Continuum Dynamics in Dripline Nuclei

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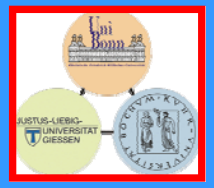


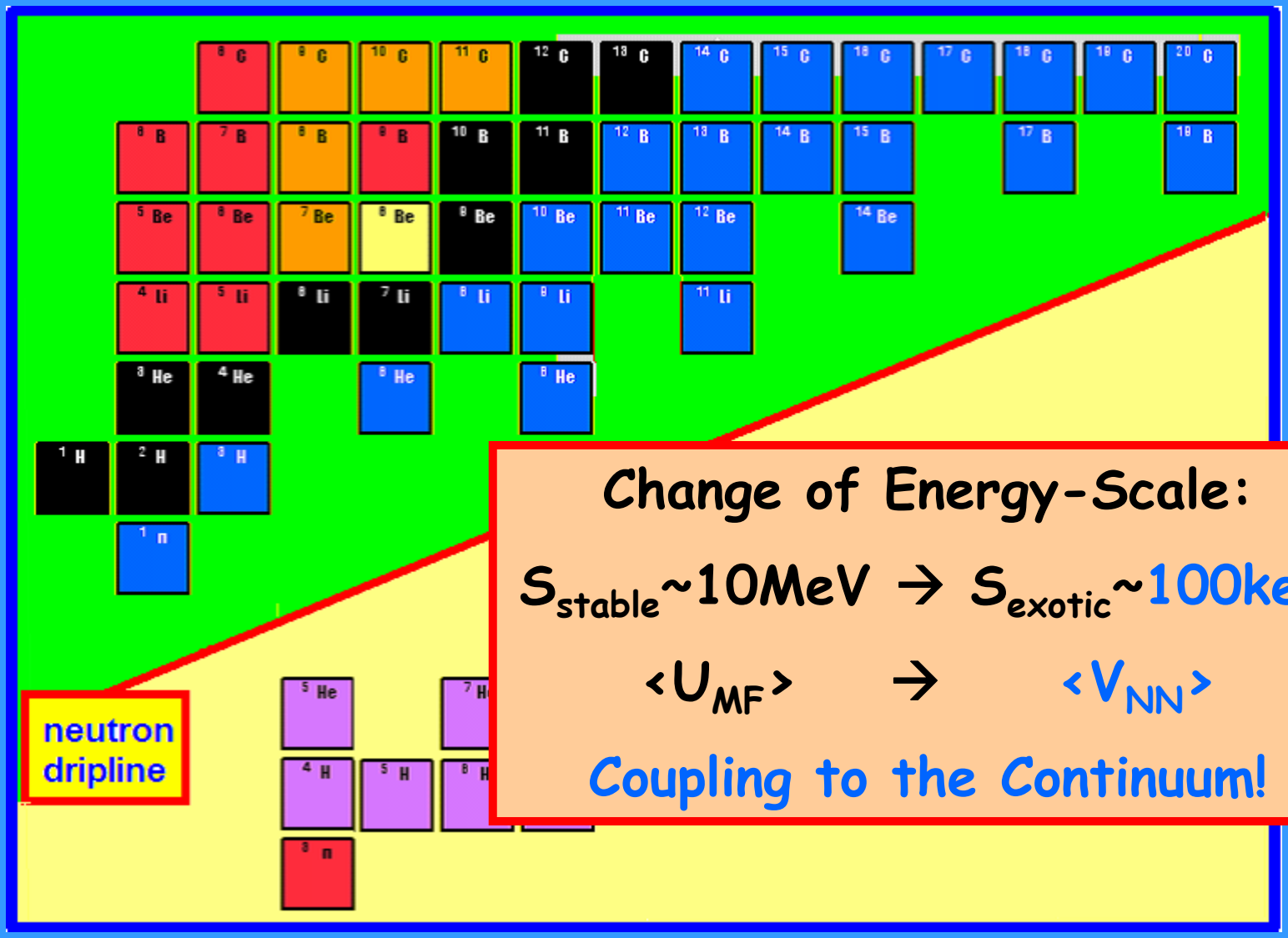
SFB/TR 16

Continuum Dynamics in Dripline Nuclei

Topics:

- Pairing in the Continuum
- Fano Resonances and Dynamical Polarization
- Skins and Threshold Effects: Pygmy Dipole Resonance
- Conclusions and Outlook

Fluctuating (Fractal?) Structure of Neutron Dripline (0≤Z≤6)



Change of Energy-Scale:

S_{stable}~10MeV → S_{exotic}~100keV

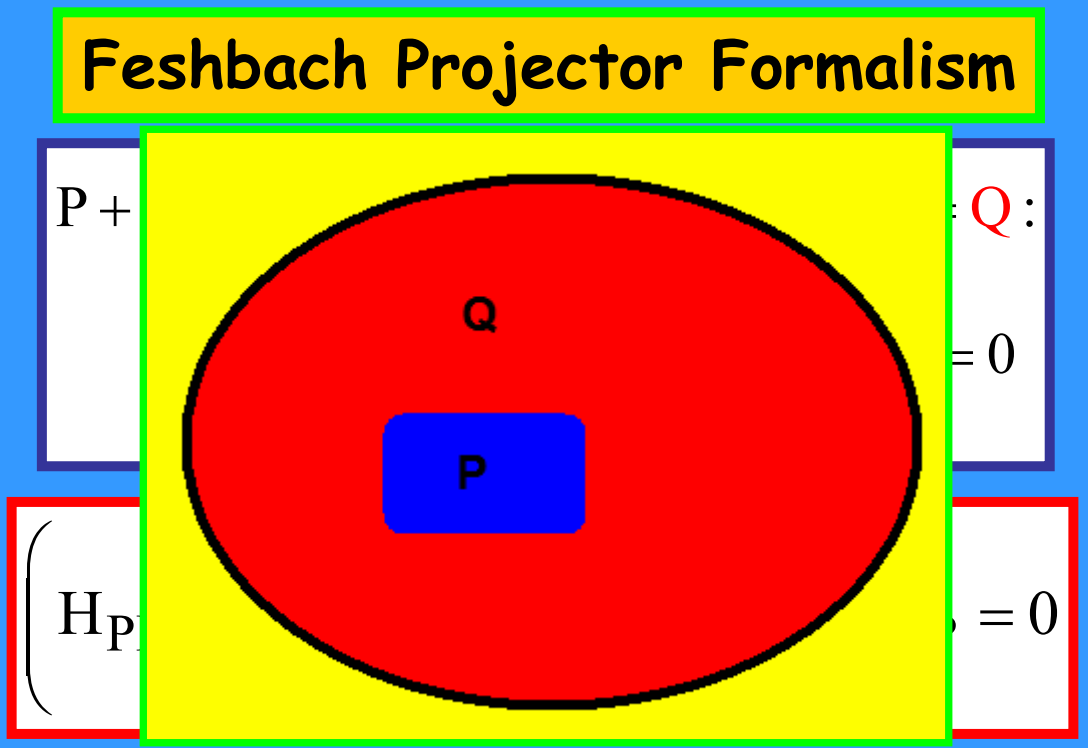
$\langle U_{MF} \rangle$ → $\langle V_{NN} \rangle$

Coupling to the Continuum!

Nuclei as Open Quantum Systems

- Interplay of Many-body and Single Particle Dynamics
- Validity of the Mean-Field Concept?
- Model Space Problem: P/Q-Space and Effective interactions
- Polarization self-energies and dissipation (optical potential)

Feshbach Projector Formalism



Extended HFB Theory as Coupled Channels Problem: The Gorkov-Equations

$$\begin{pmatrix} H-\lambda & -\Delta \\ -\Delta^{+} & -(H-\lambda) \end{pmatrix} \begin{pmatrix} \phi_{+} \\ \phi_{-} \end{pmatrix} = E \begin{pmatrix} \phi_{+} \\ \phi_{-} \end{pmatrix}$$

$$\phi_{+} \sim u_{\ell j}^{(q)}(r)\,|(\ell s)\,jm\rangle;\ \phi_{-} \sim v_{\ell j}^{(q)}(r)\,|(\ell s)\,jm\rangle$$

Mean-Field Hamiltonian (q = p,n):

$$\mathrm{H} = -\frac{\hbar^2}{2\mathrm{m}}\vec{\nabla}^2 + \mathrm{U}(\rho)$$

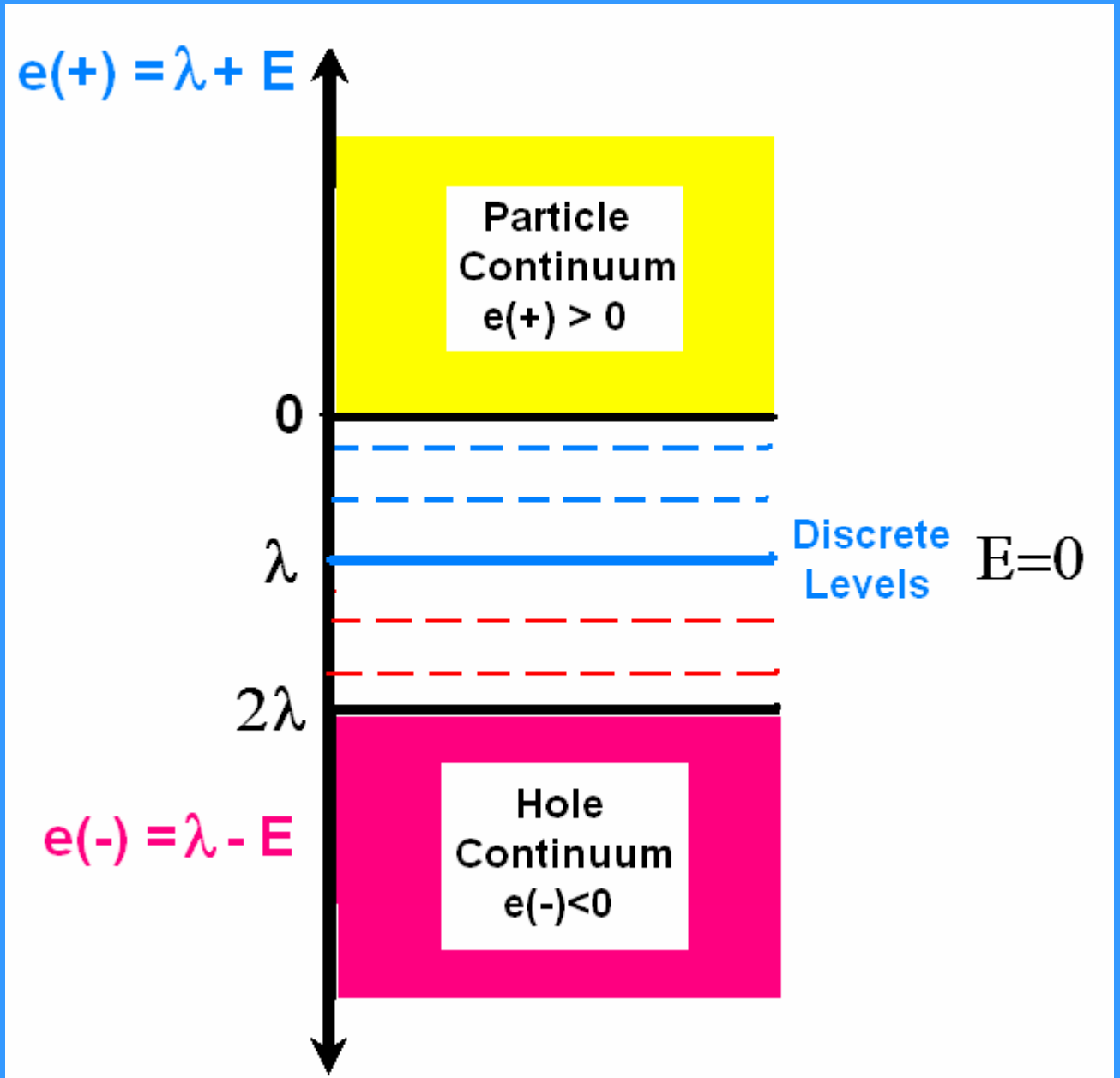
$$\rho_{\mathrm{q}}(\mathrm{r}) = \sum_{\mathrm{n}\ell\mathrm{j}} \frac{2\mathrm{j}+1}{4\pi} |\, \mathrm{v}_{\mathrm{n}\ell\mathrm{j}}^{(\mathrm{q})}(\mathrm{r})\,|^2$$

Pairing-Field & Density (q = p,n):

$$\Delta_q = \frac{1}{2} V_{SE} \kappa_q$$

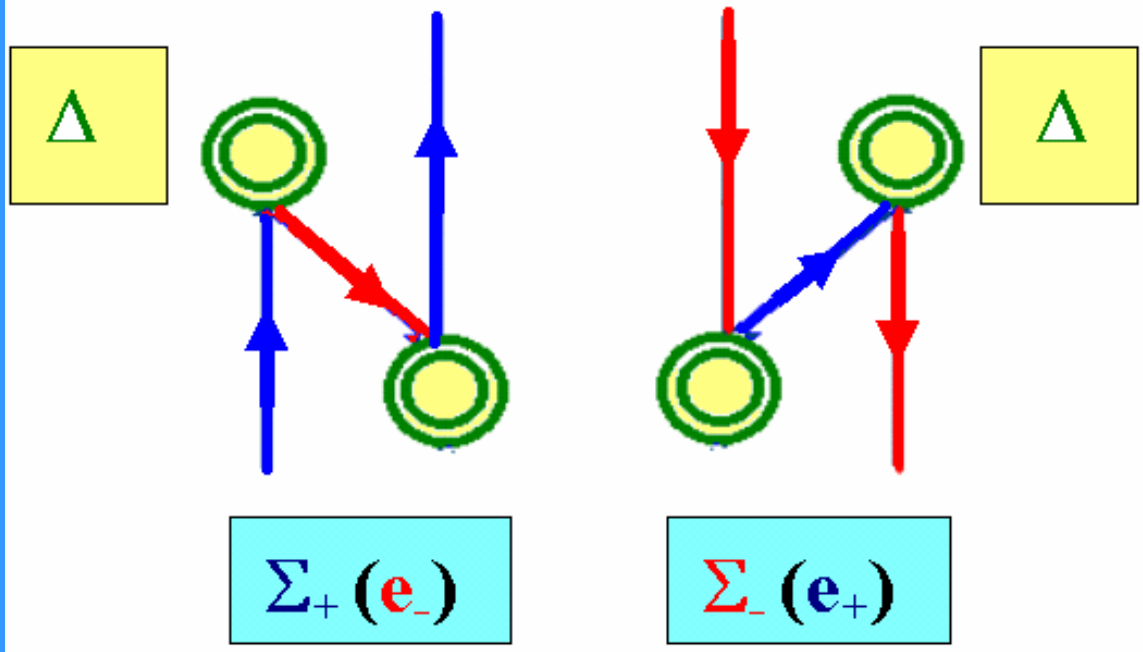
$$\kappa_q(r) = \sum_{n\ell j} \frac{2j+1}{4\pi} u_{n\ell j}^{(q)}(r) v_{n\ell j}^{(q)*}(r)$$

Spectrum of the Gorkov Equation:



