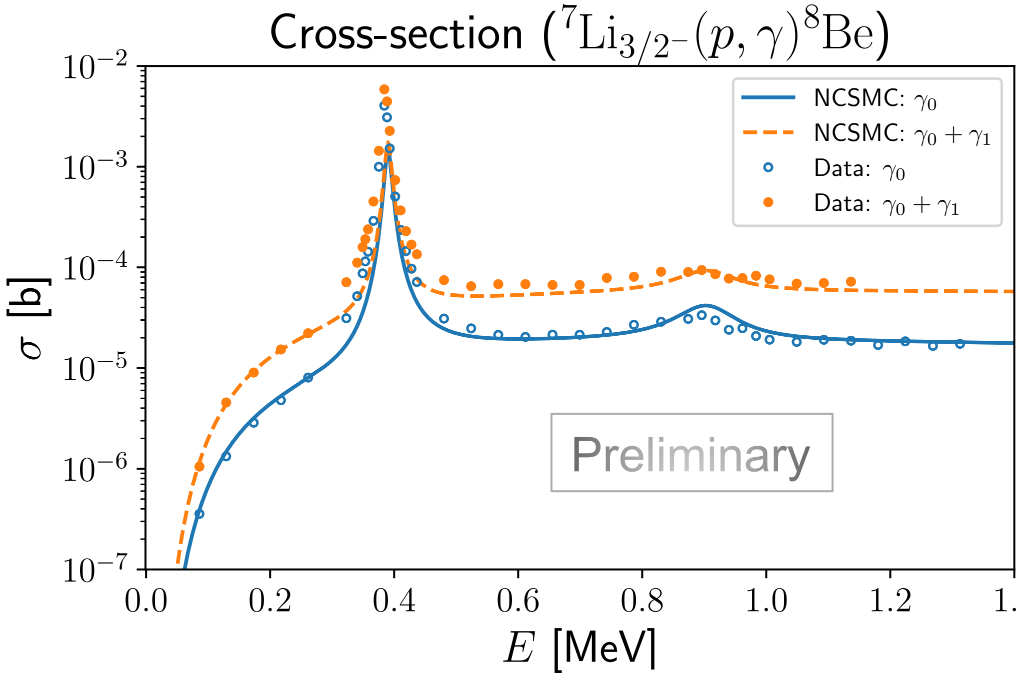

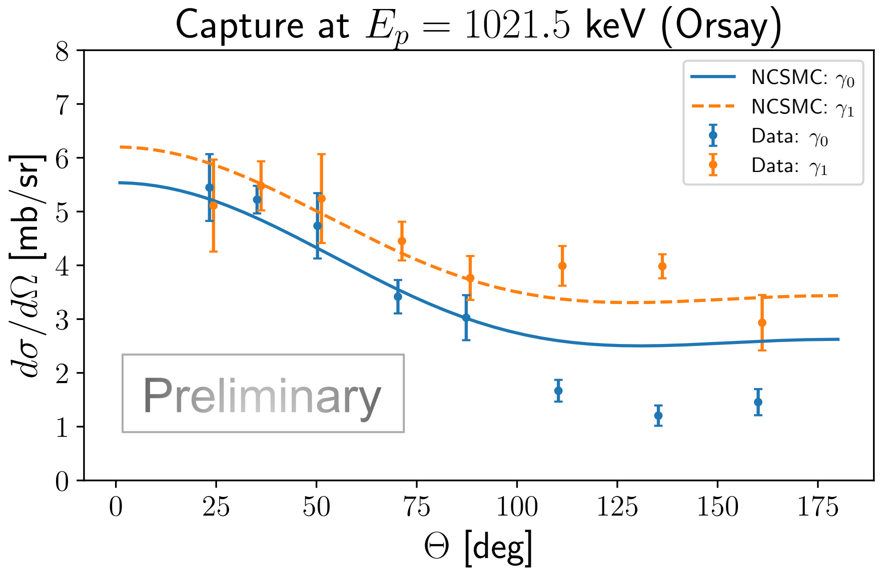

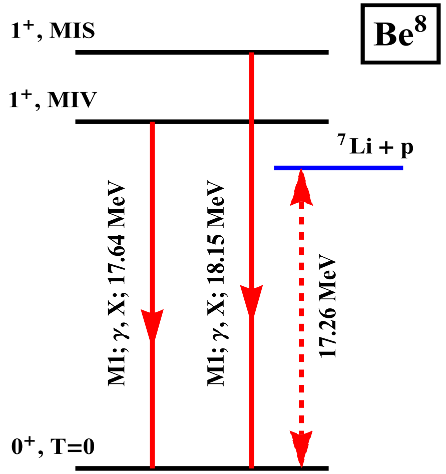

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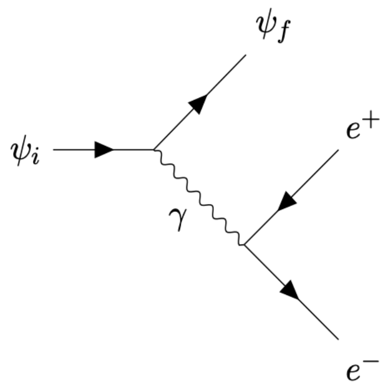
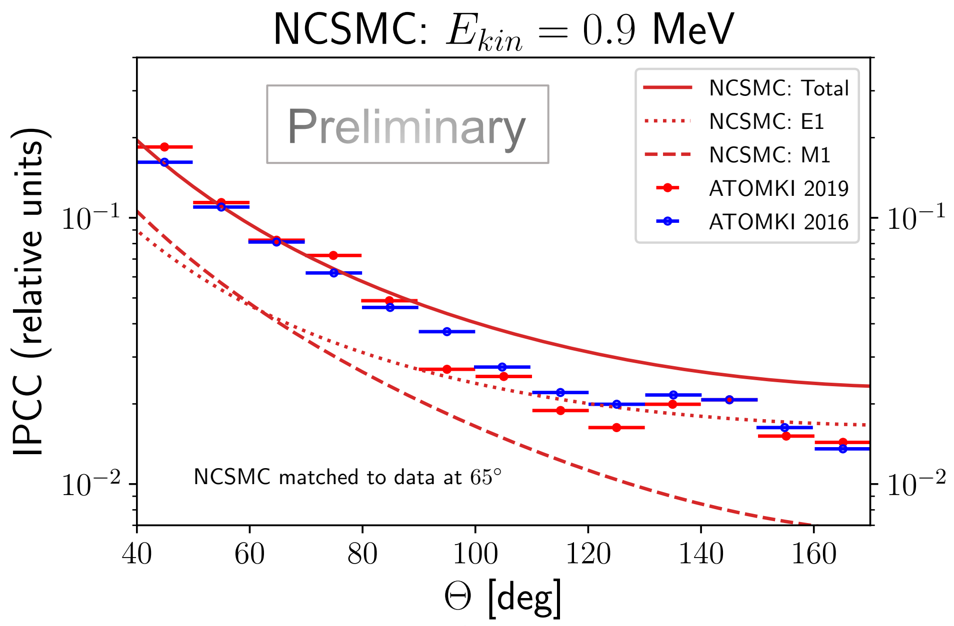
Internal electron-positron pair conversion correlation

Assuming J=1 → 0^{+} bound-to-bound like decay rate



NCSMC IPCC results consistent with LANL R-matrix phenomenology
arXiv: 2106.06834; Phys. Rev. C **105**, 055502 (2022)



Angle between e^{-} and e^{+}

NCSMC calculations lead by P. Gysbers (UBC/TRIUMF PhD student)

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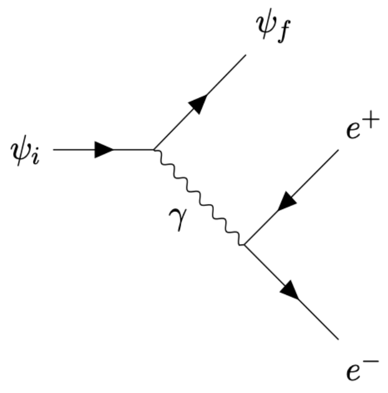

