Ab Initio Investigation of Radiative Capture and Electron-Positron Pair Production

Peter Gysbers
Facility for Rare Isotope Beams

SM75 - July 21, 2024

Acknowledgements

Ab Initio investigation of the $^{7}\mathrm{Li}(p, e^{+}e^{-})^{8}\mathrm{Be}$ process and the X17 boson.
PRC **110**, 015503 (2024) arXiv:2308.13751

Coauthors

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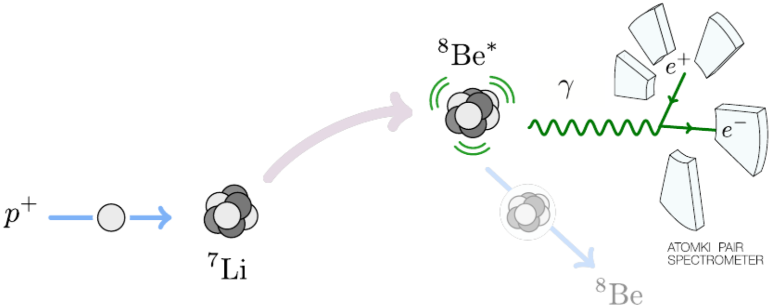
- IJCLab: Guillaume Hupin

The X17 Anomaly in $p + {}^7\mathrm{Li} \to {}^8\mathrm{Be} + e^+e^-$

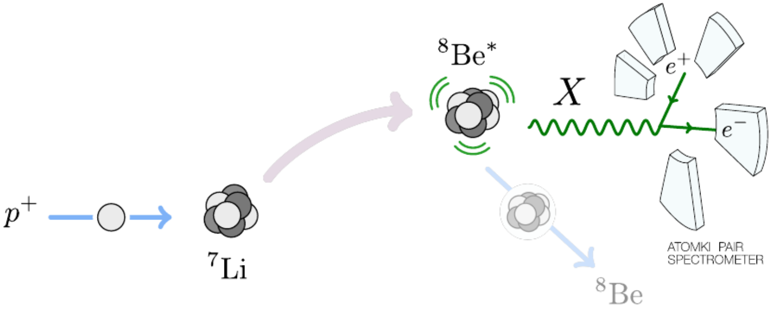
- ${}^7\mathrm{Li}(p, e^+e^-)^8\mathrm{Be}$ @ATOMKI (Hungary) [PRL **116** 042501 (2016)]
- Decay of composite ${}^8\mathrm{Be}$ produces electron-positron pairs



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

The X17 Anomaly in $p + {}^7\mathrm{Li} \to {}^8\mathrm{Be} + e^+e^-$

- ${}^7\mathrm{Li}(p, e^+e^-){}^8\mathrm{Be}$ @ATOMKI (Hungary) [PRL **116** 042501 (2016)]
- Decay of composite ${}^8\mathrm{Be}$ produces electron-positron pairs
- Anomaly in pair distribution implies an intermediate particle of mass 17 MeV



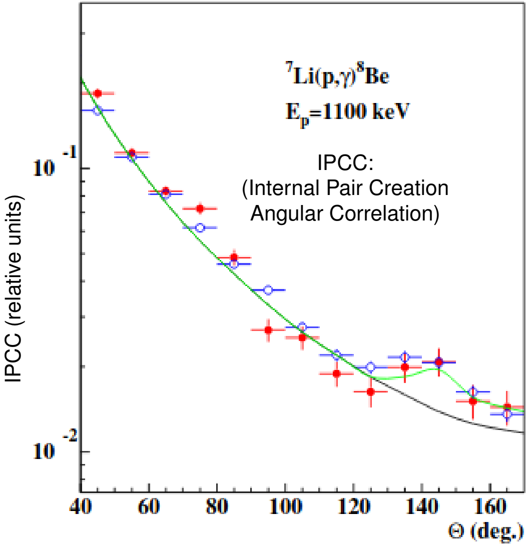
[Feng PRD **95**, 035017 (2017)]

The X17 Anomaly in $p + {}^{7}\mathrm{Li} \to {}^{8}\mathrm{Be} + e^{+}e^{-}$

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

- The angle Θ between the electron and positron was measured
- Anomaly in pair distribution observed at the energy of the second 1^{+} resonance

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

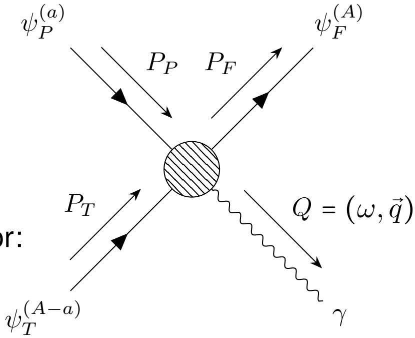


Radiative Capture: $P + T \to F + \gamma$

- Notation: $T(P,\gamma)F$
- Often astrophysically relevant:
  - Stellar burning: $d(p,\gamma)^3\mathrm{He}$, $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$, ...
  - Big Bang Nucleosynthesis: $d(p,\gamma)^3\mathrm{He}$, $^4\mathrm{He}(d,\gamma)^6\mathrm{Li}$, ...
  - Search for new physics: $^7\mathrm{Li}(p,\gamma)^8\mathrm{Be}$, $^3\mathrm{H}(p,\gamma)^4\mathrm{He}$, $^{11}\mathrm{B}(p,\gamma)^{12}\mathrm{C}$

[Adapted from:
Feng PRD **95**, 035017 (2017)]

Calculating Radiative Capture



To calculate the rate of reaction (cross section) we need:

- initial wavefunction: $|\Psi_i\rangle$ $(P + T)$
- final wavefunction: $|\Psi_f\rangle$ (F)
- photon emission (electromagnetic transition) operator:
  $\hat{O}_\gamma(\lambda, q) = \vec{e}^{\,*}_\lambda \cdot \vec{\mathcal{J}}(q) \sim \sum_{J\geq 1} \lambda \mathcal{T}^M_{J\lambda}(q) + \mathcal{T}^E_{J\lambda}(q)$
- approximations:
  - single-nucleon operators, long-wavelength expansion
    $\mathcal{T}^E_{1\lambda}(q) \approx \sum_i^A \frac{1+\tau_{zi}}{2} \frac{2q}{9} r_i Y_{1\lambda}(\hat{r}_i)$
- transition matrix elements: $\langle \Psi_f | \hat{O}_\gamma | \Psi_i \rangle$

$$\sigma \sim \sumint \mathrm{d}q \left| \langle \Psi_f | \hat{O}_\gamma | \Psi_i \rangle \right|^2$$