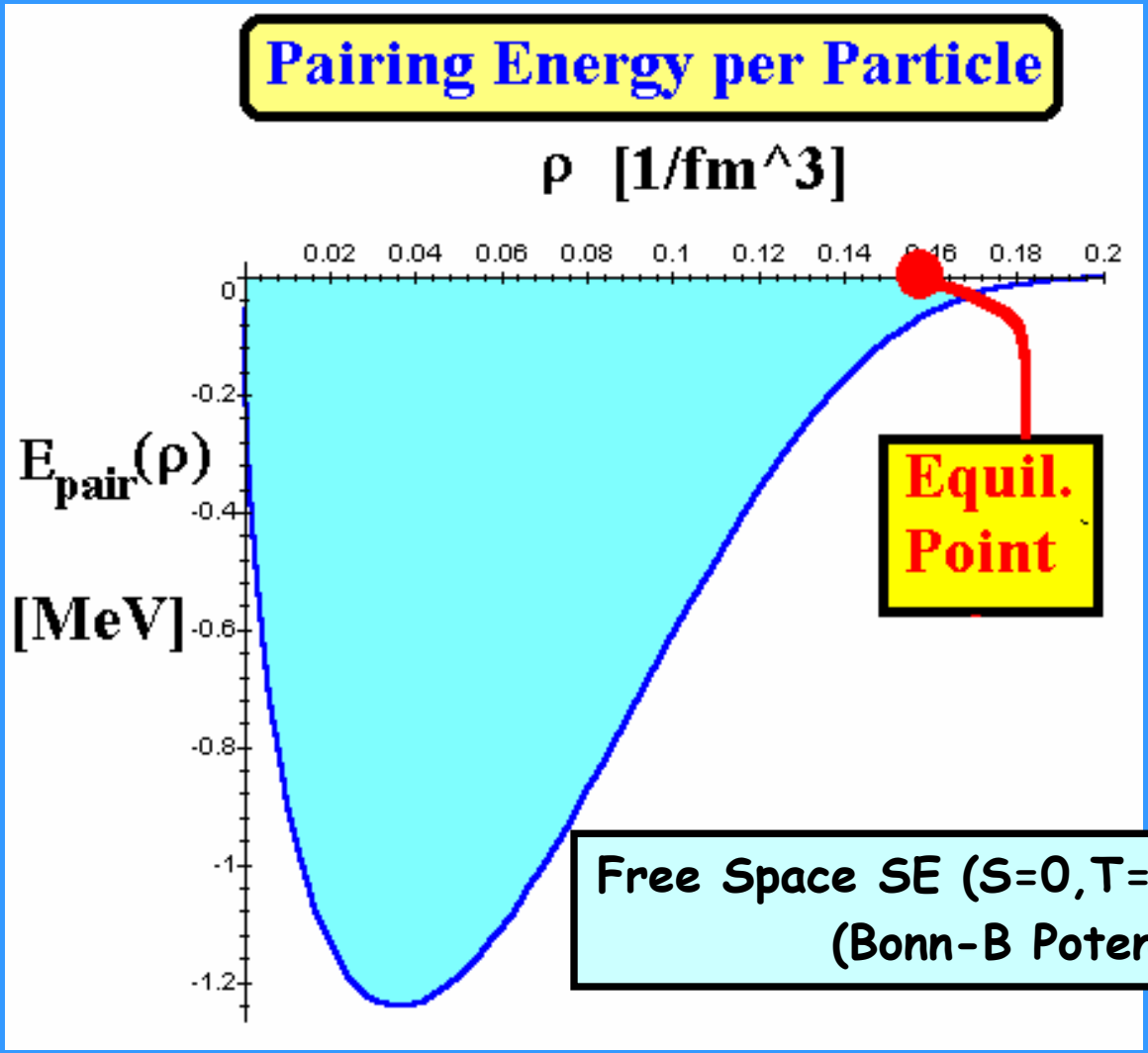
Extended HFB Theory: Pairing Self-Energies

$$(H - e_{\pm} + \Sigma_{\pm}(e_{\mp}))\Phi_{\pm} = 0$$



- Energy Shifts and Widths
- Spectral Functions for particles and holes

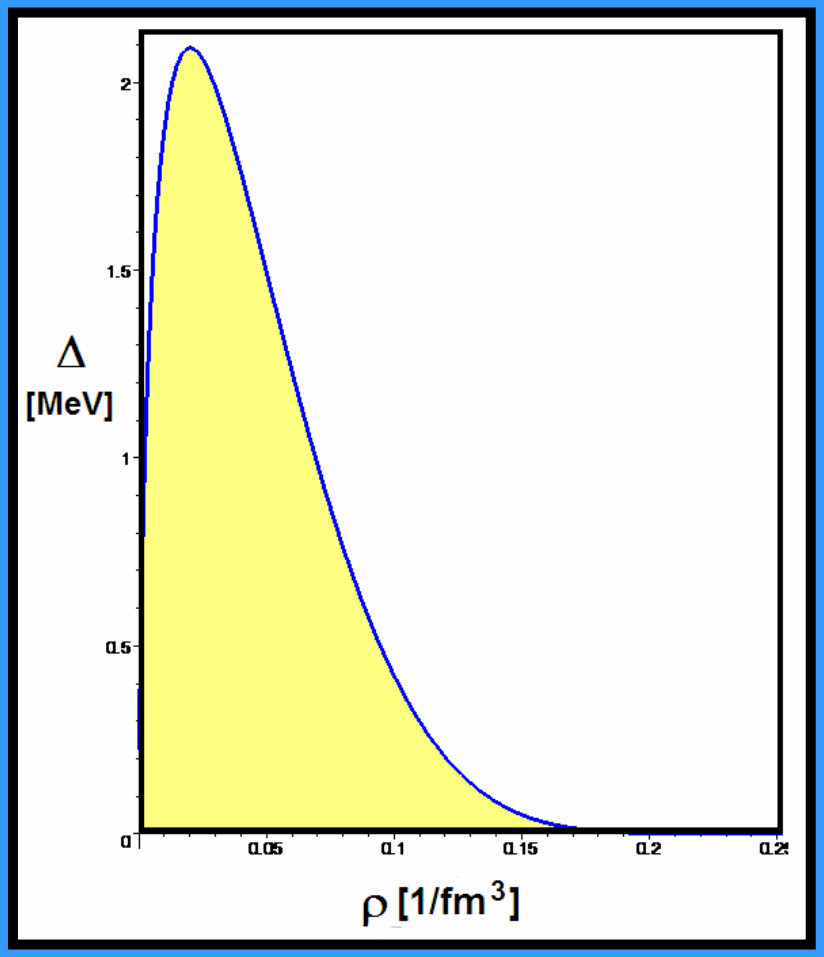
Pairing in Infinite Nuclear Matter

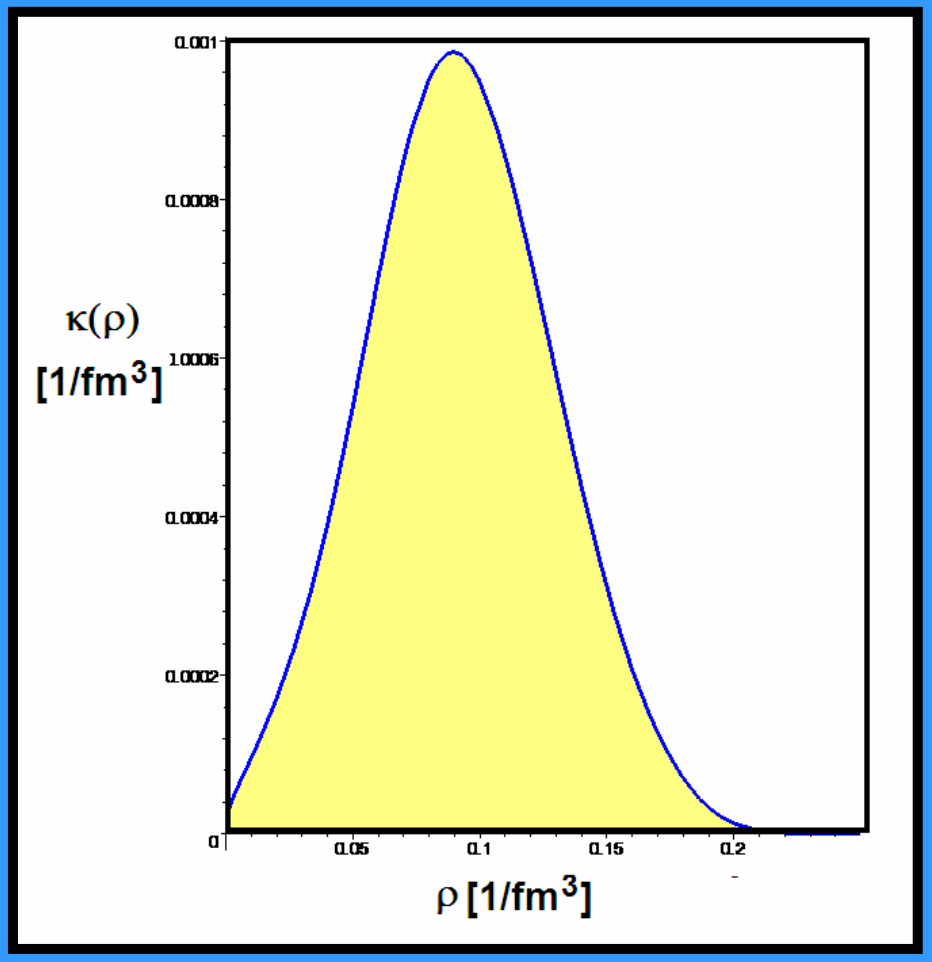


Free Space SE (S=0,T=1) Interaction:
(Bonn-B Potential)

Pairing is a LOW DENSITY Phenomenon

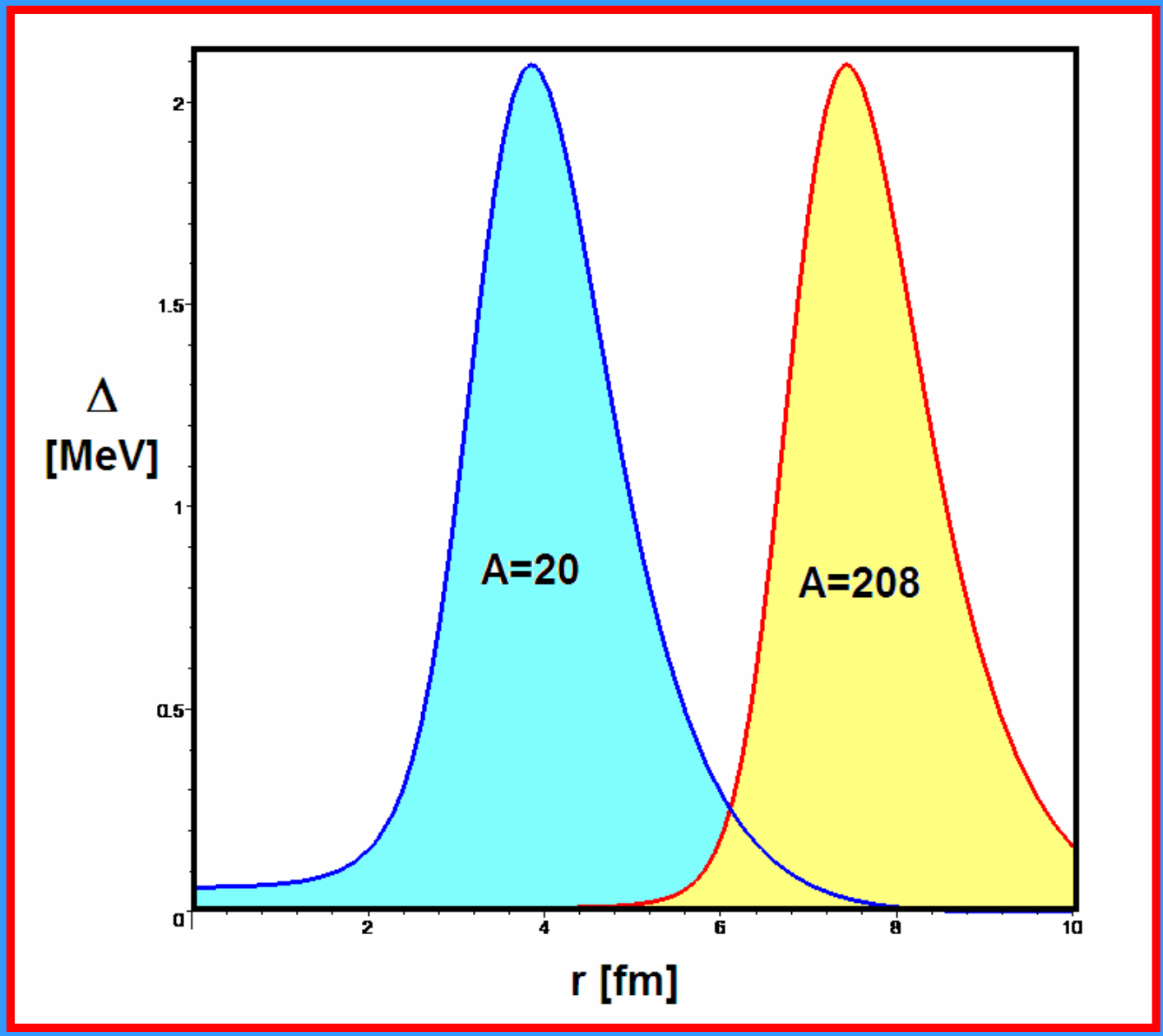
Pairing Correlations in Nuclear Matter





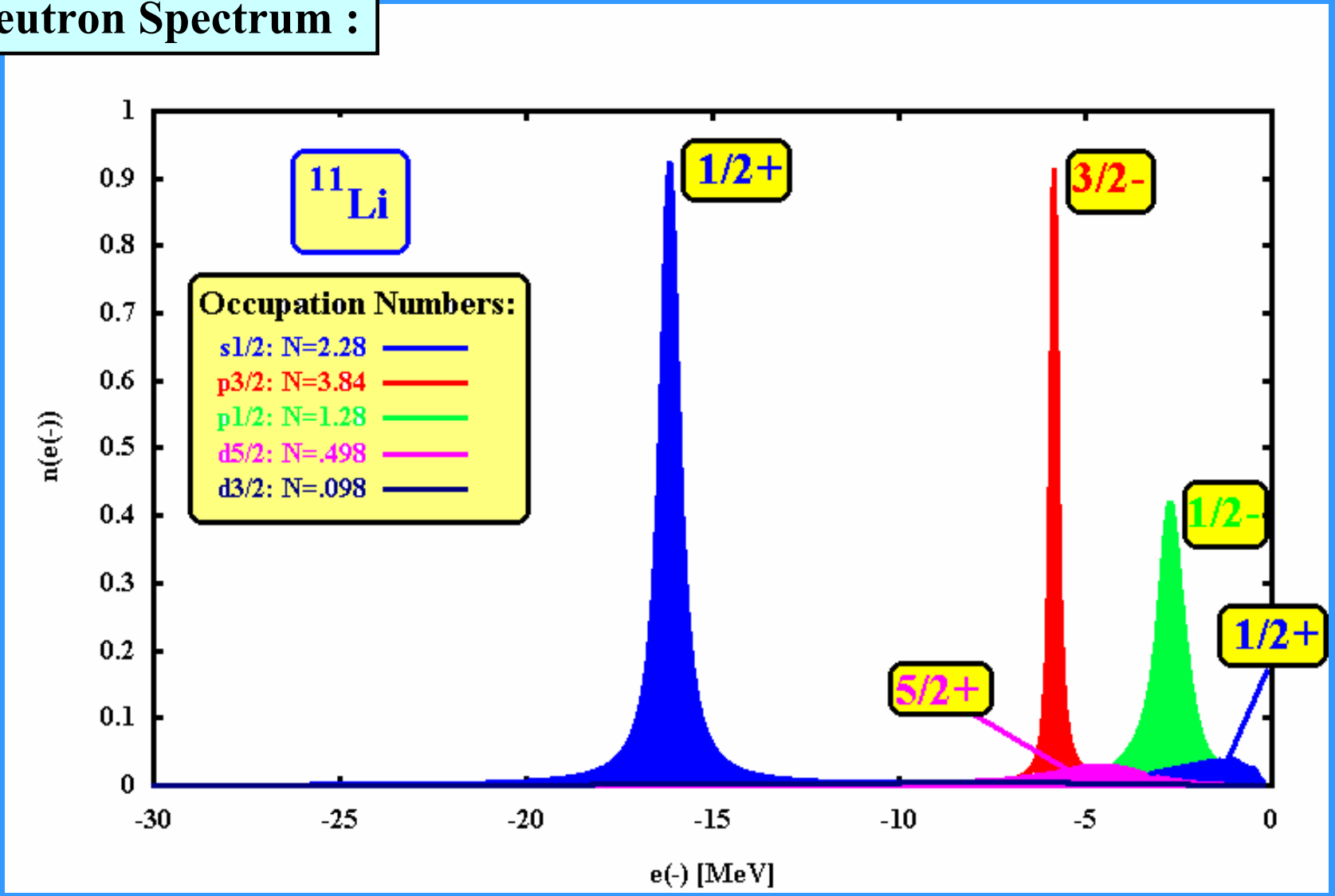
Pairing Gap Δ and Anomal Density κ in Symmetric Nuclear Matter