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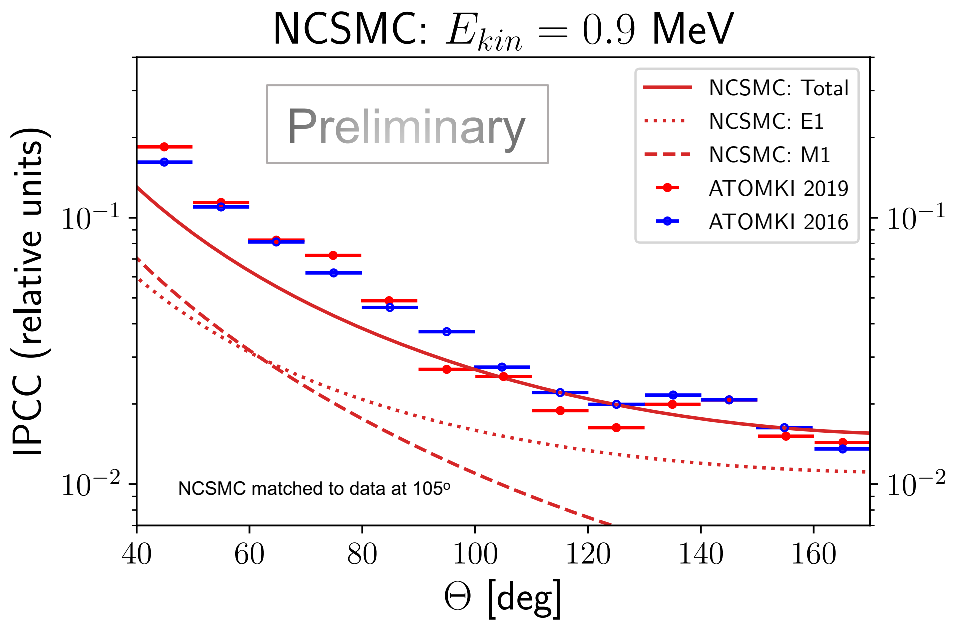

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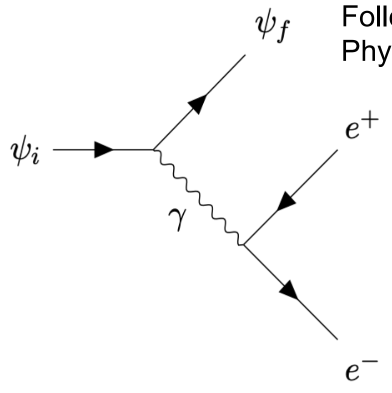
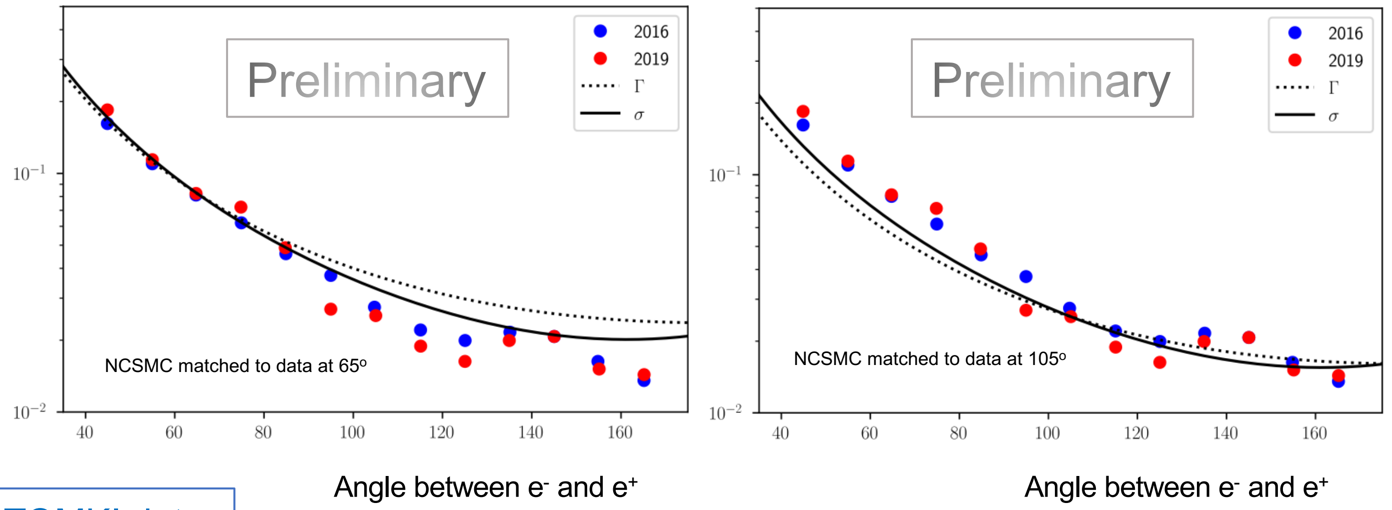
Internal electron-positron pair conversion correlation