Bound States: $|\Psi_f\rangle = \left|J_f^{\pi_f}\right\rangle$

$NN + 3N_{lnl}$

Somá et al, PRC **101** 014318 (2020)

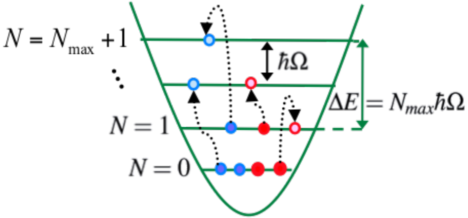
Eigenstate of the nuclear Hamiltonian:

$$H^A |\Psi_k\rangle = E_k |\Psi_k\rangle \text{, where } H^A = \sum_i^A T_i + \sum_{i<j} V_{ij}^{NN} + \sum_{i<j<f} V_{ijf}^{3N}$$

The No-Core Shell Model (NCSM)

Expand in anti-symmetrized products of harmonic oscillator single-particle states:

$$|\Psi_k\rangle = \sum_{N=0}^{N_{max}} \sum_j c_{Nj}^k |\Phi_{Nj}\rangle$$



Convergence to an exact solution as $N_{max} \rightarrow \infty$

Unbound (Continuum) States: $|\Psi_i\rangle = \left[\left(|\psi_P\rangle \, |\psi_T\rangle \right)^{(S_i)} \psi_{L_i}(\vec{r}_P - \vec{r}_T) \right]^{(J_i^{\pi_i})}$

- The incoming state is made of distinct clusters with relative motion
- Harmonic oscillator states cannot describe long-range physics (the tails of the wavefunction are too small)
- A method beyond the NCSM is needed for scattering, reactions and proper bound state asymptotics

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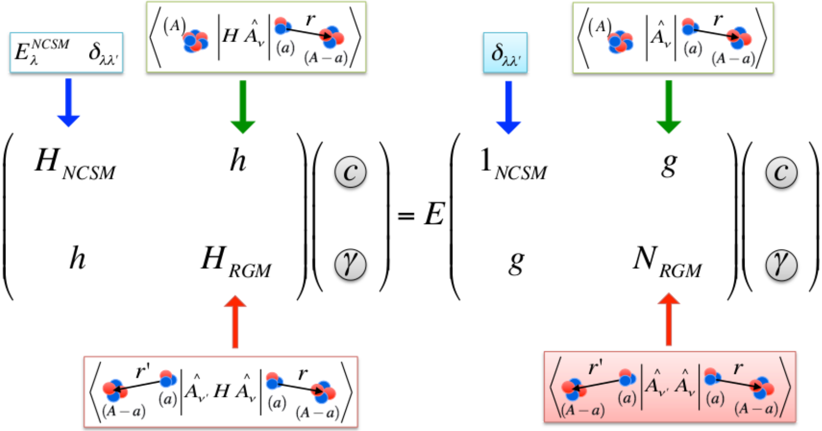
No-Core Shell Model with Continuum (NCSMC)

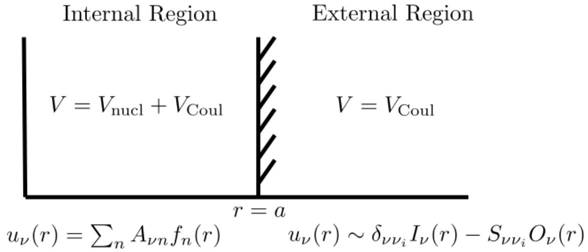
- Solution: extend the NCSM basis!

NCSMC Equations

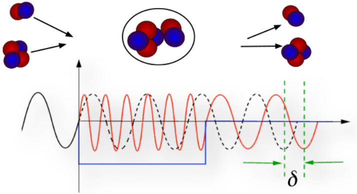
$$H\,\Psi^{(A)} = E\,\Psi^{(A)}$$



More Details



- R-matrix on a Lagrange mesh
- Solve for generalized S-matrix: $S^{J\pi}_{\nu\nu_i}$
- Diagonal phase shifts: $S^{J\pi}_{\nu\nu} \sim e^{2i\delta^{J\pi}_\nu}$
- Eigen-phase shifts: $e^{2i\delta^{J\pi}_\mu}$, eigenvalues of S



NCSMC for $^7\mathrm{Li}(p,\gamma)^8\mathrm{Be}$

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

Process:

- Solve NCSM for each constituent nucleus: $^8\mathrm{Be}$, $^7\mathrm{Li}$ and $^7\mathrm{Be}$
  - 30 eigenstates from $^8\mathrm{Be}$
  - 5 eigenstates each from $^7\mathrm{Li}$ and $^7\mathrm{Be}$
- Solve NCSMC for $c_\lambda(E)$, $\gamma_\nu(r,E)$, $\gamma_\mu(r,E) \to |\Psi(E)\rangle$
- Cross-section depends on transition matrix elements e.g. $\left\langle\Psi(E_f)\right| M1 \left|\Psi(E_i)\right\rangle$

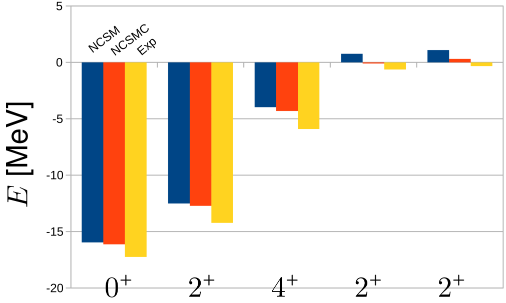
Results

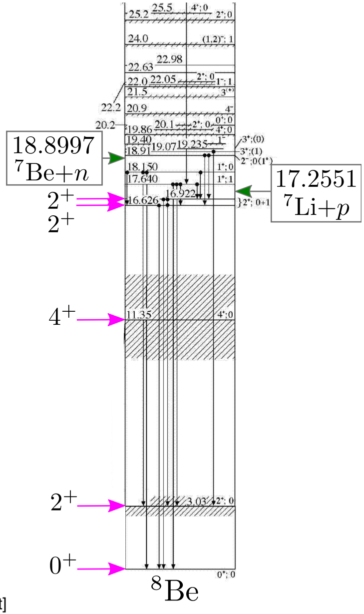
The NCSMC allows simultaneous calculation of many observables