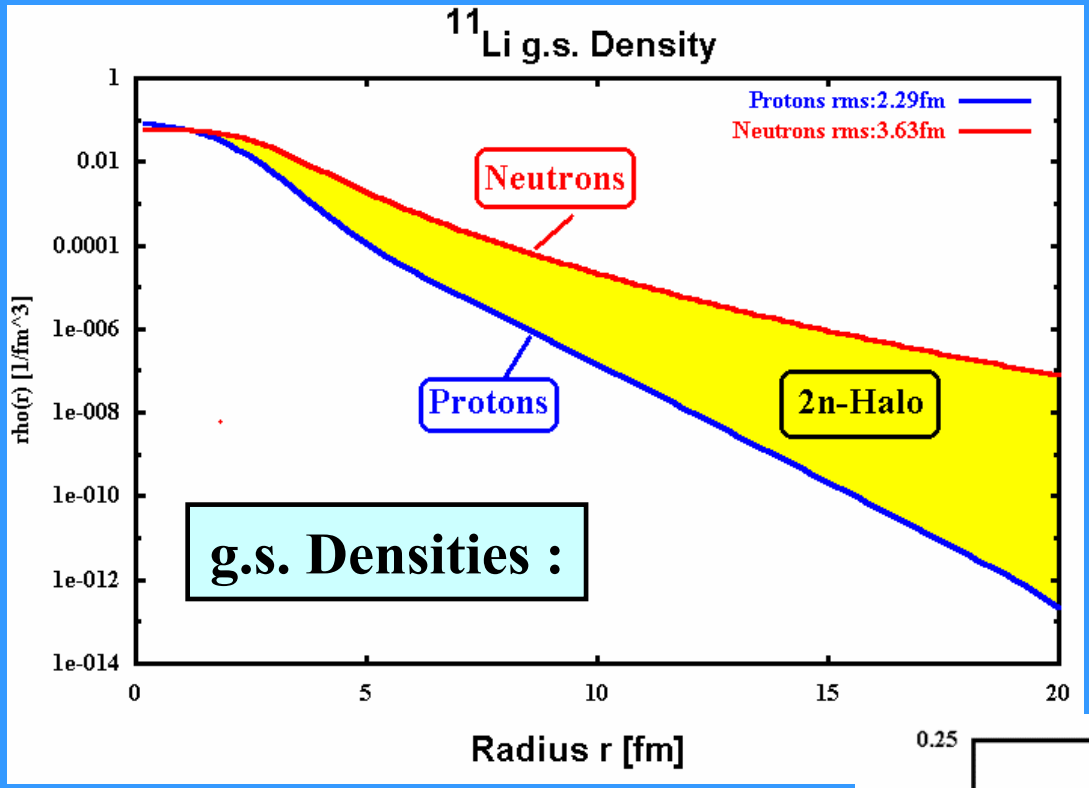
Pairing Gap in a Nucleus (Local Density Appr.)



^{11}Li : Continuum HFB Spectral Functions

Neutron Spectrum :



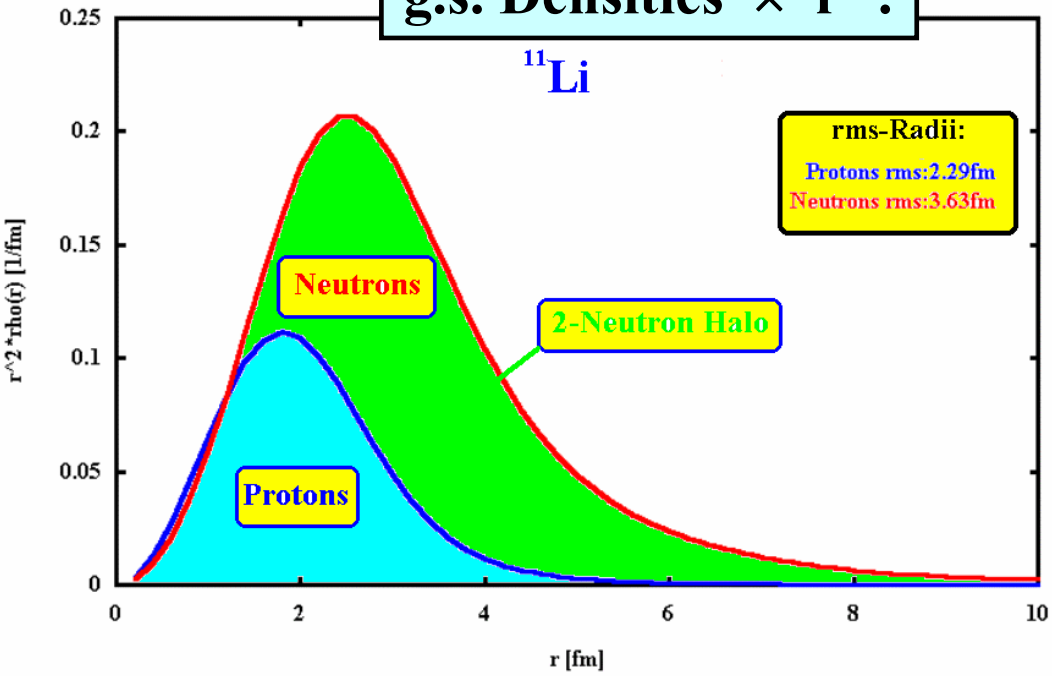


^{11}Li : Continuum HFB g.s. Densities

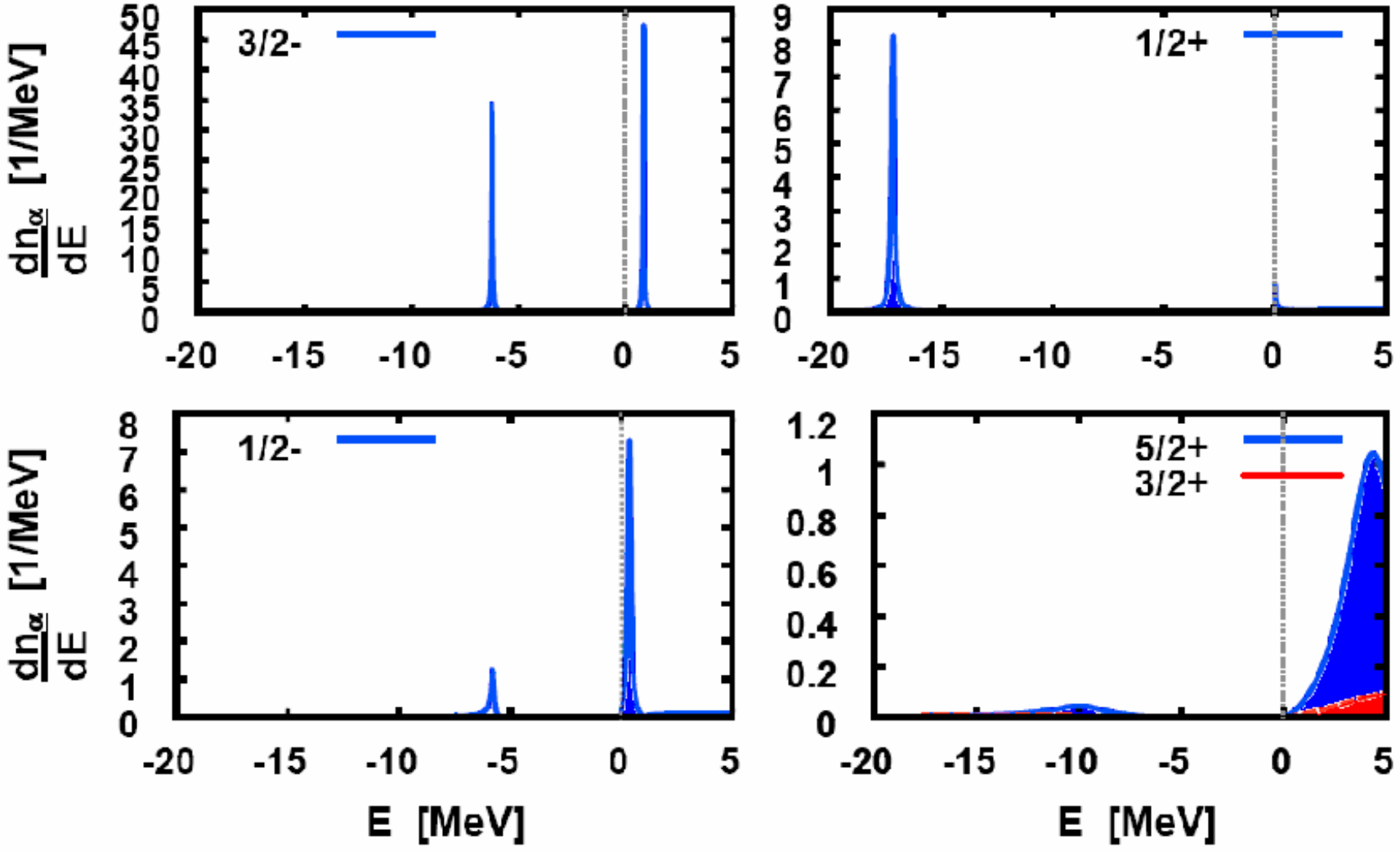
$$for\ q = p,n : \phi_{-}^{(q)} = v_{\ell j}^{(q)}(r)\,|\,(\ell s)\,jm>$$

$$\rho_q(r) = \sum_{\ell j} \frac{2j+1}{4\pi} \int_{-\infty}^{\lambda_q} de\,|\,v_{\ell j}^{(q)}(e,r)\,|^2$$

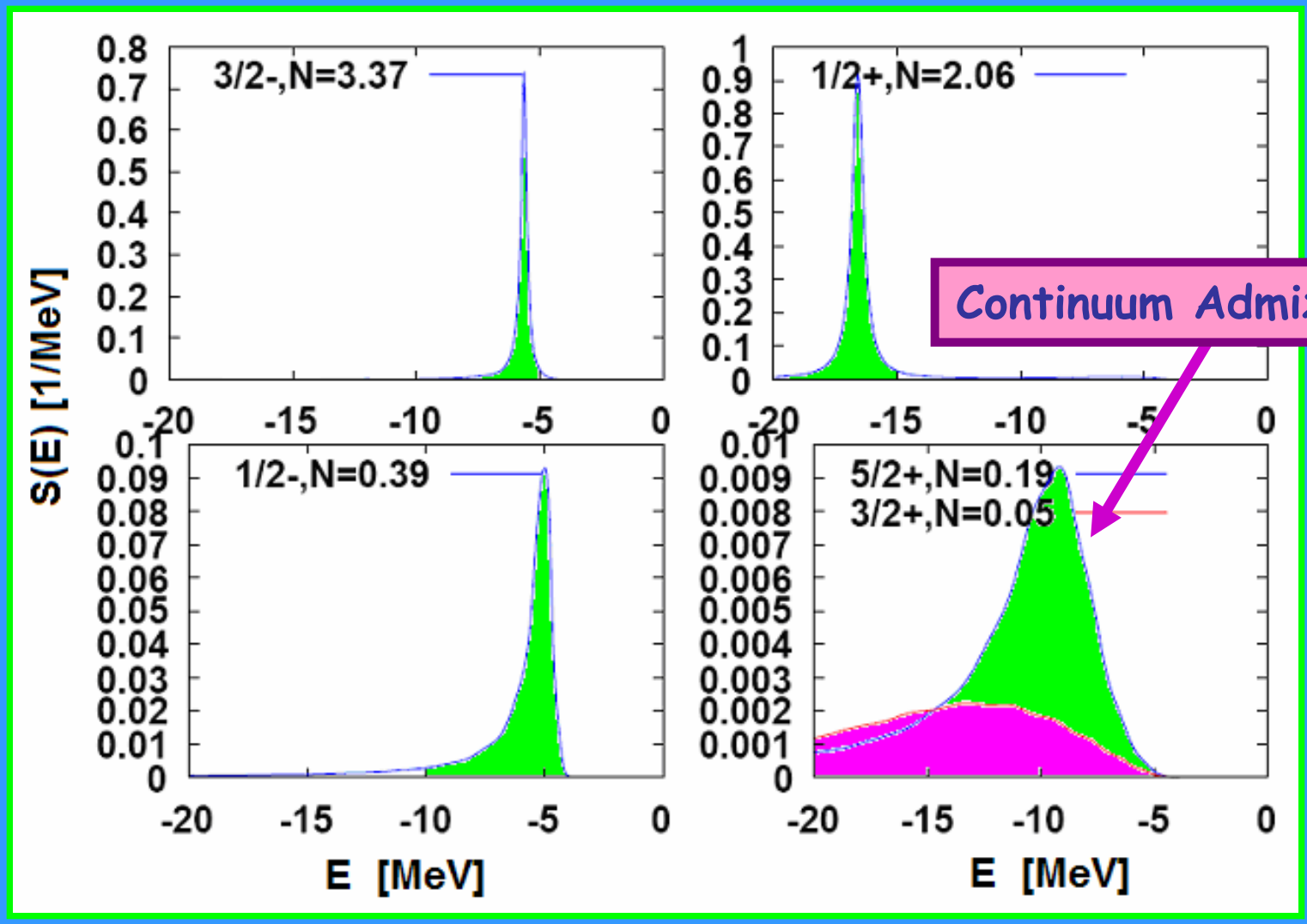
g.s. Densities × r^2 :