Calculating properly the pair production cross section with the interference of different multipoles



Following formalism by Viviani *et al.* Phys. Rev. C **105**, 014001 (2022)



NCSMC pair production cross section more in line with ATOMKI data

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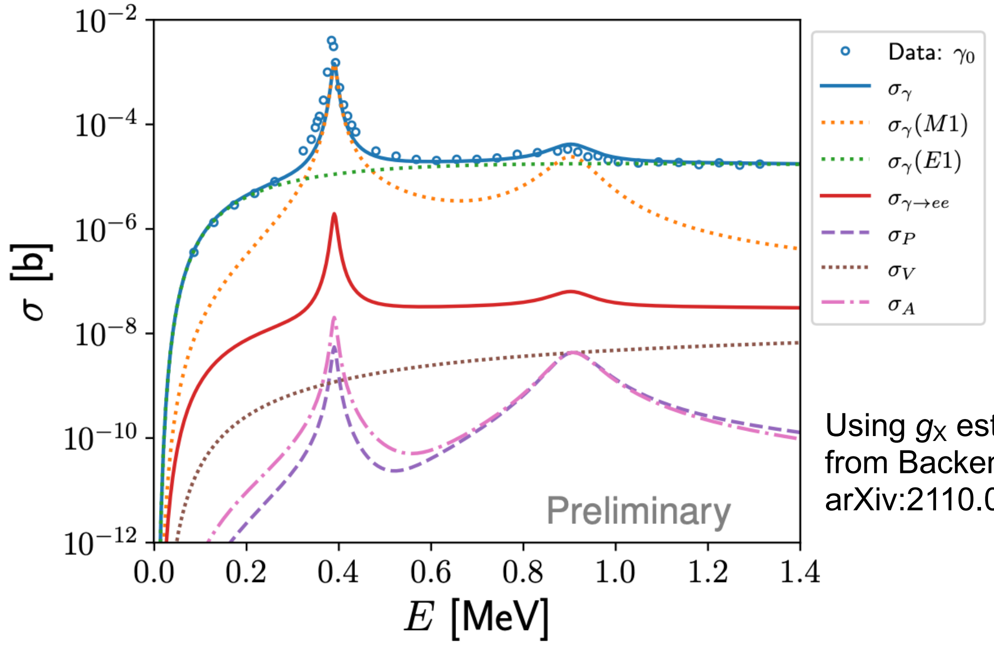
Integrated cross sections



Using g_X estimates from Backens *et al.* arXiv:2110.06055

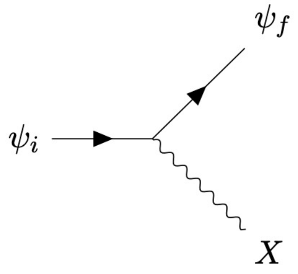
Data: Zahnow *et al.*
Z.Phys.A **351** 229-236 (1995)

X17 Candidate Bosons

($m_X \simeq 17$ MeV, $\Delta E \geq 17.2251$ MeV [$^7\text{Li} + p$], $k_X = \sqrt{\Delta E^2 - m_X^2}$, $k_\gamma = \Delta E$)

Operators for $1^\pm \to 0^+$ decay (in the long-wavelength approximation)

- Pseudo-scalar (0^-): $\langle X_P \rangle \sim \epsilon_P \left\langle \hat{S} \right\rangle k_X$
- Axial-vector (1^+): $\langle X_A \rangle \sim \epsilon_A \left\langle \hat{S} \right\rangle \sqrt{2 + \frac{m_X^2}{\Delta E^2}}$
- Vector (1^-): $\langle X_V \rangle \sim \epsilon_V \langle E1 \rangle \frac{k_X}{k_\gamma}$
- For comparison: γ (E1 (1^-), M1 (1^+), E2 (2^+), etc)
  $\langle E1 \rangle \sim \langle r Y_1 \rangle k_\gamma$
  $\langle M1 \rangle \sim \left(g_l \left\langle \hat{L} \right\rangle + g_s \left\langle \hat{S} \right\rangle \right) k_\gamma$