- $^{8}\mathrm{Be}$ Structure
- Scattering: $^{7}\mathrm{Li}(p,p)^{7}\mathrm{Li}$, $^{7}\mathrm{Be}(n,n)^{7}\mathrm{Be}$
- Transfer Reactions: $^{7}\mathrm{Li}(p,n)^{7}\mathrm{Be}$, $^{7}\mathrm{Be}(n,p)^{7}\mathrm{Li}$
- Radiative Capture: $^{7}\mathrm{Li}(p,\gamma)^{8}\mathrm{Be}$
- Search for new physics: $^{7}\mathrm{Li}(p,e^{+}e^{-})^{8}\mathrm{Be}$, $^{7}\mathrm{Li}(p,X)^{8}\mathrm{Be}$

^{8}Be Structure

Calculations of ^{8}Be "bound" states (w.r.t. ^{7}Li + p threshold) are improved by inclusion of the continuum (N_{max} = 9)





- Energies likely too high due to neglected $\alpha + \alpha$ breakup
- Matches experiment well, except the 3rd 2^{+} is still slightly above the ^{7}Li + p threshold

[TUNL Nuclear Data Evaluation Project]

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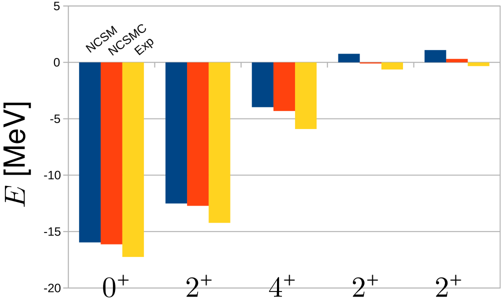

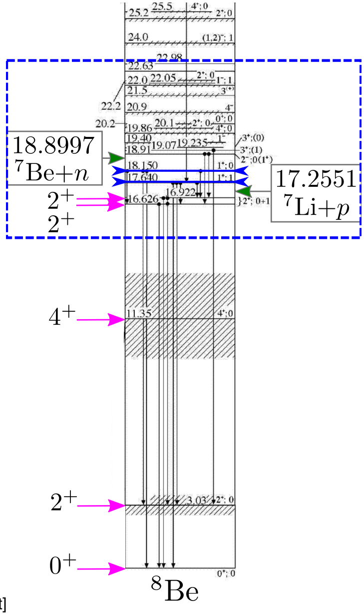

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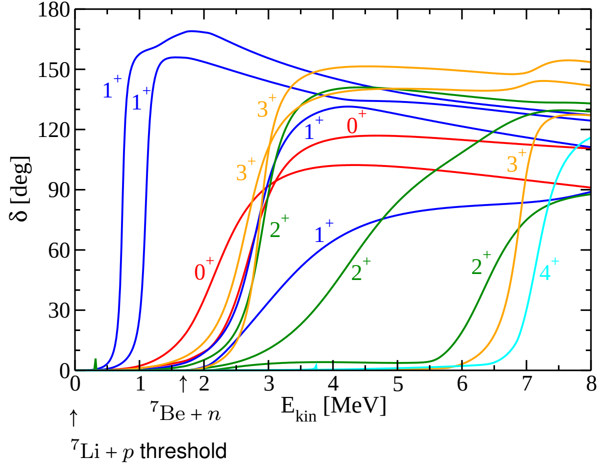
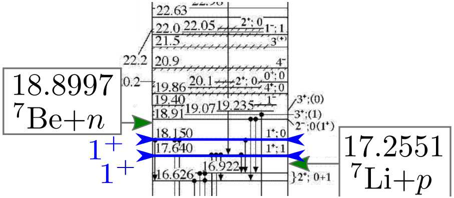
[TUNL Nuclear Data Evaluation Project]

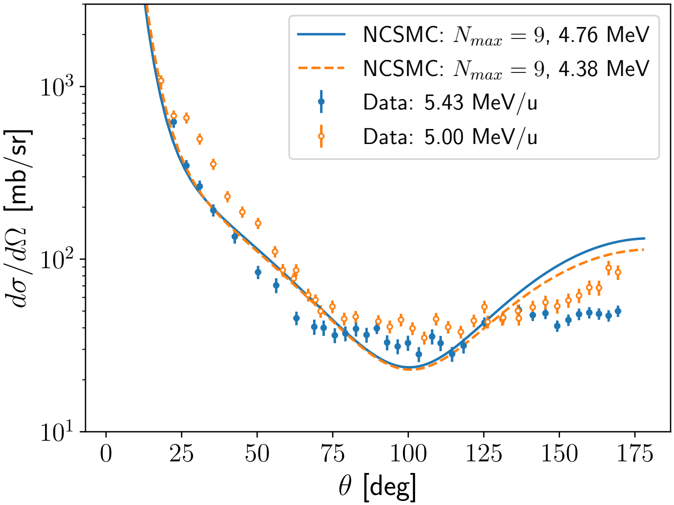
Eigenphase-shift Results (positive parity)





Additional resonances are seen compared to TUNL data evaluation

$^7\mathrm{Li}(p,p)^7\mathrm{Li}$ Elastic Scattering

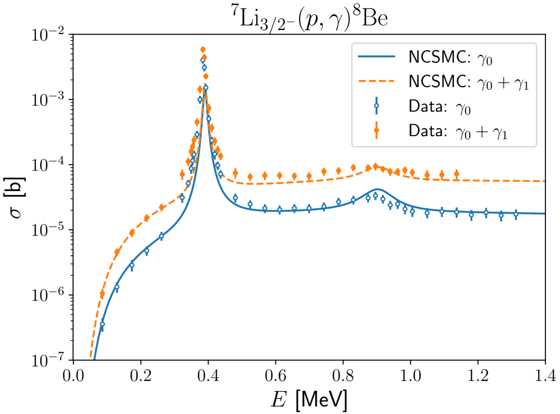


$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} \sim \sum_\nu (1 - \Re(S_{\nu\nu}))$$

Radiative Capture

$$\hat{O}_\gamma = E1 + M1 + E2$$

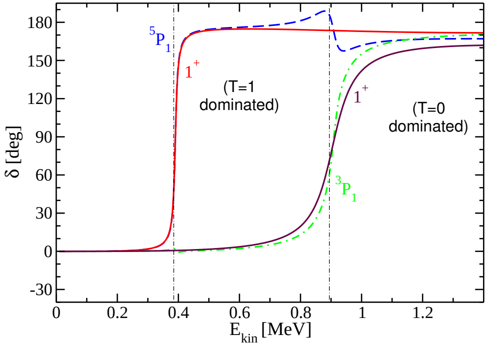
$${}^{2S+1}P_J : \left[\left(\left|{}^7\mathrm{Li}\right\rangle |p\rangle\right)^{(S)} Y_L(\hat{r})\right]^J \quad P : L = 1$$