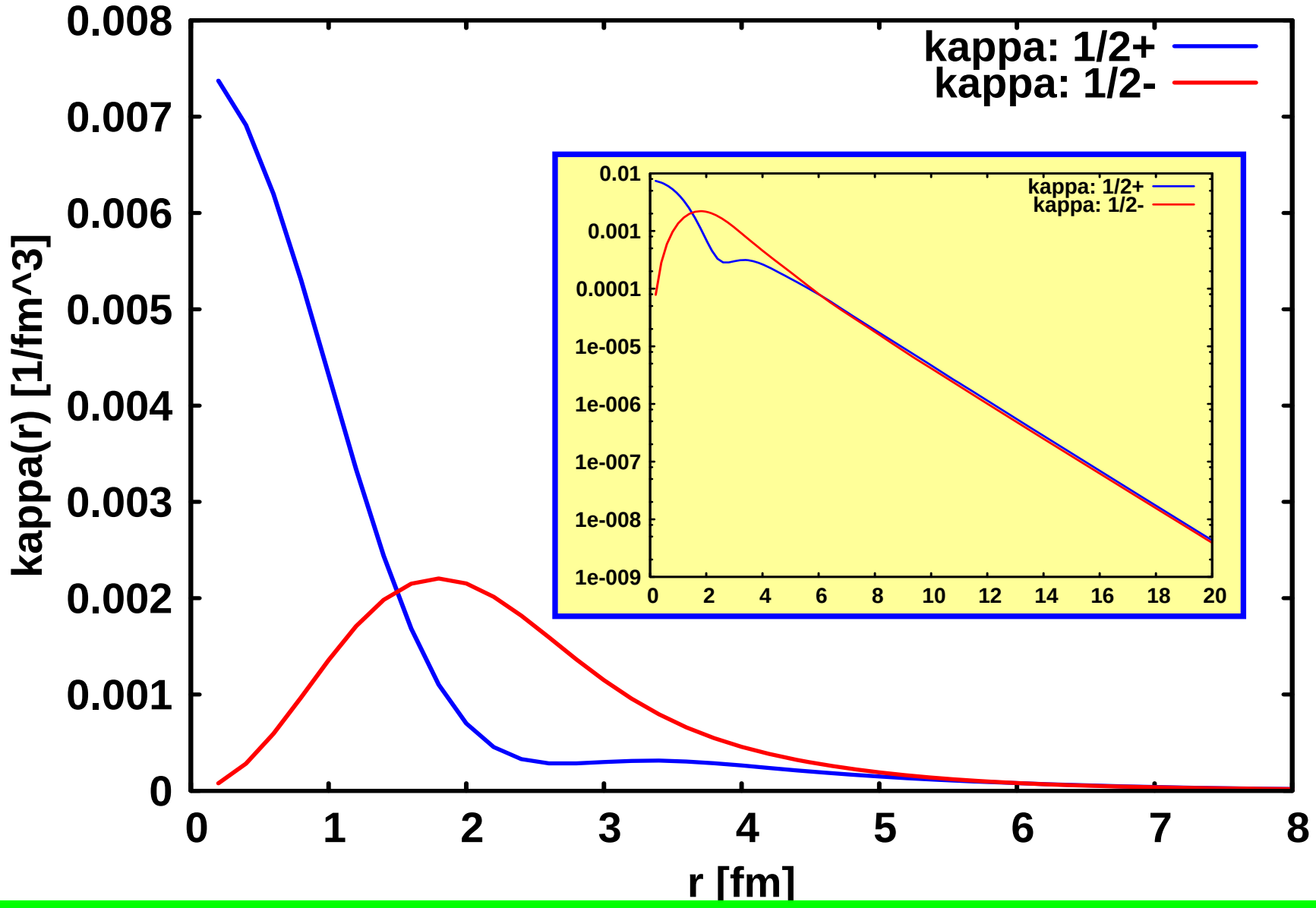
Neutron Spectral Functions in ^{9}Li(3/2-) (Gorkov Pairing)



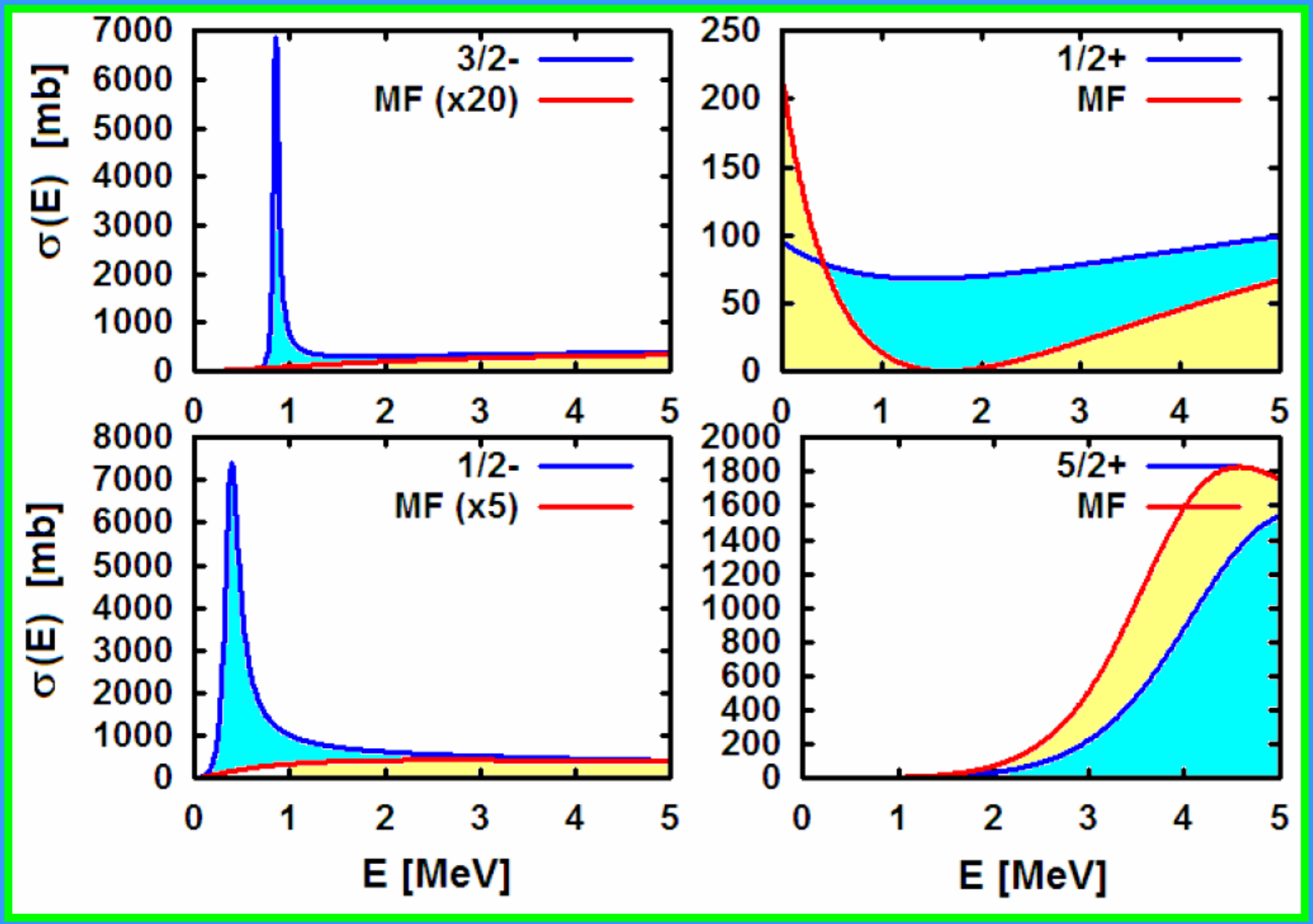
Neutron Spectral Functions in ^{9}Li(3/2-): Continuum Admixtures into the g.s.



Anomalous (Pairing) Density κ(r) in ^{9}Li



Spectral Distributions and Elastic Scattering
$^{10}Li=^{9}Li+n$



Reminder: Some Facts about Reactions to Unbound Final States

- **3-body Final State:**

$$d\sigma_{\beta\alpha} = \frac{1}{I_\alpha}\frac{d^3P_\beta}{(2\pi)^3}\frac{d^3k_\beta}{(2\pi)^3}\frac{d^3q_\beta}{(2\pi)^3}\delta(\vec{P}_\beta - \vec{P}_\alpha)\delta\left(\frac{\hbar^2k_\beta^2}{2\mu_\beta} + \frac{\hbar^2q_\beta^2}{2\tilde{M}_\beta} + \Delta M - \frac{\hbar^2k_\alpha^2}{2\mu_\alpha}\right)\left|X_{\beta\alpha}(\vec{k}_\beta, \vec{q}_\beta, \vec{k}_\alpha)\right|^2$$

- **Inclusive Cross Sections:**

$$\frac{d^2\sigma_{\beta\alpha}}{d\Omega_\beta dE_\beta} = \sum_{\ell j} D(q_\beta)\frac{d\sigma_{\beta\alpha}^{\ell j}}{d\Omega_\beta}$$

$$\frac{d\sigma_{\beta\alpha}^{\ell j}}{d\Omega} = \frac{\mu_\alpha\,\mu_\beta}{\left(2\pi\,\hbar^2\right)^2}\frac{k_\beta}{k_\alpha}\frac{1}{(2j_\alpha+1)(2J_\alpha+1)}\sum_{m_\alpha M_\alpha m_\beta M_\beta}\left|T_{\beta\alpha}^{\ell j}(\vec{\mathbf{k}}_\beta, q_\beta, \vec{\mathbf{k}}_\alpha)\right|^2$$

- **Nucleon Field Operator:**

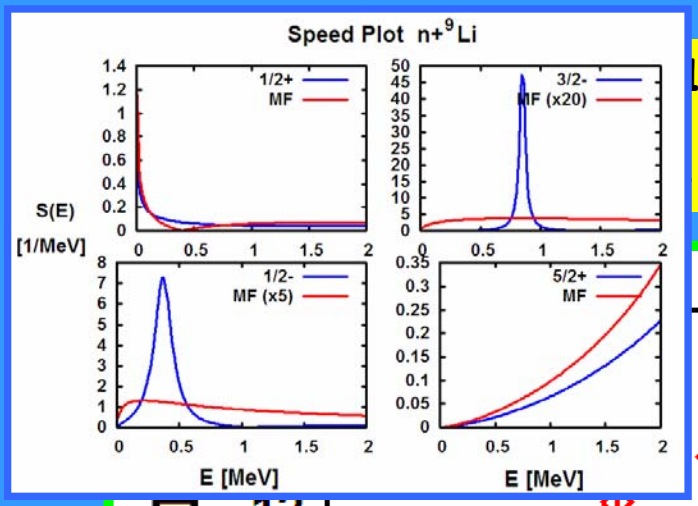
$$\Psi(x) = \sum_n\left(a_n^\dagger\varphi_n^*(x) + \tilde{a}_n\varphi_n(x)\right) + \int\frac{d^3k}{(2\pi)^3}\left(a_{\vec{k}}^\dagger\chi_{\vec{k}}^*(x) + \tilde{a}_{\vec{k}}\chi_{-\vec{k}}(x)\right)$$

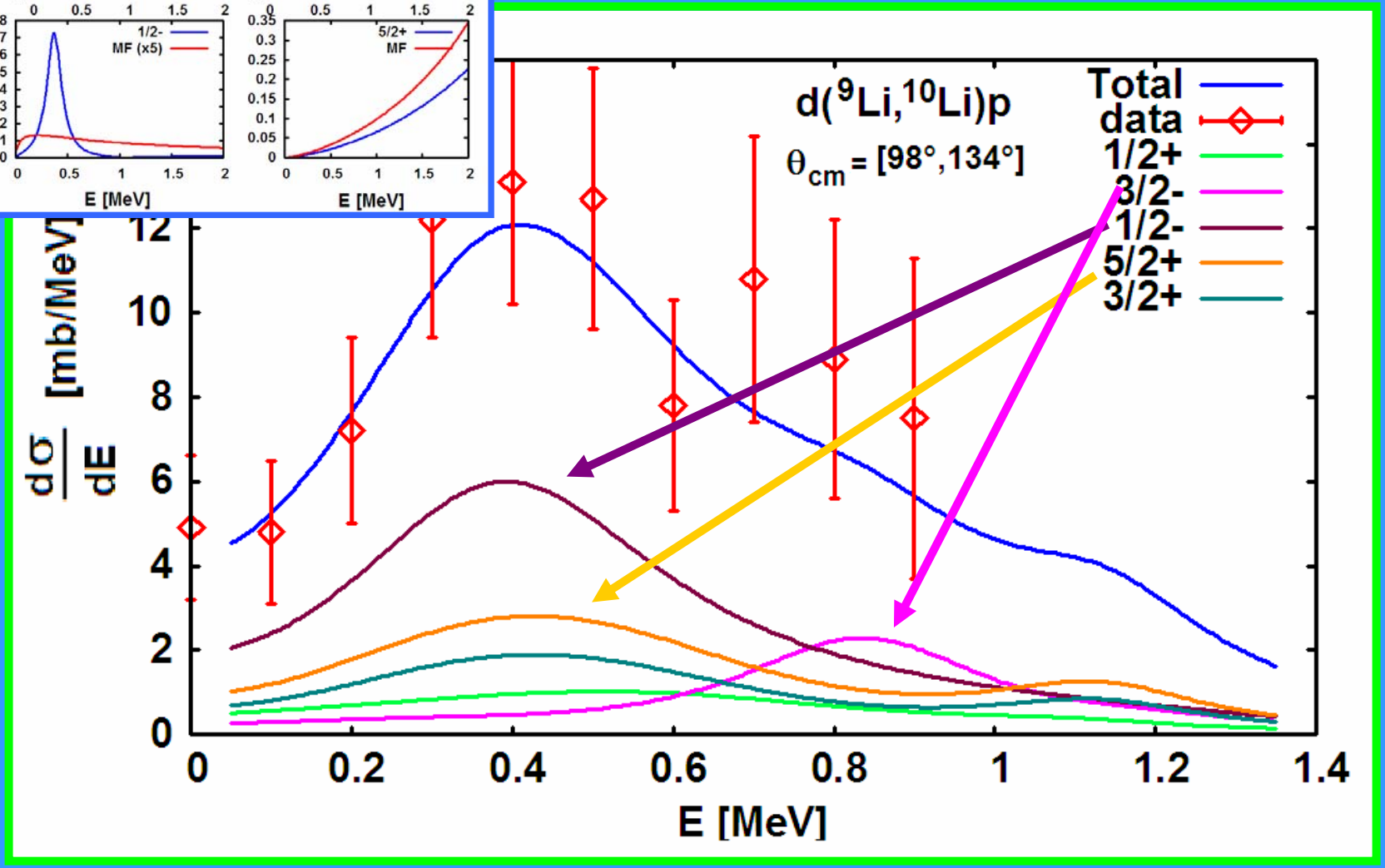
$$\left\{\Psi^\dagger(\vec{r},t), \Psi(\vec{r}\,',t)\right\} = \delta(\vec{r} - \vec{r}\,')$$

$$\left\{a_{\vec{k}}^\dagger, a_{\vec{q}}\right\} = (2\pi)^3\delta(\vec{k} - \vec{q})$$

$$\langle B|\Psi_A|A\rangle = \langle A|\{\Gamma_\beta, \Psi_A\}|A\rangle = z_{\vec{k}_\beta}(E_\beta)u_{\vec{k}_\beta}(\vec{r})$$