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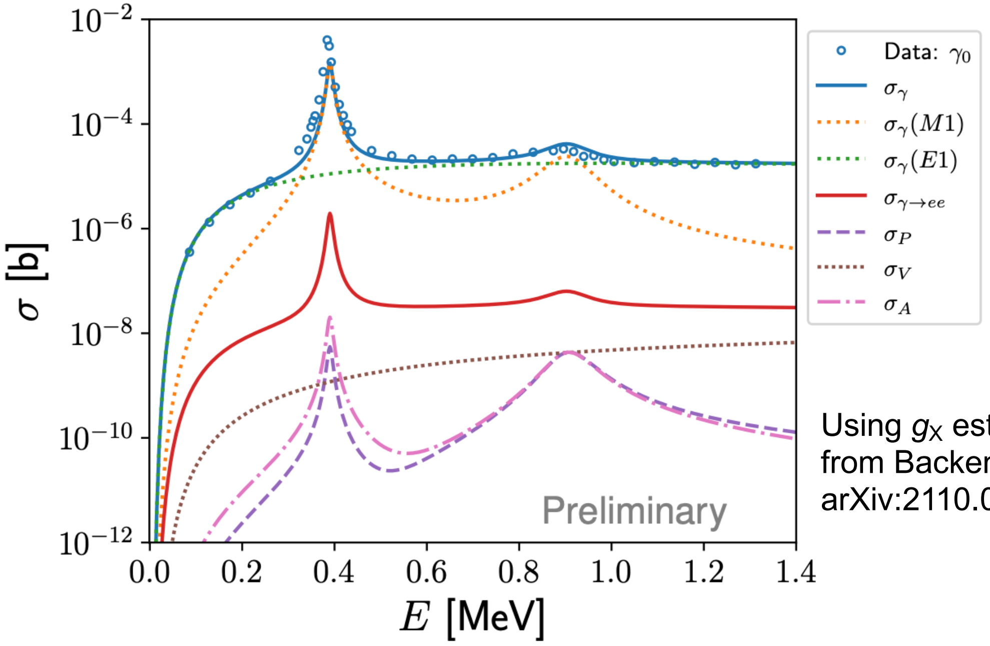

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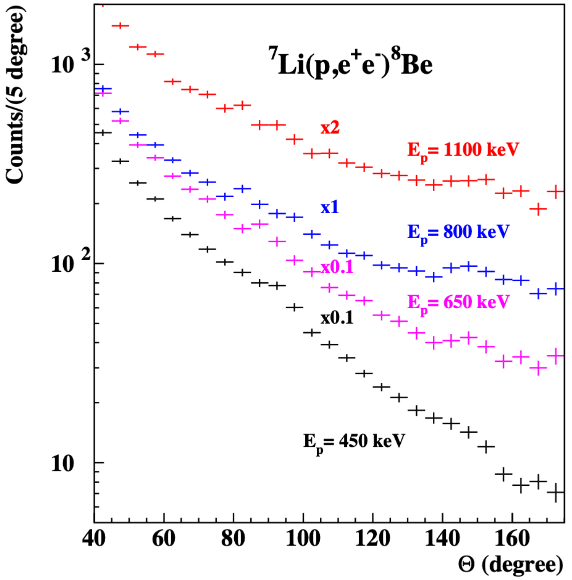
Latest developments (arXiv: 2205.07744):
Anomaly in E1 direct capture – X17 a vector boson



… more calculations to do

NCSMC calculations lead by P. Gysbers (UBC/TRIUMF PhD student)

Conclusions

- *Ab initio* nuclear theory
  - Makes connections between the low-energy QCD and many-nucleon systems
  - Applicable to nuclear structure, reactions including those relevant for astrophysics, electroweak processes, tests of fundamental symmetries
  - Very recently reach extended to heavy nuclei

- Applications of *ab initio* NCSMC to
  - ^{11}Be β decay with the proton emission
  - Radiative capture of protons on ^{7}Be and deuteron capture on ^{4}He
  - Proton capture on ^{7}Li - internal pair conversion and the X17 boson claim

In synergy with experiments, *ab initio* nuclear theory is the right approach to understand low-energy properties of atomic nuclei

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Thank you!
Merci!

Discovery, accelerated