γ_0: decay to ground state (0^+)

γ_1: decay to first excited (2^+)

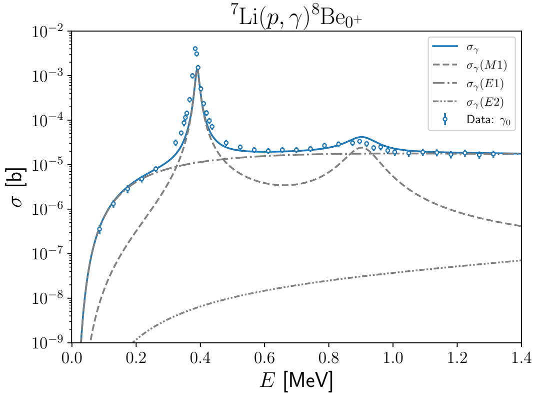
[Data: Zahnow et al
Z.Phys.A **351** 229-236 (1995)]

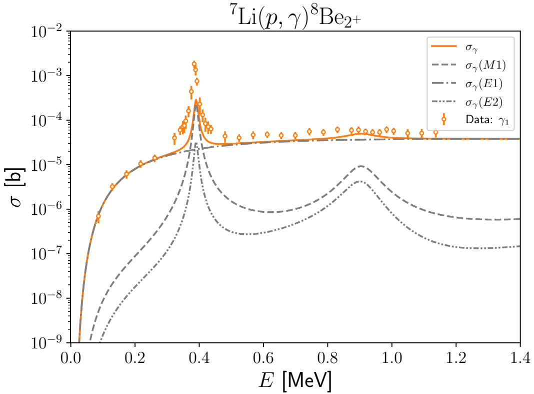


Phenomenological adjustment: fit threshold and resonance positions to match experiment

Integrated Cross Sections

$$\hat{O}_\gamma = E1 + M1 + E2$$





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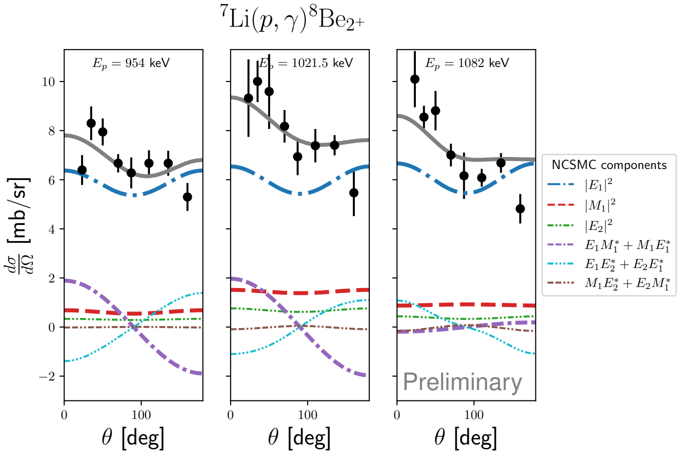
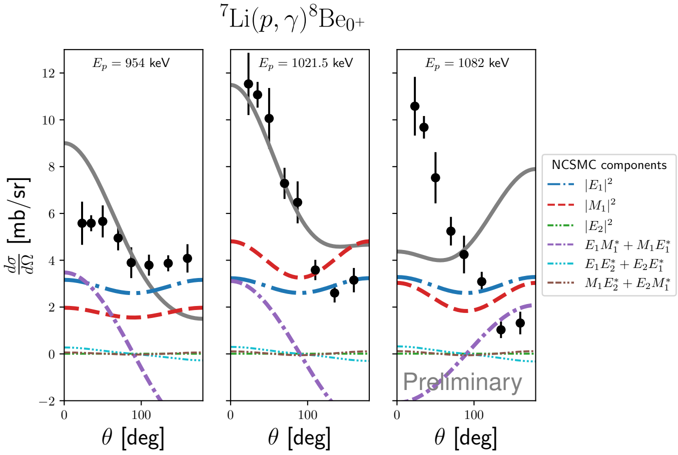
Differential Cross Sections



- Preliminary data from IJCLab (Orsay, FR)
- $\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} \sim \sum_K a_K P_K(\cos\theta)$
- Interference between initial channels

Differential Cross Sections



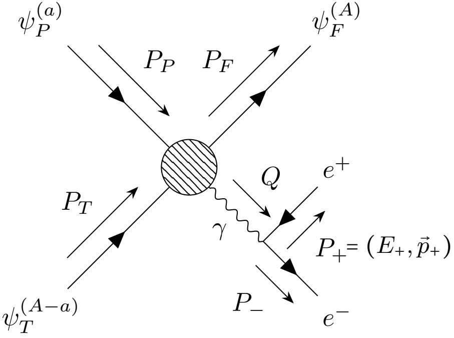
- Preliminary data from IJCLab (Orsay, FR)
- $\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} \sim \sum_K a_K P_K(\cos\theta)$
- Interference between initial channels
- Data could be contaminated by protons with energy lost in target

Electron-Positron Pair Production

$$\frac{d^4\sigma}{d\Omega_+ d\Omega_-}(\Theta) = \int dy \frac{2\alpha^2}{(2\pi)^3}\frac{\omega p_+ p_-}{Q^4}\sum_{n=1}^{6} v_n R_n$$