^{10}Li(J$^{\pi}$))p @ T_{lab}=2.36AMeV averaged Spectrum

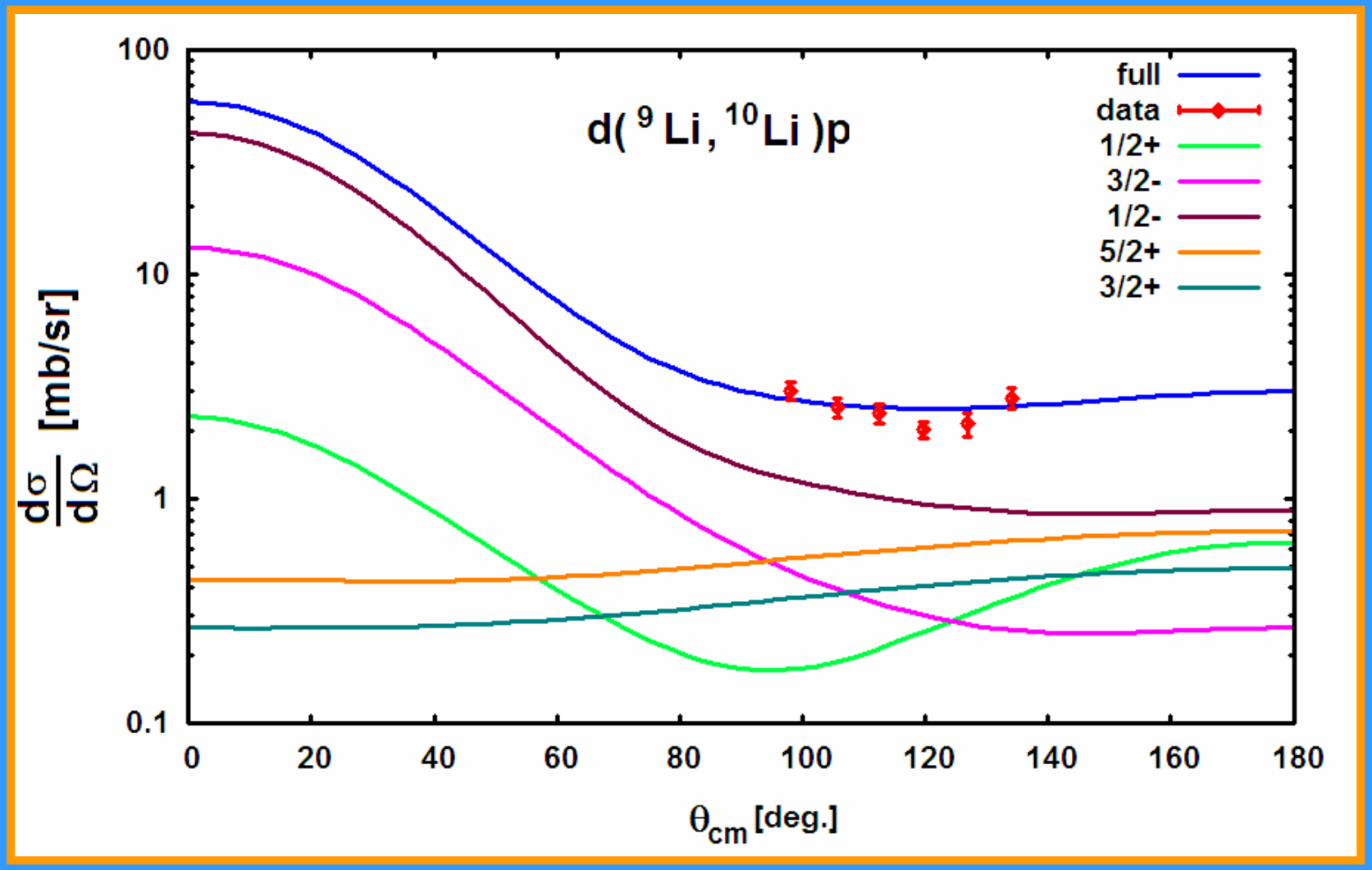




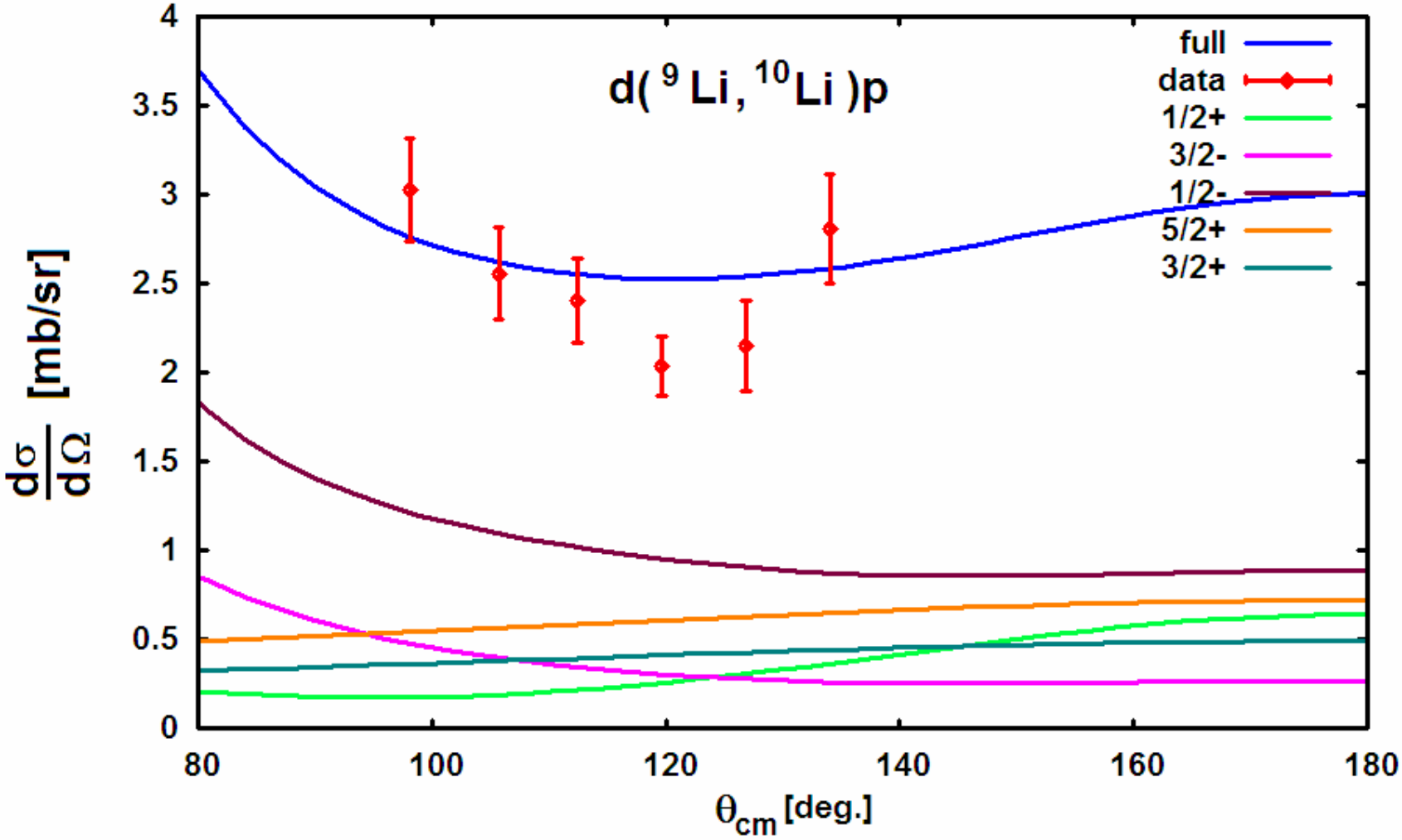
S. Orrigo, H.L., PLB

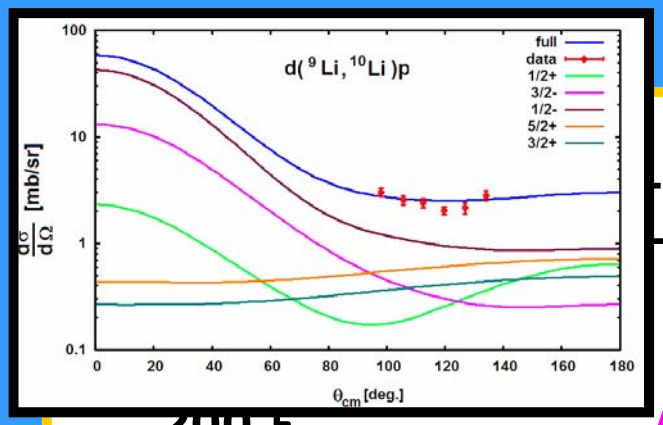
Data: H.Jeppesen et al., Phys. Lett. B 642 (2006) 449

d(⁹Li(3/2-),¹⁰Li(Jᵖ))p @ T_{lab}=2.36AMeV
energy-integrated Angular Distribution



d(⁹Li(3/2-),¹⁰Li(Jᵖ))p @ T_{lab}=2.36AMeV
energy-integrated Angular Distribution
The Carlos B.-Special: Linear Scale





10Li spectrum - theta=[0,180]

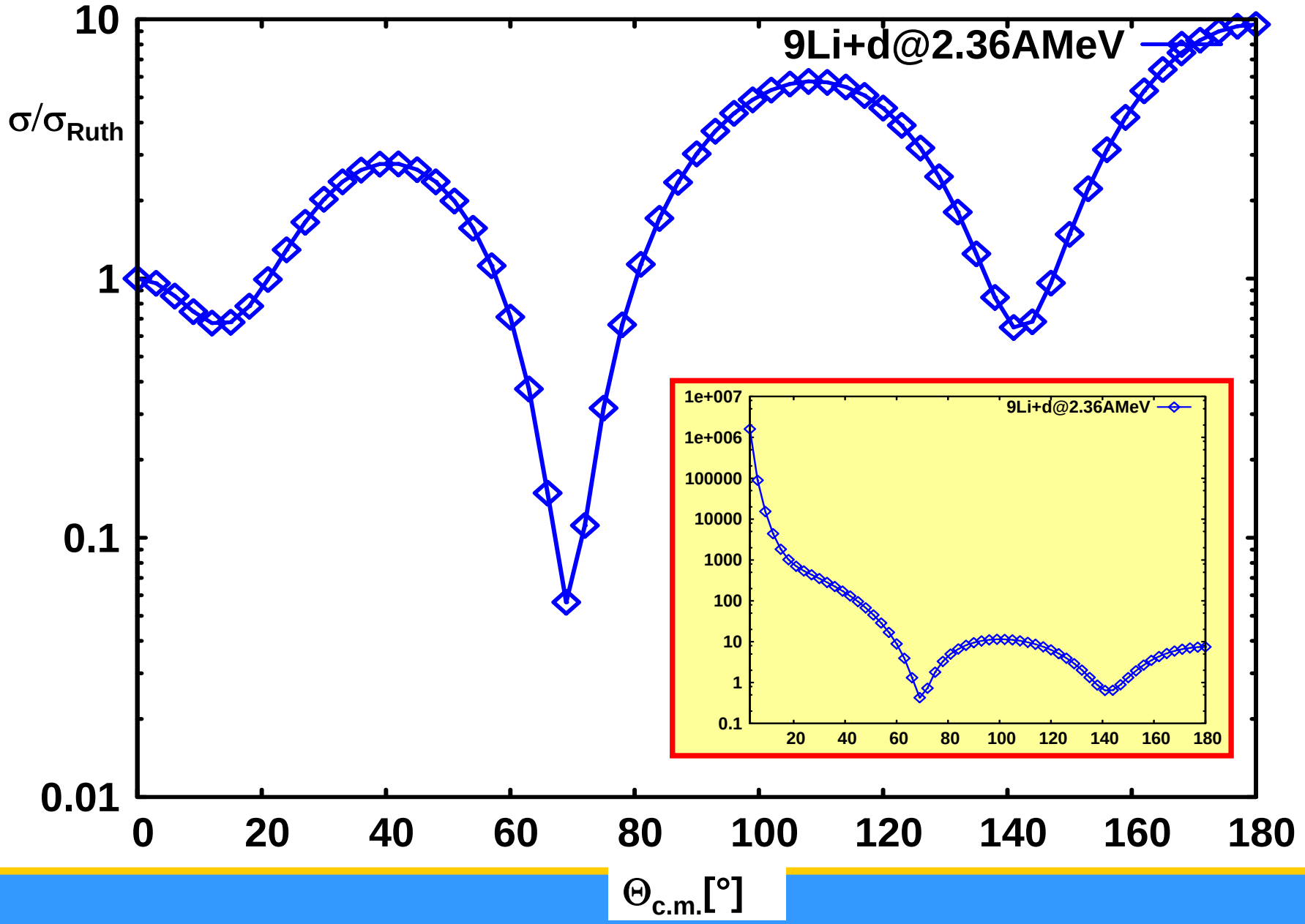
data
Total XS (fold)
Total XS (bare)

Data: [98°-134°]

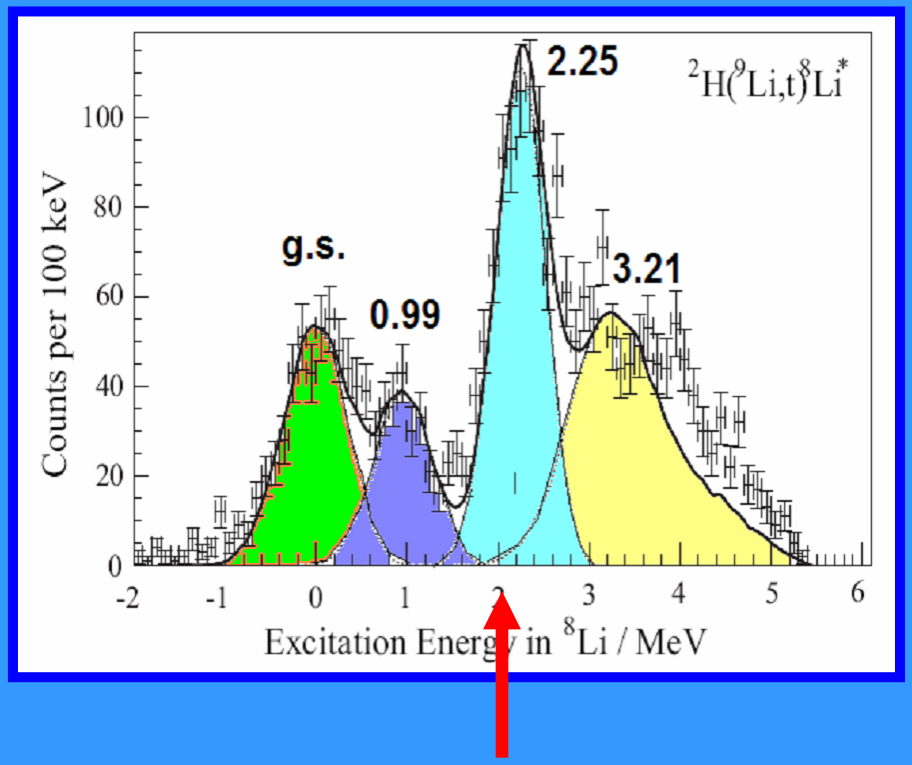
dsig/dE [mb/MeV]

E [MeV]