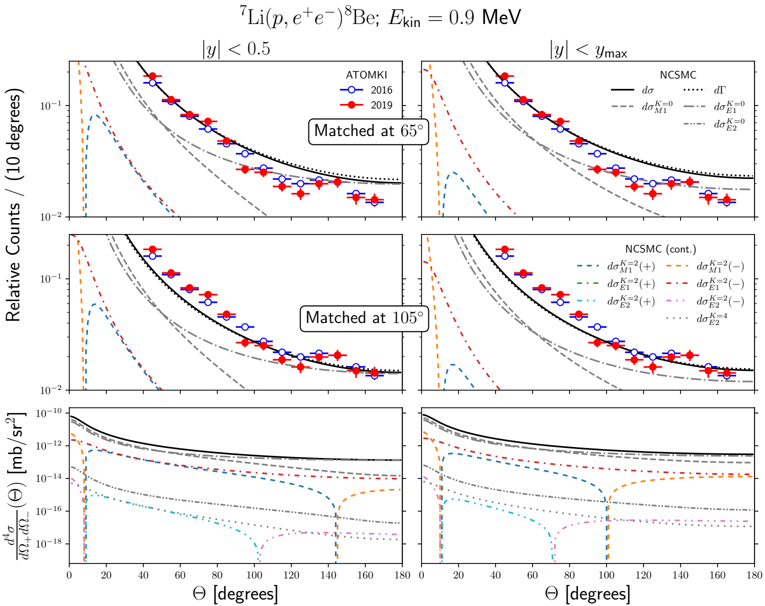
- $\hat{O}_{ee} \sim \ell_\mu \mathcal{J}^\mu$
- v_n are kinematic factors
- R_n are products of operator matrix elements
  - $R_1 \sim |\mathcal{C}|^2$: Coulomb
  - $R_4 \sim |\mathcal{T}|^2$: Transverse
  - others mix e.g. $\mathcal{C}^*\mathcal{T} + \mathcal{T}^*\mathcal{C}$
- y is the "pair asymmetry":

$$y = \frac{E_+ - E_-}{E_+ + E_-}$$



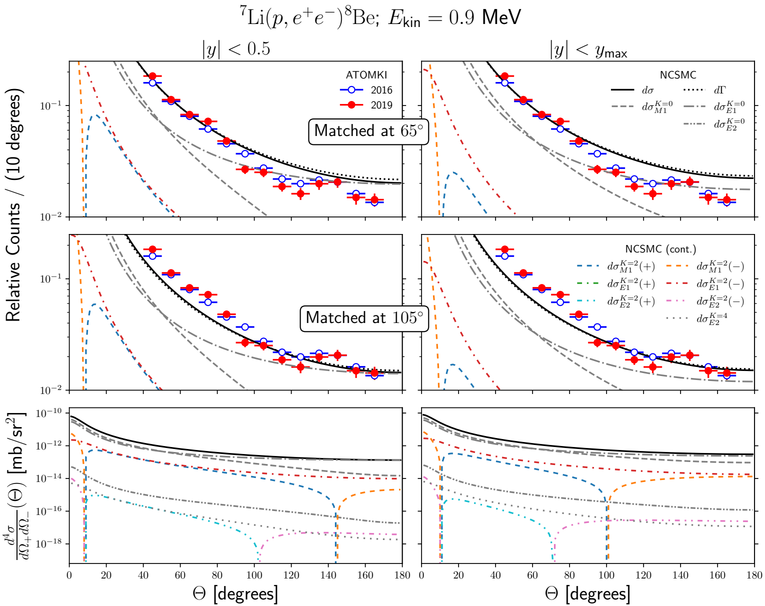
Results

- Measurement against the electron-positron separation angle Θ



Results

- Measurement against the electron-positron separation angle Θ
  - v_n and Q are functions of $\cos\Theta$
  - $R_n \sim \sum_K a_K^{(n)} P_K(\cos\frac{\pi}{2})$



Results

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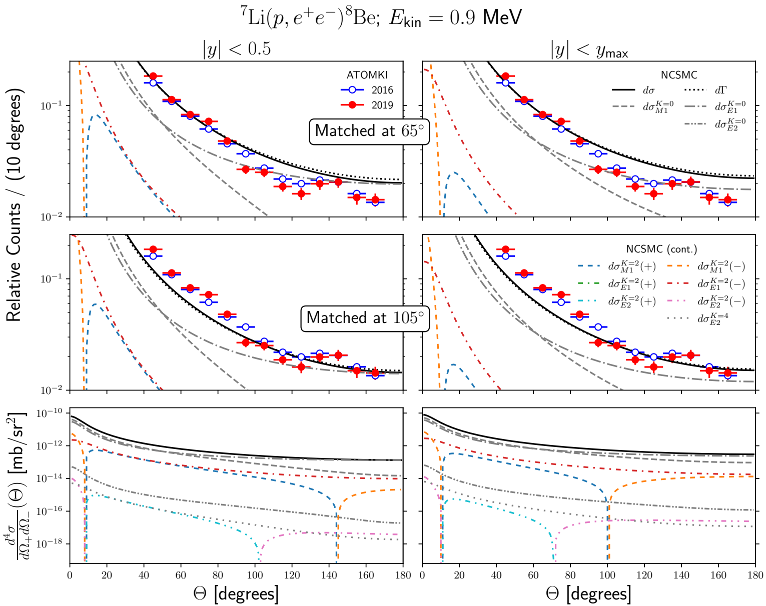
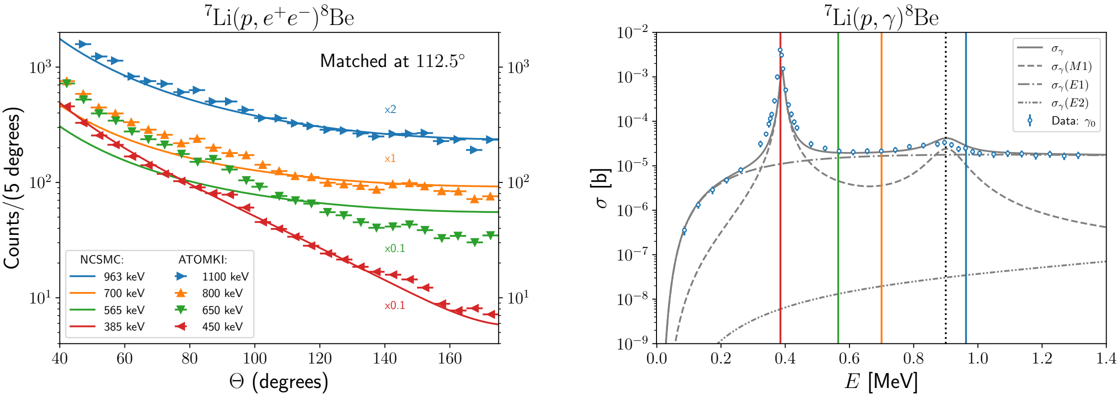
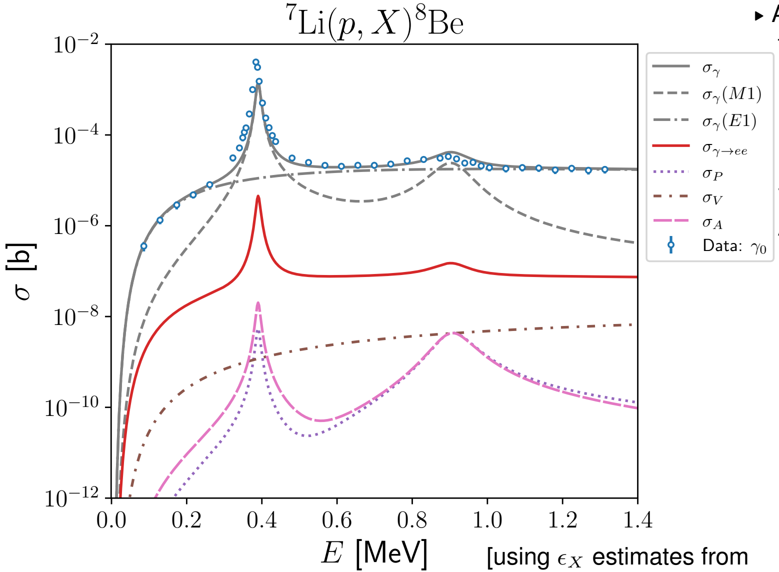
  - v_n and Q are functions of $\cos\Theta$
  - $R_n \sim \sum_K a_K^{(n)} P_K(\cos\frac{\pi}{2})$
- $E1$ and $M1$ are dominant
- Inclusion of interference between initial channels improves agreement with data



More Results



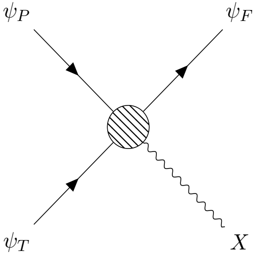
- Updated ATOMKI data (2022) arXiv:2205.07744
- Data in-between resonances seems to be contaminated by $M1$ from first resonance



- A vector X17 is the best candidate for anomalies off-resonance

[arXiv:2205.07744]

Pseudo-scalar (0^-)
Vector (1^-)
Axial-vector (1^+)



[using ϵ_X estimates from Backens, PRL **128** 091802 (2022)]

Summary and Outlook

- The NCSMC successfully describes the spectrum of $^{8}\mathrm{Be}$, radiative capture and electron-positron production
- The X17 remains unconfirmed
  - apparent contamination of data between resonances due to proton energy loss in the thick target
  - independent experimental tests are in analysis phase (e.g. the NewJEDI collaboration)
- To do:
  - ATOMKI experiments in other systems: $^{3}\mathrm{H}(p, e^{+}e^{-})^{4}\mathrm{He}$, $^{11}\mathrm{B}(p, e^{+}e^{-})^{12}\mathrm{C}$
  - investigate γ angular distributions at more energies
  - pair production for capture to the 2^{+}
- Investigation and adjustment of higher-lying resonances necessary for scattering and charge exchange reactions

Backup Slides

The X17 Anomaly in $p + {}^7\mathrm{Li} \to {}^8\mathrm{Be} + e^+e^-$

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

- The angle Θ between the electron and positron was measured
- Anomaly in pair distribution observed at the energy of the second 1^+ resonance
- Bump could be explained by 17 MeV bosons decaying to e^+e^-

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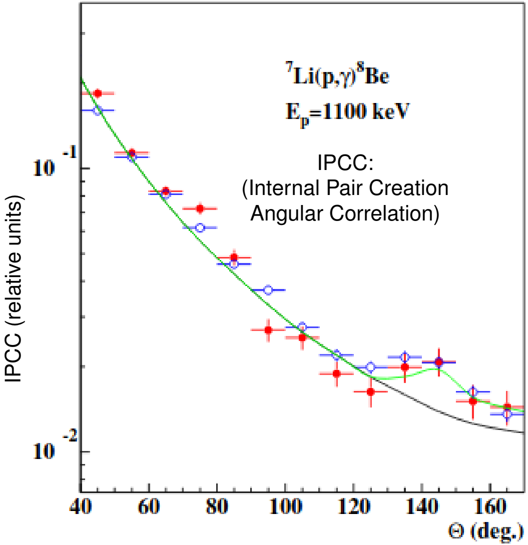


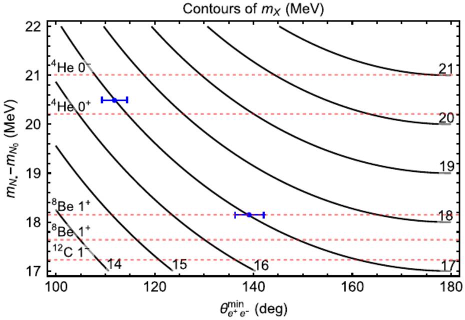
Constraints on m_X

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

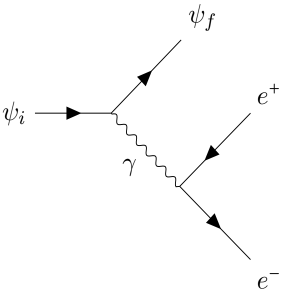
In the frame of the X boson the electron and positron momenta are anti-parallel. Boosted to a minimum separation angle:

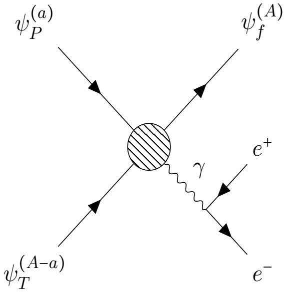
$$\Theta = 2\sin^{-1}\left(\frac{m_X}{E_X}\right)$$

- Anomaly in pair distribution observed at the energy of the second 1^+ resonance
- Observed in-between resonances in $^4\mathrm{He}$ ($^3\mathrm{H}(p, e^+e^-)^4\mathrm{He}$)
- Both experiments consistent with 17 MeV bosons decaying to e^+e^-



Pair Production: Bound vs Continuum





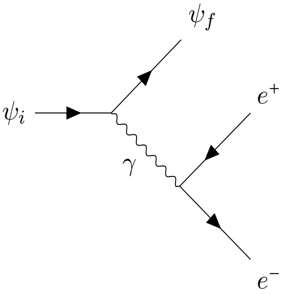
- Rate:

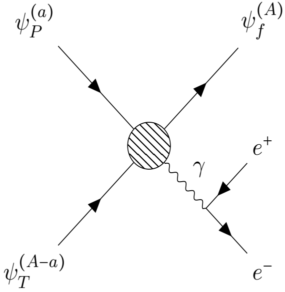
$$\mathrm{d}\Gamma \sim \bar{\sum_{M_i}} \sum_{M_f} \sum_{s_+ s_-} |\mathcal{M}_{fi}^{s_+ s_-}|^2 \mathrm{d}^3 p_+ \mathrm{d}^3 p_-$$