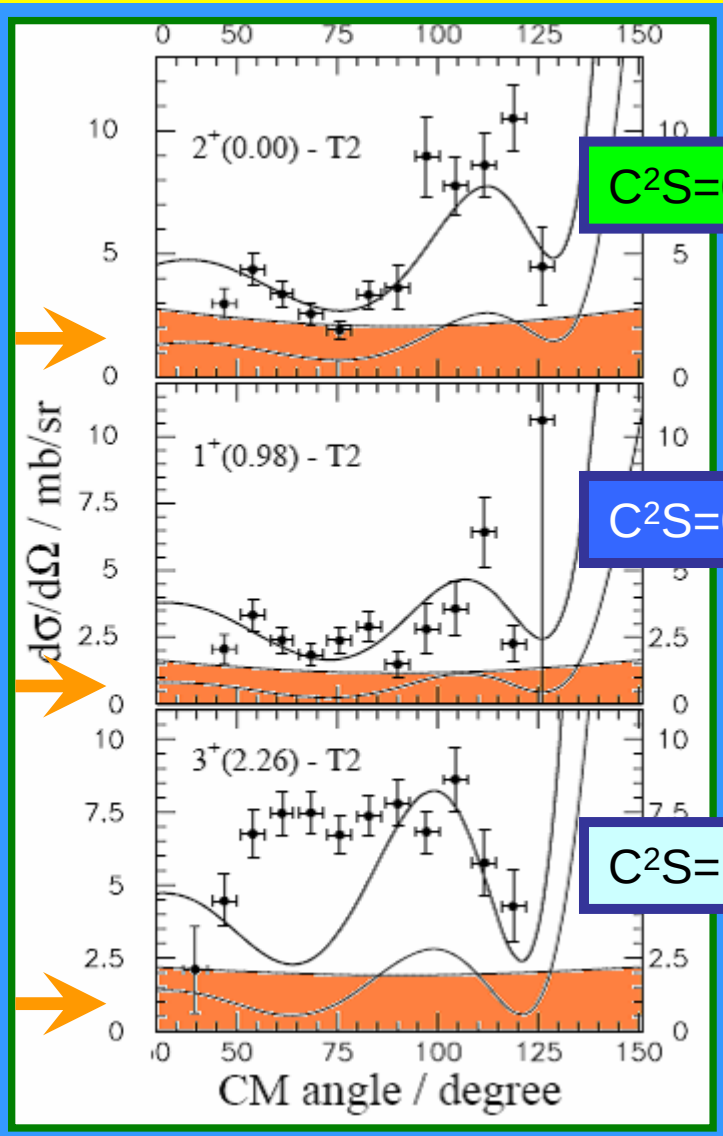
Elastic Scattering



The ^{9}Li+d → ^{8}Li+t Reaction @ REX-ISOLDE
Theory and Data T_{lab}=2.36 AMeV



S_n=2.032MeV



C^2S=0.89

C^2S=0.34

C^2S=1.33

H. Jeppesen,..B. Jonson,..., H.L,...
A. Richter et al., PLB635 (2006) 17

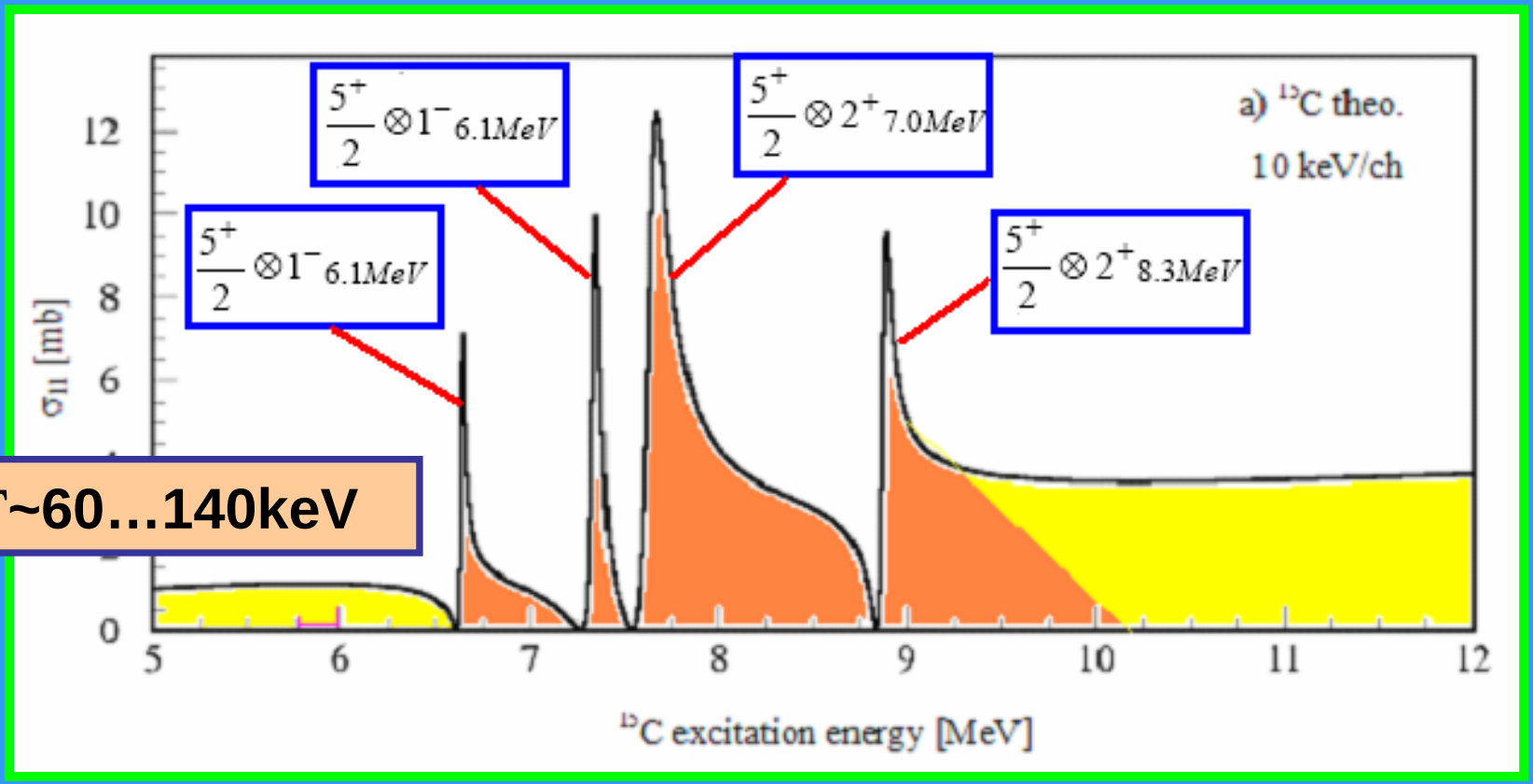
Fano-Resonances in the Nuclear Continuum

$$\left(h_{j}^{(1)} - \varepsilon_1\right)\phi_j + \sum_{j'\ J_C} \left\langle 0 \left| V_{13} \right| J_C \right\rangle \phi_{j'J_c} = 0$$

g.s., elastic

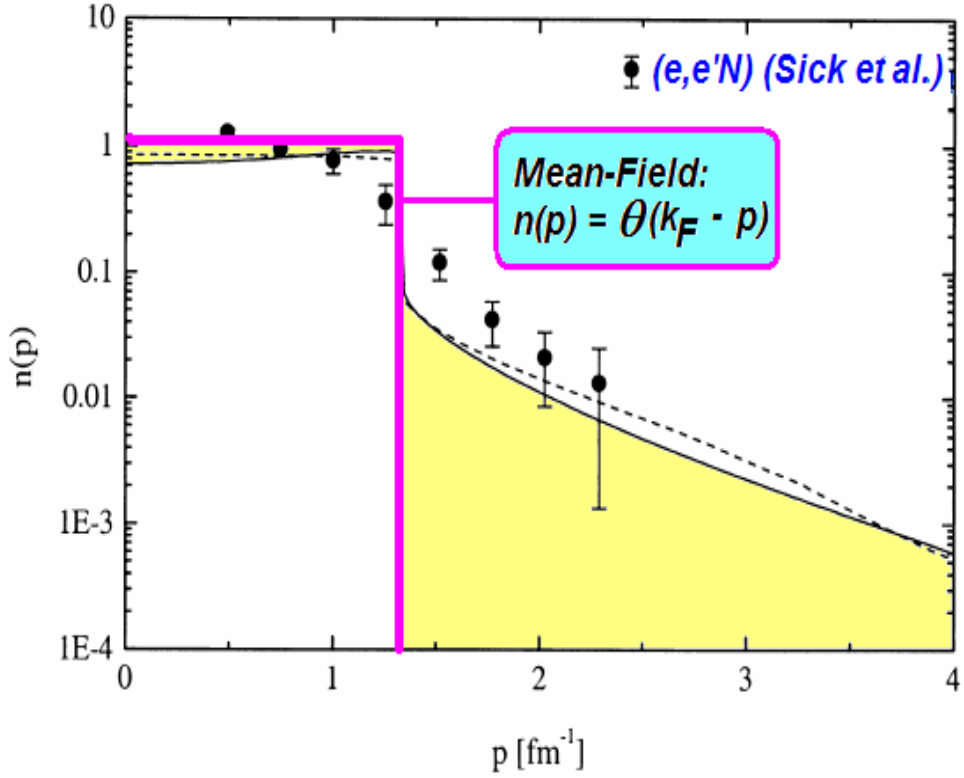
$$\left(h_{j'J_C}^{(i)} - \varepsilon_i\right)\phi_{j'J_c} + \sum_{n} \left\langle J_C \left| V_{13} \right| 0 \right\rangle \phi_j = 0$$

inelastic



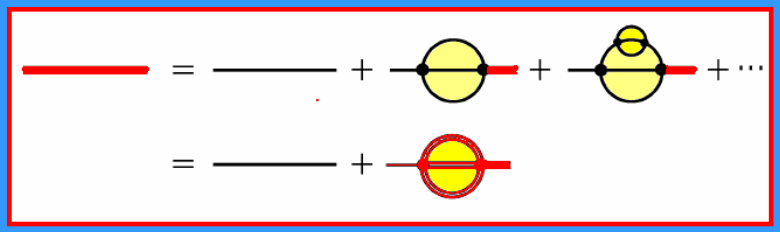
Γ~60…140keV

Beyond the Mean-Field: Short-range Correlations in Nuclear Matter



Momentum Distribution

$$n(p) = N(k_F) \int a(p,\omega)\, d\omega$$

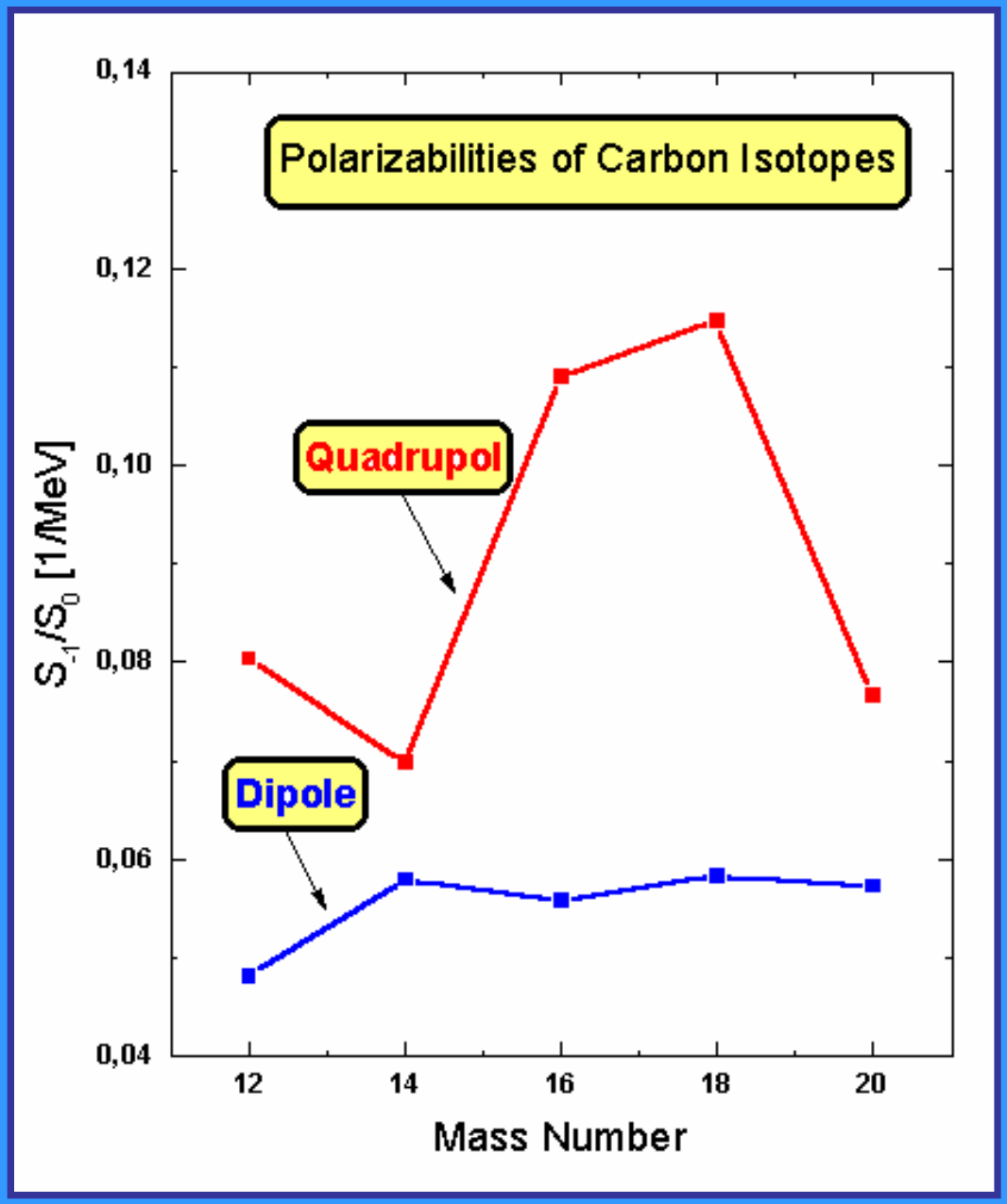


Self-consistent inclusion of sun-set diagrams:

$V \sim V_{\omega,\sigma} + V_{\rho} \sim g^2 \sim |M|^2$

$$a(\omega, p) = \frac{\Gamma(\omega, p)}{\left(\omega - \frac{p^2}{2m} - \Sigma^{\mathrm{mf}} - \mathrm{Re}\,\Sigma^{\mathrm{ret}}(\omega, p)\right)^2 + \frac{1}{4}\Gamma^2(\omega, p)},$$

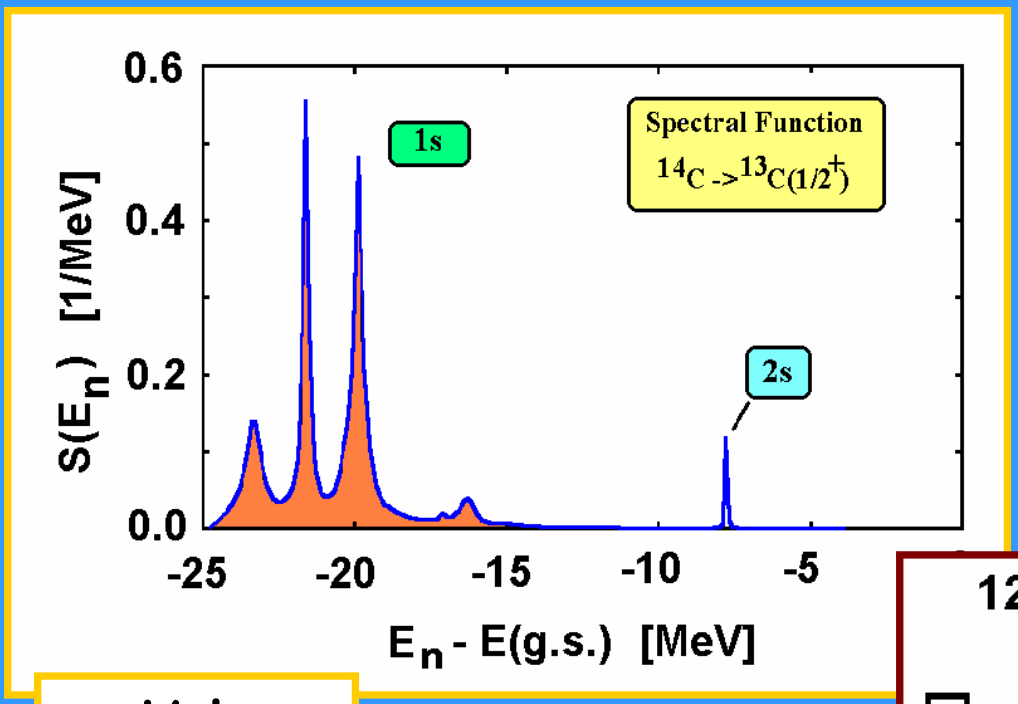
PLB483 (2000) 324
NPA723 (2003) 544
NPA (2005)in print