- Cross section:

$$\mathrm{d}\sigma \sim \frac{1}{v} \bar{\sum_{M_P M_T}} \sum_{M_f} \sum_{s_+ s_-} |\mathcal{M}_{fi}^{s_+ s_-}|^2 \mathrm{d}^3 p_+ \mathrm{d}^3 p_-$$

Pair Production: Bound vs Continuum





- Transition Matrix Elements:

$$\mathcal{M}_{fi}^{s_+ s_-} \sim \left(\frac{e^2}{Q^2}\right) \ell_\mu^{s_+ s_-} \left\langle J_f \middle| \middle| \mathcal{J}^\mu \middle| \middle| J_i \right\rangle$$

- 2 terms: longitudinal and transverse

- Transition Matrix Elements:

$$\mathcal{M}_{fi}^{s_+ s_-} \sim \left(\frac{e^2}{Q^2}\right) \ell_\mu^{s_+ s_-} \sum_{\nu_i} \left\langle J_f \middle| \middle| \mathcal{J}^\mu \middle| \middle| \nu_i \right\rangle$$

- 6 terms

Leptons:

$$\ell_\mu^{s_+ s_-} \sim \bar{u}^{s_-}(P_-)\gamma_\mu v^{s_+}(P_+)$$

$$\sum_{s_+ s_-} \ell_\mu \ell_\nu \sim P_{+\mu}P_{-\nu} + P_{+\nu}P_{-\mu} - \eta_{\mu\nu}(P_{+\alpha}P_-^\alpha + m_e^2)$$

Nuclear Currents: $\mathcal{J}_\mu = (\rho, \vec{\mathcal{J}})$

$$\langle f| |\rho| |i\rangle \sim \sum_{J\geq 0} \mathcal{C}_J$$

$$\langle f| |\vec{e}_\lambda \cdot \vec{\mathcal{J}}| |i\rangle \sim \sum_{J\geq 1} \lambda \mathcal{T}_J^M + \mathcal{T}_J^E$$

$$\langle f| \vec{e}_0 \cdot \vec{\mathcal{J}} |i\rangle = \langle f| \mathcal{J}_z |i\rangle \sim \sum_{J\geq 0} \mathcal{L}_J$$

$$\vec{e}_{\pm 1} = \mp(\hat{x} \pm i\hat{y})$$

$$\vec{e}_0 = \hat{z}$$

Multipole Operators:

$$\mathcal{C}_{JM}(q) = \int \mathrm{d}^3 r M_{JM}(q,\vec{r})\rho(r)$$

$$\mathcal{L}_{JM}(q) = \int \mathrm{d}^3 r \left(\frac{i\vec{\nabla}}{q} M_{JM}(q,\vec{r})\right)\cdot\vec{\mathcal{J}}(\vec{r})$$

$$\mathcal{T}^{E}_{JM}(q) = \int \mathrm{d}^3 r \left(\frac{\vec{\nabla}}{q} \times \vec{M}_{JJM}(q,\vec{r})\right)\cdot\vec{\mathcal{J}}(\vec{r})$$

$$\mathcal{T}^{M}_{JM}(q) = \int \mathrm{d}^3 r \vec{M}_{JJM}(q,\vec{r})\cdot\vec{\mathcal{J}}(\vec{r})$$

$$M_{JM}(q,\vec{r}) = j_J(qr)Y_{JM}(\hat{r})$$

$$\vec{M}_{JLM}(q,\vec{r}) = j_J(qr)\vec{Y}_{JLM}(\hat{r})$$

Approximations:

$$\vec{\nabla}\cdot\vec{\mathcal{J}} = \frac{\mathrm{d}\rho}{\mathrm{d}t} \simeq -i\omega\rho \implies \begin{cases} \mathcal{L}_J & \simeq \frac{\omega}{q}\mathcal{C}_J \\ \mathcal{T}^E_J & \simeq -\frac{\omega}{q}\sqrt{\frac{J+1}{J}}\mathcal{C}_J \end{cases}$$

$$\mathcal{C}_J \sim q^J E_J = q^J e < r^J Y_J >$$

$$\mathcal{T}^M_1 \sim qM_1 = q\mu_N < g_s S + g_l L >$$

- Rate:

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\Theta} \sim a_C|\rho|^2 + a_T\sum_{\lambda}|\mathcal{J}_\lambda|^2 \sim a_C\sum_{J\geq 0}|\mathcal{C}_J(f,i)|^2 + a_T\sum_{J\geq 1}\sum_{\sigma=E,M}|\mathcal{T}_J^\sigma(f,i)|^2$$

$$\left[\mathcal{J}_\lambda = \vec{e}_\lambda\cdot\vec{\mathcal{J}},\ a_C = v_1,\ a_T = v_4\right]$$

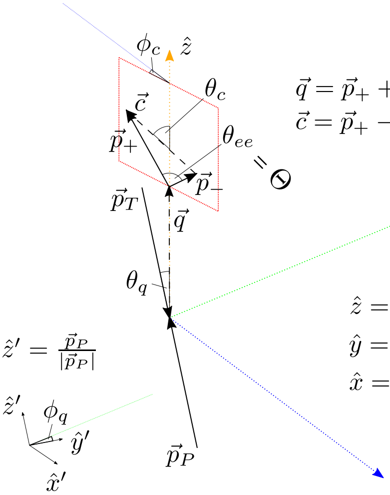
- Cross section:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\Theta} \sim \sum_{\nu_i\nu_i'}\Big\{v_1|\rho|^2 + v_2\left[\rho\left(\mathcal{J}_+ + \mathcal{J}_-\right)^* + h.c.\right] + v_3\left[\rho\left(\mathcal{J}_+ - \mathcal{J}_-\right)^* + h.c.\right] + v_4\left[|\mathcal{J}_+|^2 + |\mathcal{J}_-|^2\right] + v_5\left[\mathcal{J}_+\mathcal{J}_-^* + \mathcal{J}_-\mathcal{J}_+^*\right] + v_6\left[\mathcal{J}_+\mathcal{J}_-^* - \mathcal{J}_-\mathcal{J}_+^*\right]\Big\}$$