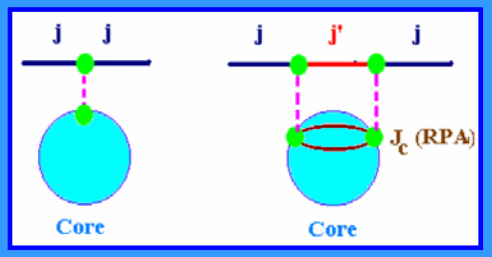
HFB+QRPA results

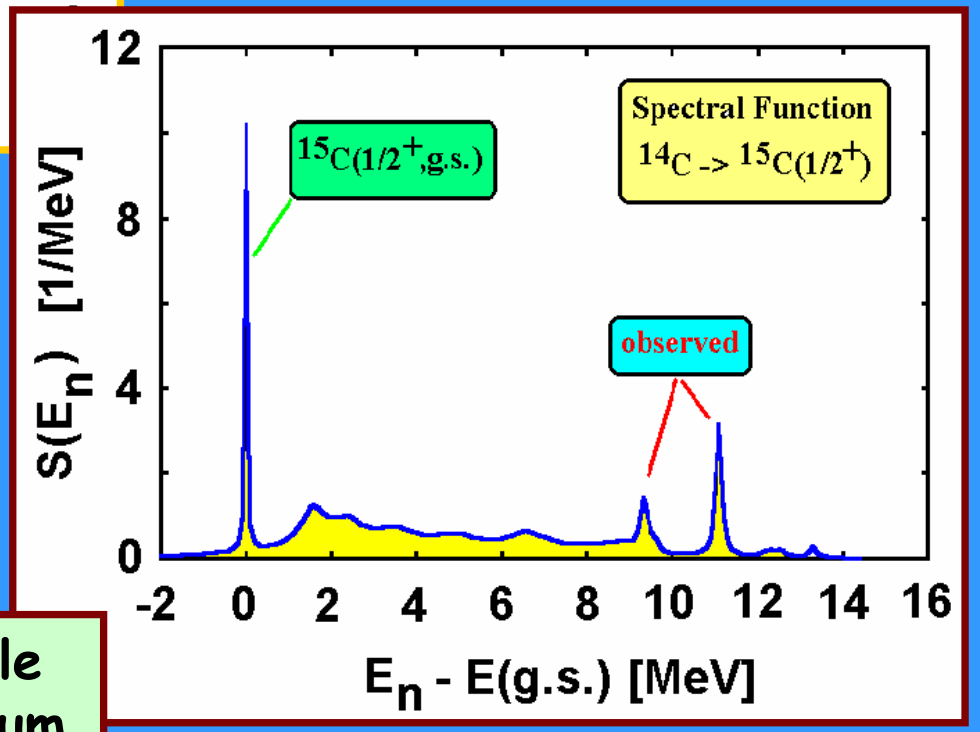
Dynamical Core Polarization:

- HFB g.s.: „3-body renormalized“ G-Matrix
- ph-Interactions: Fermi Liquid Theory



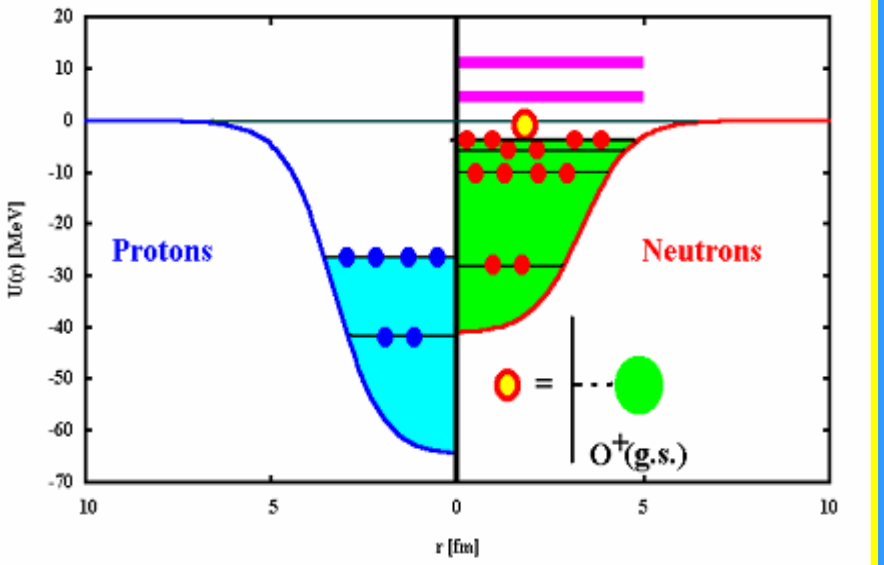
Hole Spectrum



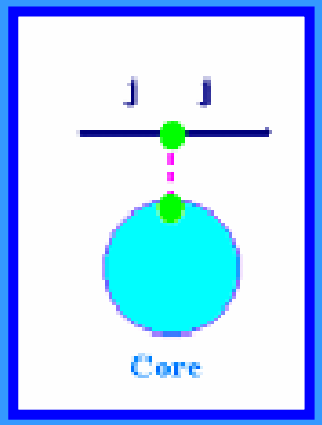


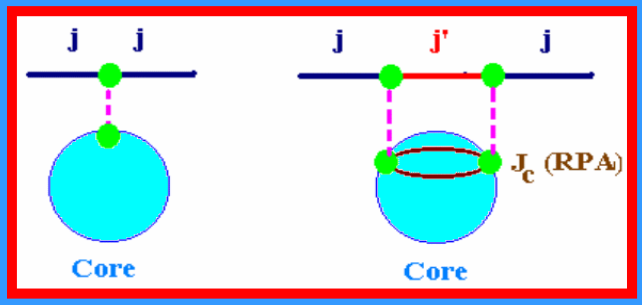
Particle Spectrum

The Neutron Halo in ^{19}C: Transition from Mean-Field to Correlation Dynamics

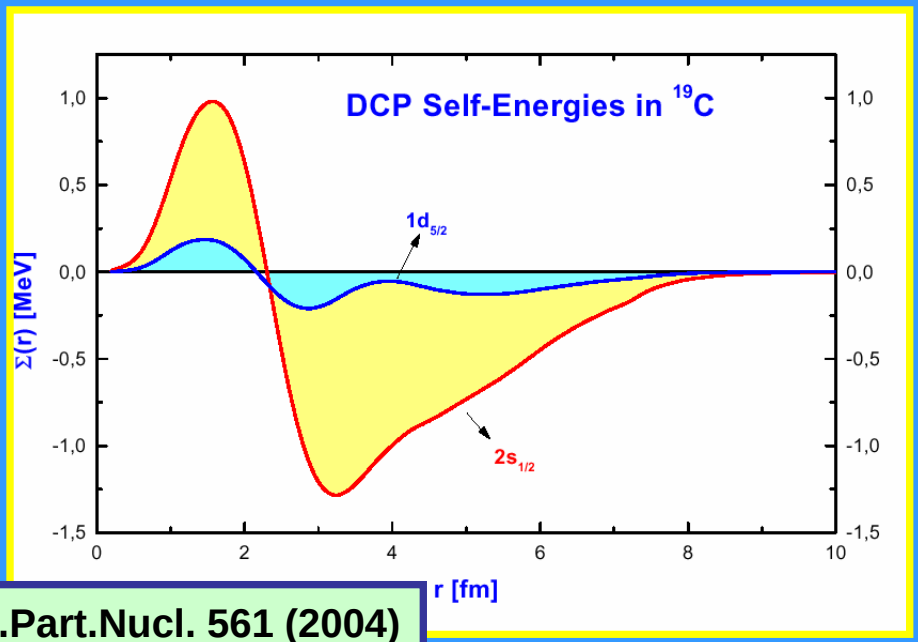


The s.p. shell model picture



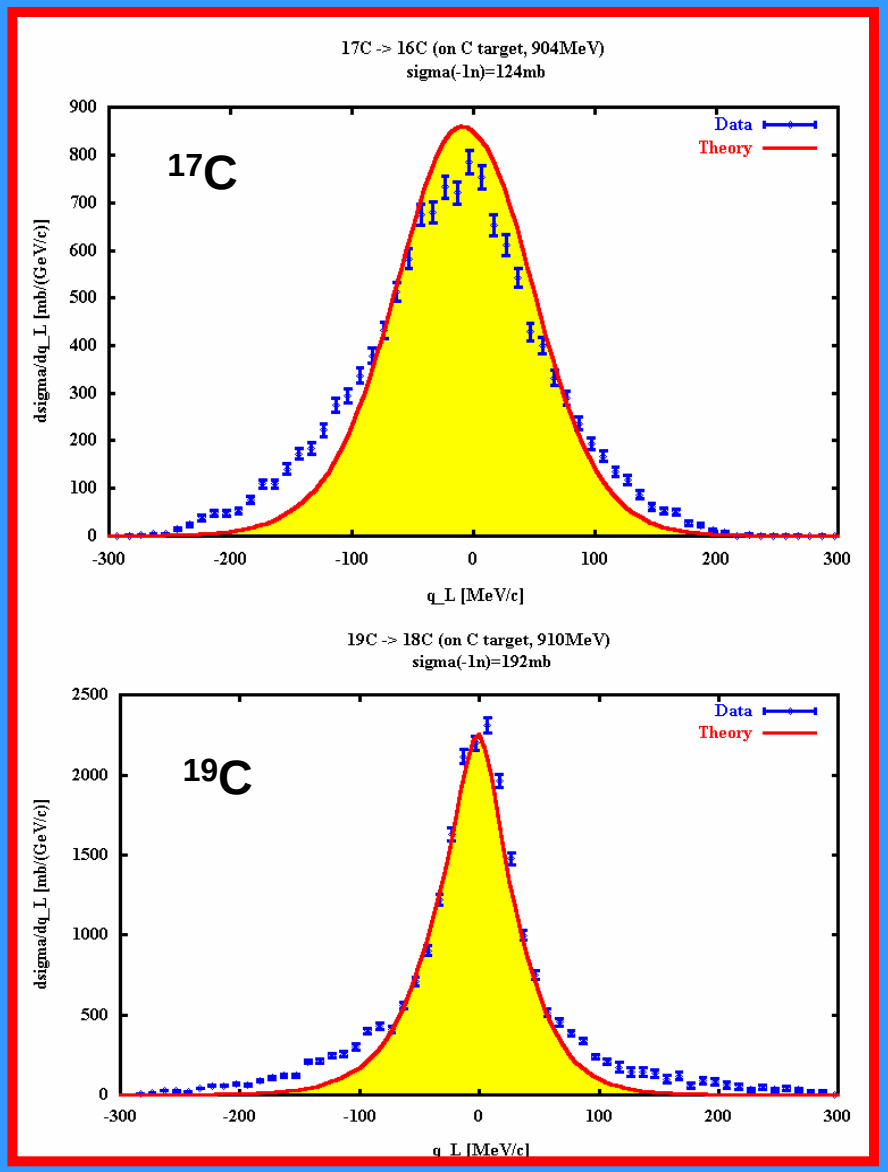


The DCP picture: Binding by Virtual Continuum Coupling



H.L.,J. Prog.Part.Nucl. 561 (2004)

Longitudiunal Momentum Distributions: $^{17,19}C \rightarrow ^{16,18}C + n$
Carbon Target, $E_{lab} \approx$ 900 AMeV



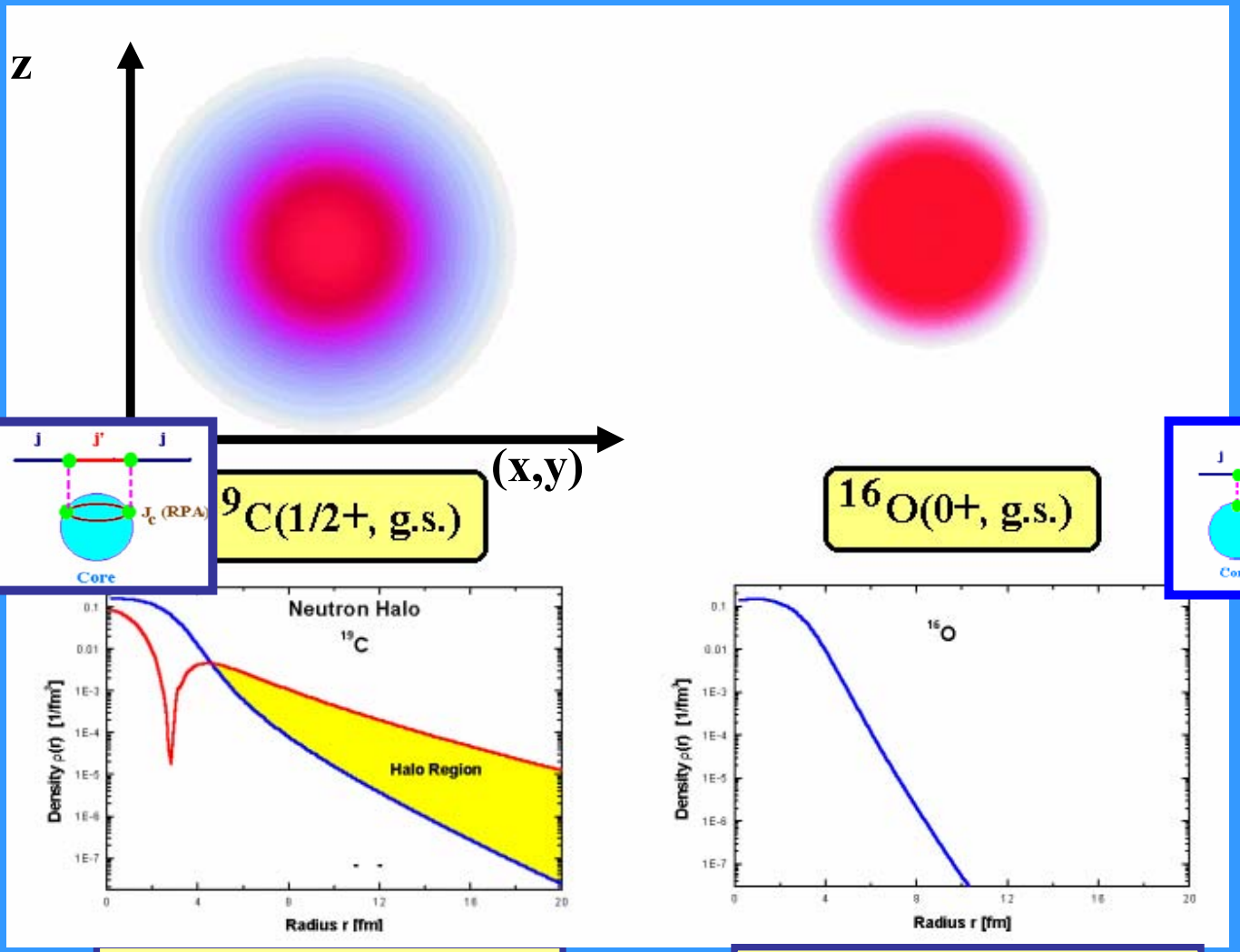
- **Binding: Correlation Dynamics**
- **^{17}C(5/2+,g.s.)**
- **S_n(the.)=715keV**
- **C^2S(g.s.) = 0.41**

Γ(the.): 132 MeV/c
Γ(exp.): 143 ± 5 MeV/c
σ(-1n,the.): 124 mb
σ(-1n,exp.): 129± 22 mb

- **Binding: Correlation Dynamics**
- **^{19}C(1/2+,g.s.)**
- **S_n(the.)=263keV**
- **C^2S(g.s.) = 0.40**

Γ(the.): 69 MeV/c
Γ(exp.): 68 ± 3 MeV/c
σ(-1n,the.): 192 mb
σ(-1n,exp.): 233± 51 mb

Shape and Size of ^{19}C and ^{16}O



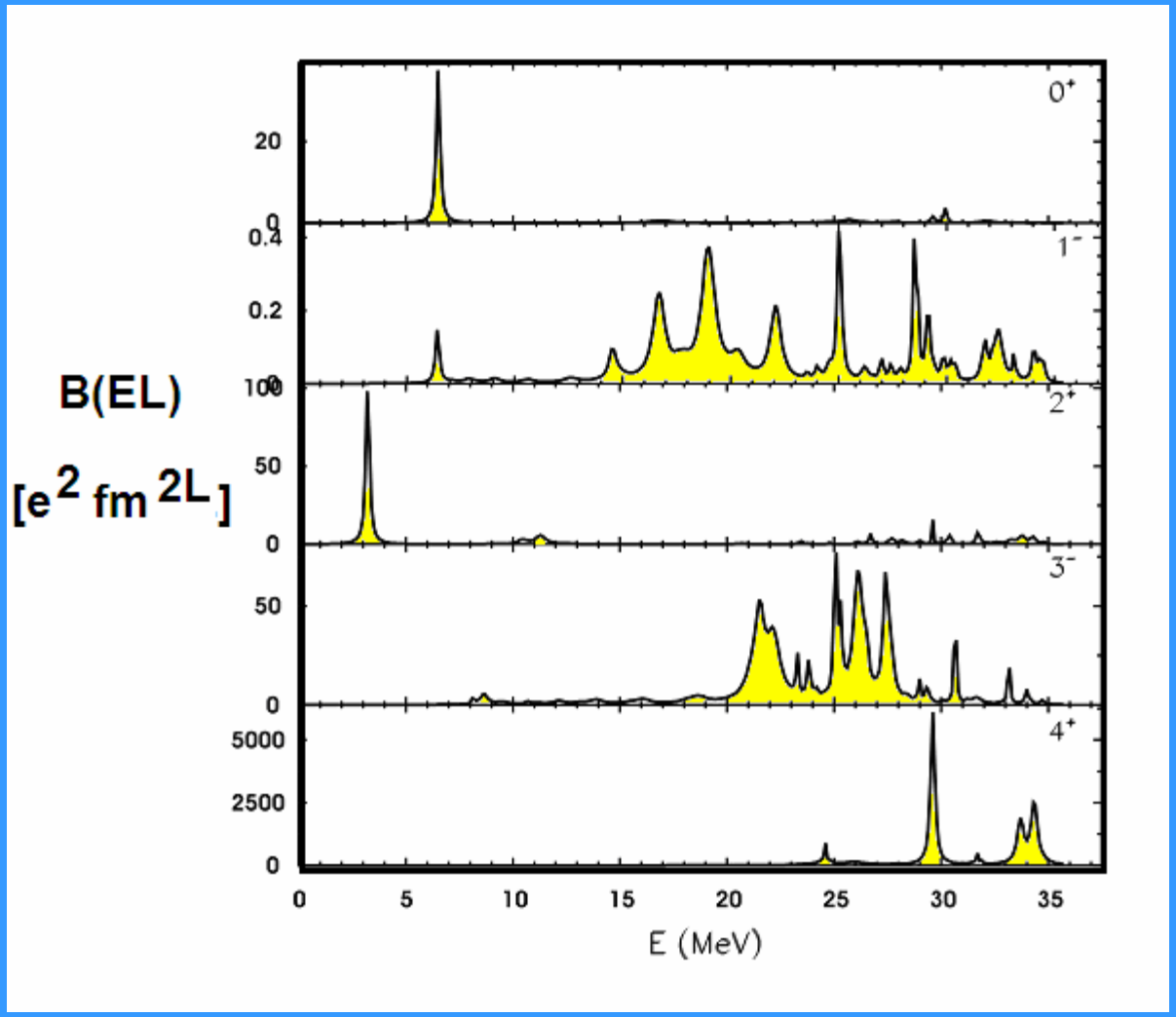
$\sqrt{<r^2>(1/2+)} = 5.34$ fm

S = 0.40

$\sqrt{<r^2>(1/2-)} = 2.96$ fm

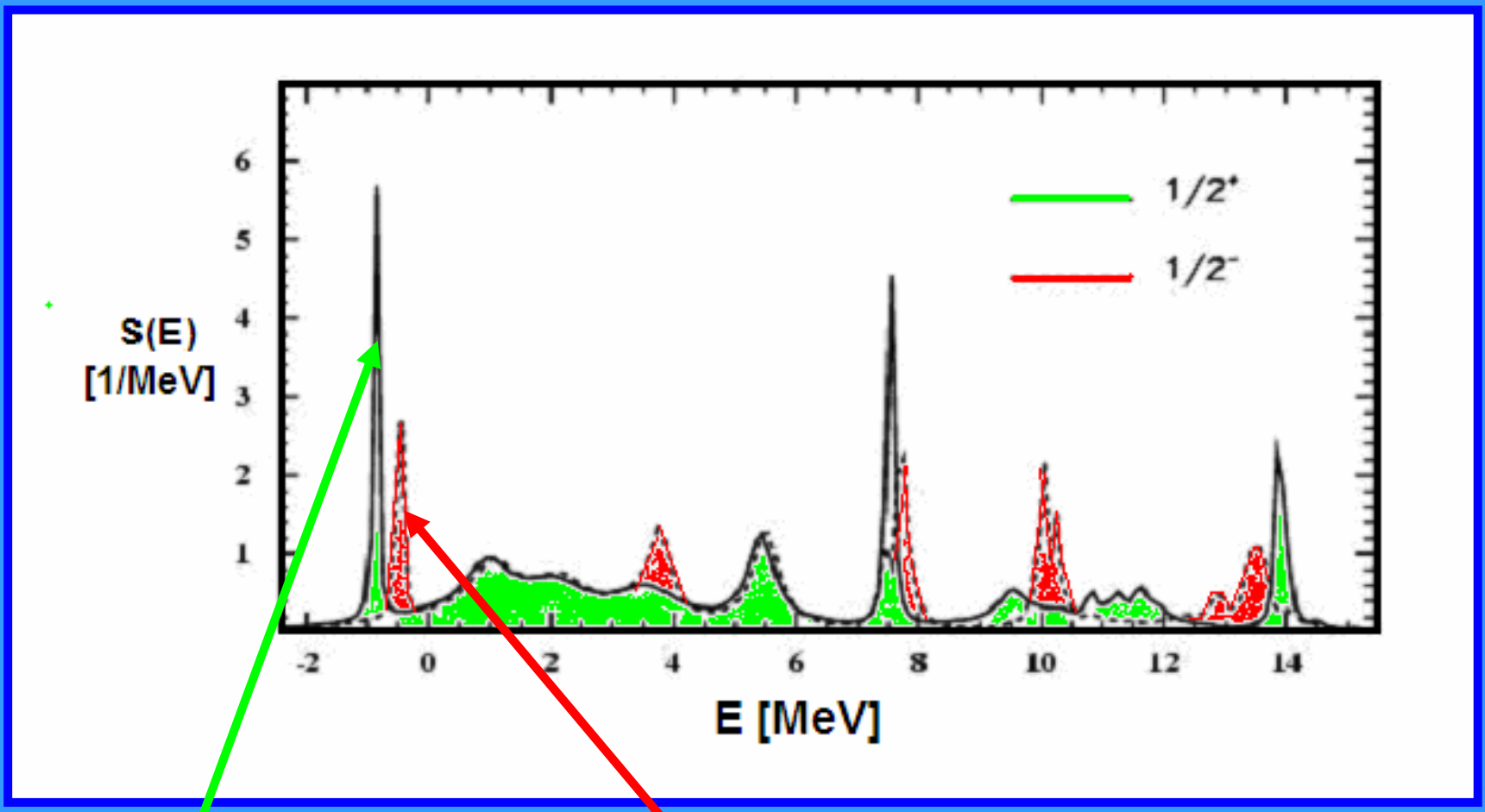
S = 0.97

QRPA Response in ^{10}Be



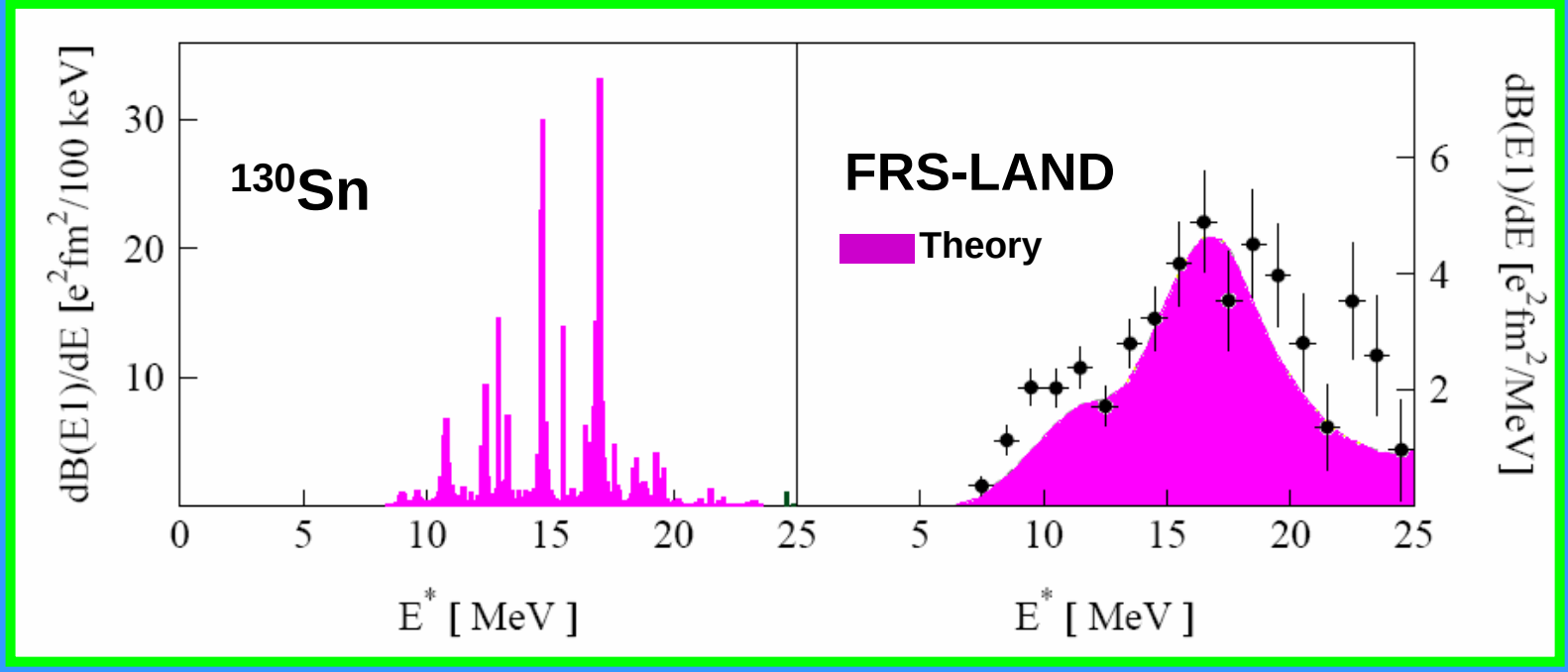
	E_{th} [MeV]	E_{exp} [MeV]
2^+	3.220	3.368
1^-	6.423	5.960
0^+	6.513	6.179
2^-	6.446	6.263
3^-	7.372	7.371
4-		(9.270)
1^+	7.122	
3^+	7.159	
0^-	7.374	

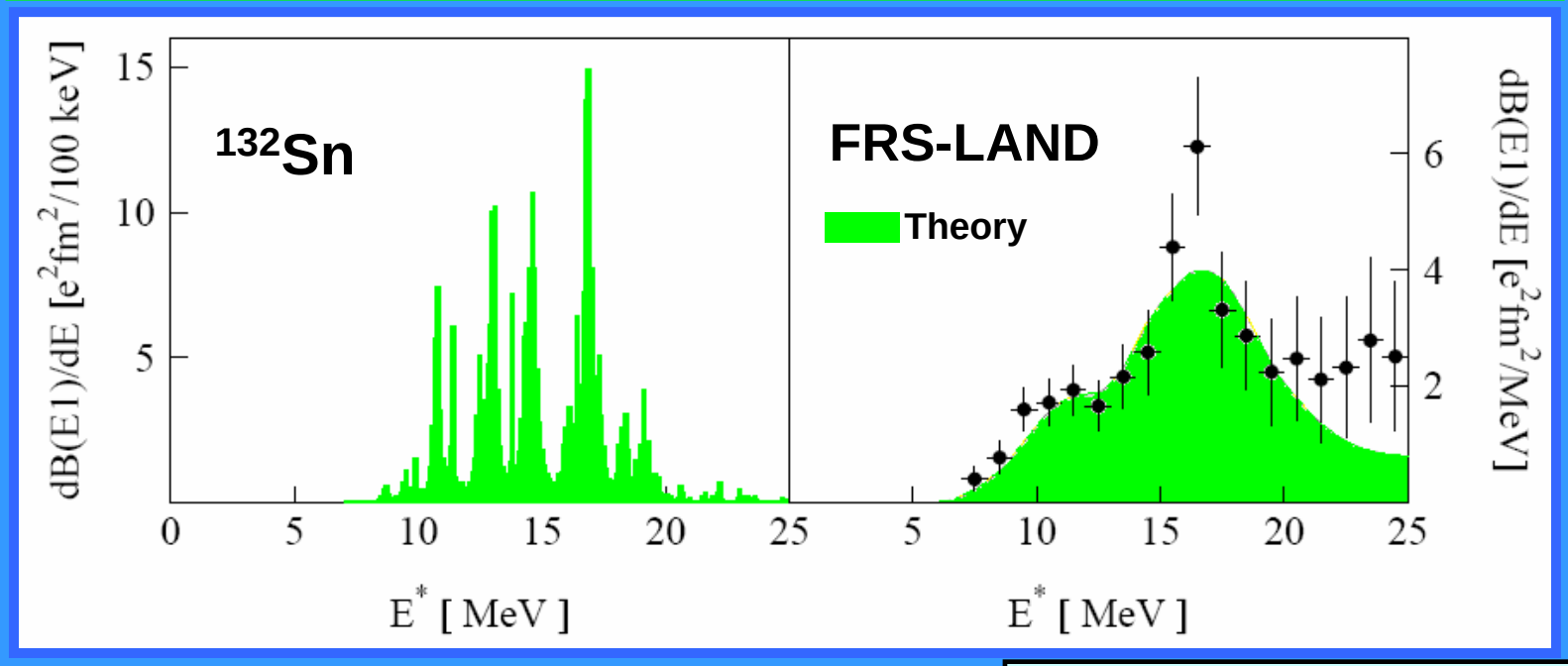
DCP Neutron Spectral Distributions in ^{10}Be



[$0^+ \times 1/2+$]: 0.79
[$2^+ \times 5/2+$]: 0.18

[$0^+ \times 1/2-$]: 0.58
[$2^+ \times 3/2-$]: 0.28





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Summary and Outlook:

- *ab initio* description of stable and unstable Nuclei
- Pairing in the Continuum
- Halos and Skins
- New Modes
- Dynamical Correlations and Shell Structures
- Reactions on Exotic Nuclei
- Neutron Star Matter and Neutron Stars

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