Comparing to the ATOMKI Experiment

$$\frac{d^5\sigma}{dE_+ d\Omega_+ d\Omega_-} = \frac{d^5\sigma}{\frac{\omega}{2} dy\, d\cos\Theta\, d\phi_c\, d\theta_q\, d\phi_q}$$
$$= \frac{4\alpha^2}{(2\pi)^3}\frac{f_r}{v}\frac{p_+p_-}{Q^4}\sum_\kappa v_\kappa R_\kappa$$

$$Q = (\omega, \vec{q}) = (E_+ + E_-, \vec{p}_+ + \vec{p}_-)$$
$$y = \frac{E_+ - E_-}{\omega}$$
$$\vec{p}_+ \cdot \vec{p}_- = p_+ p_- \cos\Theta$$
$$f_r \simeq 1$$



$$\vec{q} = \vec{p}_+ + \vec{p}_-$$
$$\vec{c} = \vec{p}_+ - \vec{p}_-$$

$$\hat{z} = \frac{\vec{q}}{|\vec{q}|}$$
$$\hat{y} = \frac{\vec{p}_P \times \vec{q}}{|\vec{p}_P \times \vec{q}|}$$
$$\hat{x} = \hat{y} \times \hat{z}$$

- Kinematic prefactors:

κ	v_κ	$v_\kappa(\theta_q = 90^\circ, \phi_c = 90^\circ)$
1	$\frac{Q^4}{q^4}\left(E_+E_- + \vec{p}_+ \cdot \vec{p}_- - m^2\right)$	“ ”
2	$-\frac{1}{\sqrt{2}}c_x\left(E_+ - E_- - \frac{\omega}{q}c_z\right)$	0
3	$-\frac{1}{\sqrt{2}}c_y\left(E_+ - E_- - \frac{\omega}{q}c_z\right)$	$-\frac{c_y}{\sqrt{2}}(E_+ - E_- - \frac{\omega}{q}c_z)$
4	$E_+E_- + m^2 - \frac{(\vec{p}_+\cdot\vec{q})(\vec{p}_-\cdot\vec{q})}{q^2}$	“ ”
5	$\frac{1}{2}\left(c_x^2 - c_y^2\right)$	$-\frac{1}{2}c_y^2$
6	$-c_xc_y$	0

- $R_\kappa = \sum_K a_K^{(\kappa)} P_K(\cos\theta_q), \quad a_K^{(\kappa)} \sim (j\mu j' - \mu' | K(\mu - \mu'))$
- $j = j' = 1$ channels are dominant.
- $R_3 = 0$ at $\theta_q = 90^\circ$ (only $K = 1$).
- R_5 is only $K = 2$.
- R_1 and R_4 have $K = 0$, ~~$K = 1$~~ 0 and $K = 2$.

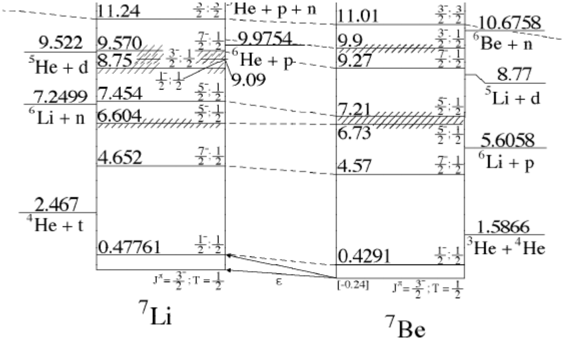
$$\begin{cases} \kappa = 1 & \mu = \mu' = 0 \\ \kappa = (2,3) & \mu = 0, \mu' = \pm 1 \\ \kappa = 4 & \mu = \mu' = \pm 1 \\ \kappa = (5,6) & \mu = -\mu' = \pm 1 \end{cases}$$

γ-capture: $a_K \sim (j1j' - 1|K0)$

Input States from NCSM

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

- 3 NCSM calculations: ${}^7\text{Li}$, ${}^7\text{Be}$ and ${}^8\text{Be}$
- $\{\frac{3}{2}^-, \frac{1}{2}^-, \frac{7}{2}^-, \frac{5}{2}^-, \frac{5}{2}^-\}$ ${}^7\text{Li}$ and ${}^7\text{Be}$ states in cluster basis
- 15 positive and 15 negative parity states in ${}^8\text{Be}$ composite state basis



TUNL Nuclear Data Evaluation Project

Input States from NCSM

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

- 3 NCSM calculations: ${}^7\text{Li}$, ${}^7\text{Be}$ and ${}^8\text{Be}$
- $\{\frac{3}{2}^-, \frac{1}{2}^-, \frac{7}{2}^-, \frac{5}{2}^-, \frac{5}{2}^-\}$ ${}^7\text{Li}$ and ${}^7\text{Be}$ states in cluster basis
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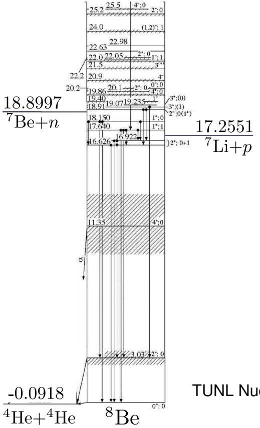


TUNL Nuclear Data Evaluation Project

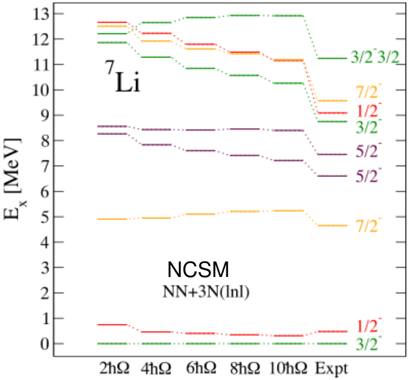
Interaction: Chiral NN N^{3}LO + 3N(lnl)

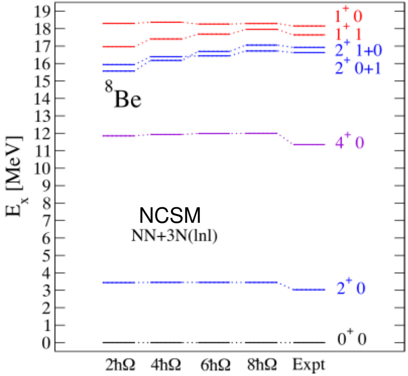
Novel chiral Hamiltonian and observables in light and medium-mass nuclei

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

- Good description of excitation energies in light nuclei
- Hamiltonian determined in $A = 2, 3, 4$ systems
  - Nucleon-nucleon scattering, deuteron, ^{3}H, ^{4}He

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





Convergence of ground state energies: