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Structure Study of Light Hypernuclei in AMD

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1. Introduction
2. AMD with Double Parity Projection
3. Results: ${}^{9}_{\Lambda}$Be, ${}^{13}_{\Lambda}$C, and ${}^{12}_{\Lambda}$C
4. Summary

⋆ Introduction: Recent Developments in Hypernuclear Spectroscopy

- High Resolution Experiments
  - ⋆ (π^+, K^+) Reaction $\Delta E < 2$ MeV
  - ⋆ γ ray with Ge array $\Delta E \sim$ keV

Fine Structures, Core Exc.

- Good YN Int & Precise Calc.
  - ⋆ Nijmegen vs Quark Model
  - ⋆ G-matrix
  - ⋆ Three-Body Corr. in OPEN shell core
  - ⋆ Three-, Four-Body Calc.

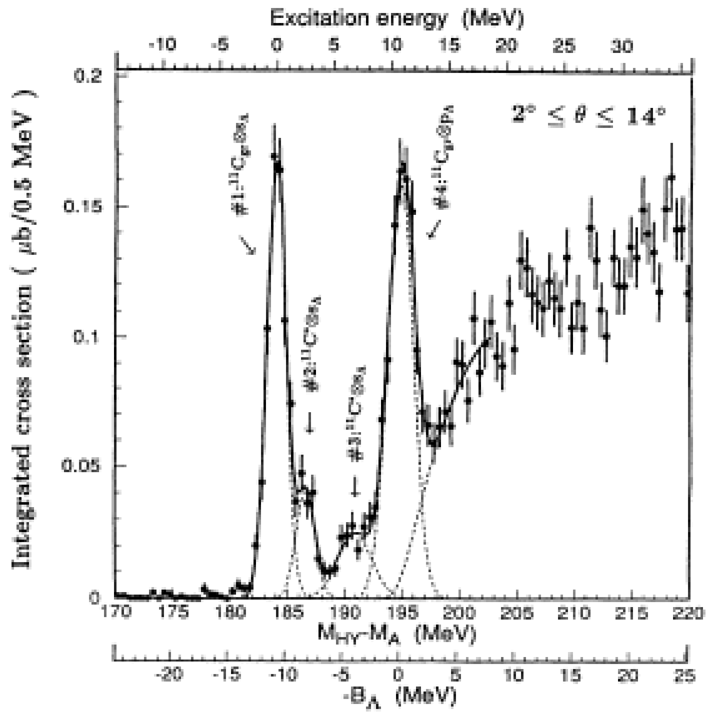


FIG. 2. Excitation spectrum of $^{12}_{\Lambda}$C observed in the (π^+, K^+) reaction at $p_\pi = 1.06$ GeV/c using the SKS spectrometer. The vertical scale gives a cross section integrated from 2 to 14 deg after correcting the angular dependence of the spectrometer acceptance. The energy resolution is better than 2.0 MeV.

T.Hasegawa et al.,
Phys. Rev. Lett. **74**, 224 (1995)

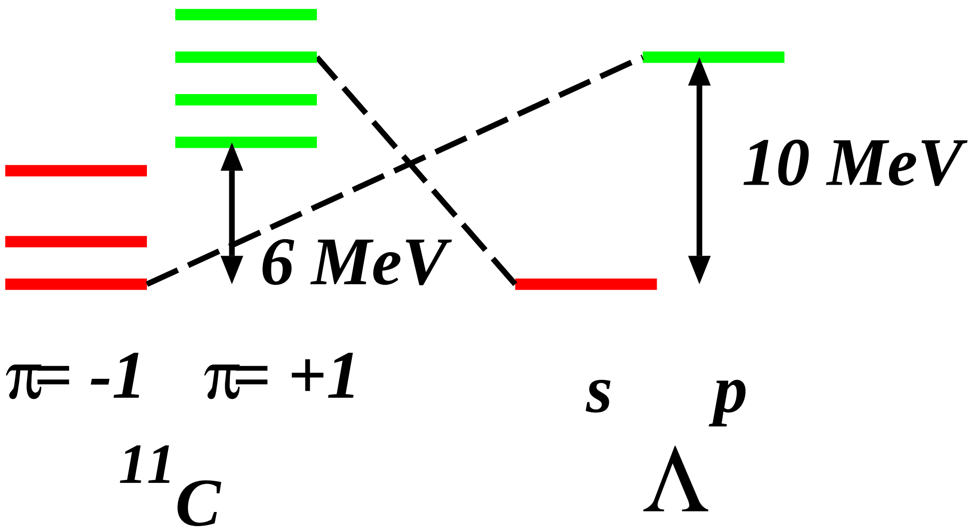
⋆ New Roles of Hyperon

- ⋆ Λ Modifies Core,
- ⋆ Λ Shrinks Core,
- ⋆ Λ sp Exc. Couples to Core Exc.,
- ⋆ Λ Mixes with Σ,
- ⋆ Λ and Σ Softens EOS,
- ⋆ ....

☞ One Typical Role, ..

Parity Mixing Intershell Coupling

T. Motoba, Nucl. Phys. **A 639** (1998) 135



Parities of Core and Λ themselves are NOT Good Quantum Numbers.

☞ Reflection Asymmetric Intrinsic State in Spin-Isospin Unsaturated System.

⋆ Antisymmetrized Molecular Dynamics (AMD)

... Intrinsic System is not necessarily spherical.

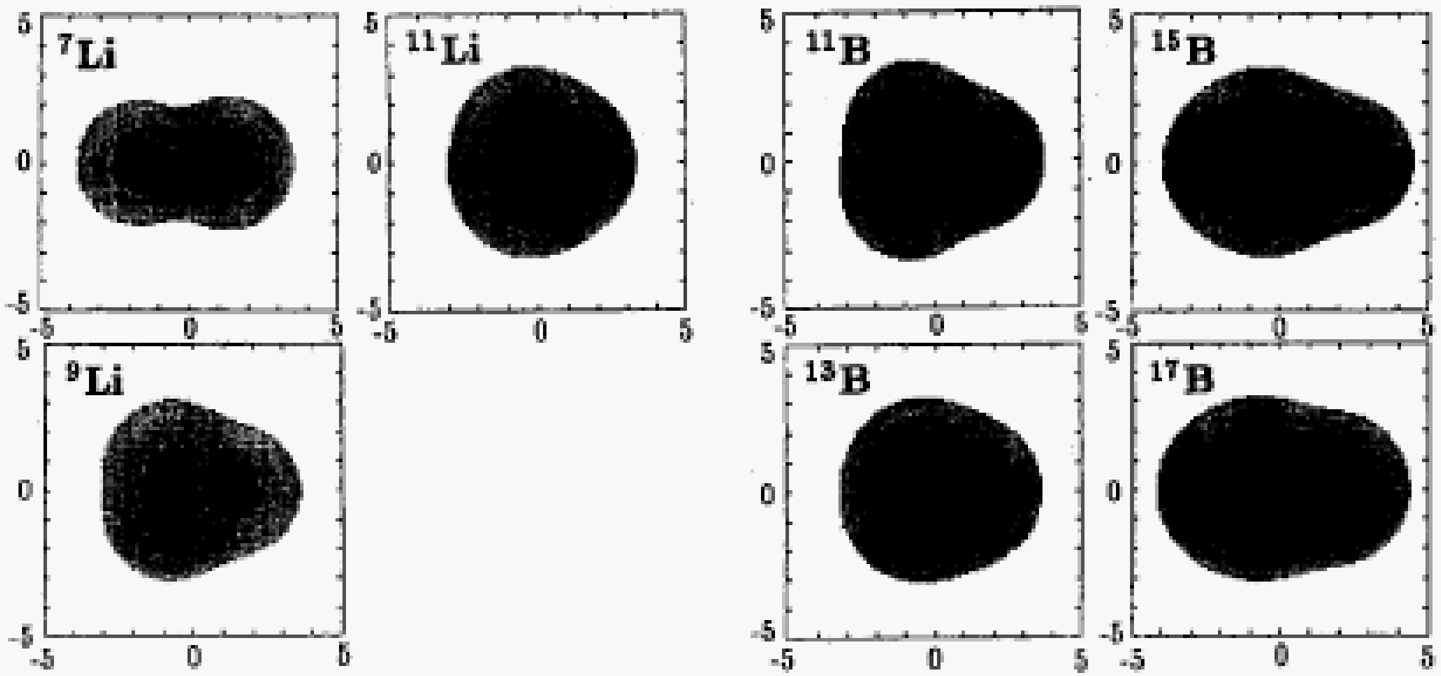


Fig.5 Density distributions of Li and B isotopes given by AMD.

H. Horiuchi and Y. Kanada-En'yo, Nucl. Phys. A 588,121(1995)

- AMD Study of Hypernuclei and Strange Systems

⋆ Slater Determinant of Baryon Gaussian Wave Packets

○ No Model Assumption on Shape and Clustering

○ Cluster/Shell Structure Change

○ Feasibility of Parity Projected Cooling
→ Reflection Asymmetry is not artificially suppressed in Intrinsic State

○ Feasibility of J^π Projection

○ Good Transition Matrix Elements (jj vs LS Coupling of Spin)

× Parities of Core and Λ are not separately projected
↔ MO by Itagaki-Okabe-Ikeda/ Double J^π Proj. by Descouvemont et al.

× Numerical J^π Proj. → Accuracy in Excitation Energies

× Single Particle Wave Function is Gaussian, and Nodes are generated by Antisymmetrization
→ No Nodes of Λ wf in Single Hypernuclei
↔ Dote-Akaishi-Horiuchi

× High CPU Cost

- Previous Applications of AMD to Strangeness Nuclear Physics

  ⋆ Hyperfragment Formation from Stopped K^-
  (Nara, Ohnishi, Harada, 1995)

  ⋆ Single/Twin/Double Hyperfragment Formation from Stopped Ξ^-
  (Hirata, Nara, Ohnishi, Harada, Randrup, 1999)

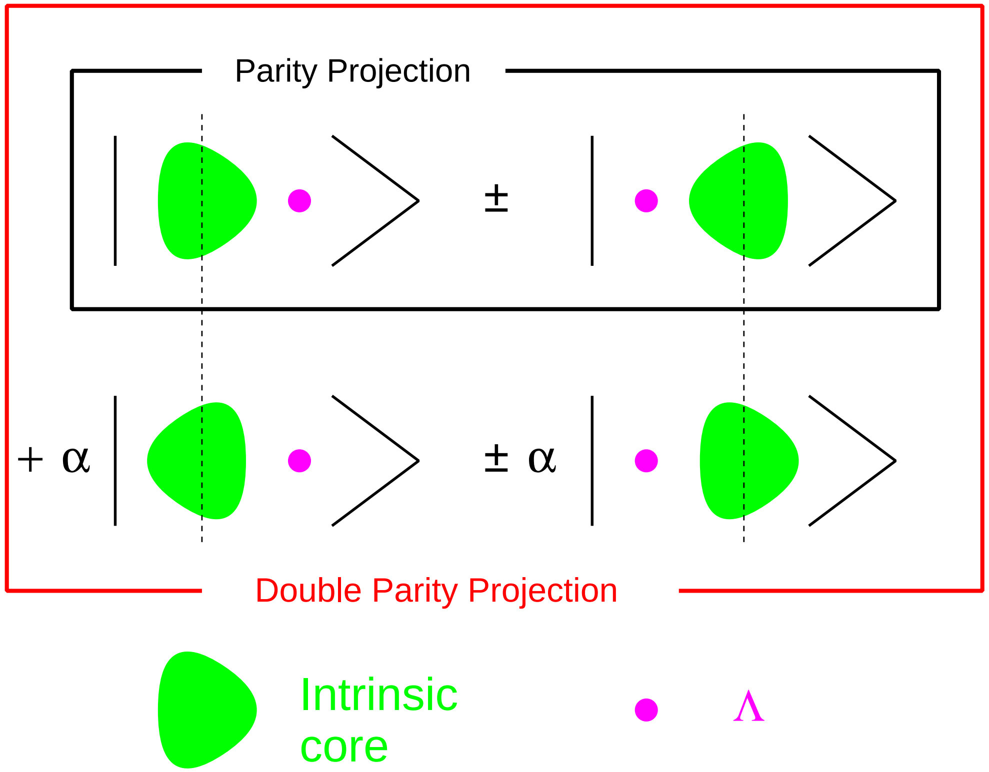
  ⋆ Kaon Implanted Nuclei
  (Dote, Akaishi, Horiuchi)

→ No Study on "Excitation Levels"

In this work, We study
Hypernuclear Excitation Spectra in AMD
with Double Parity Projection
of Core and the Total System.

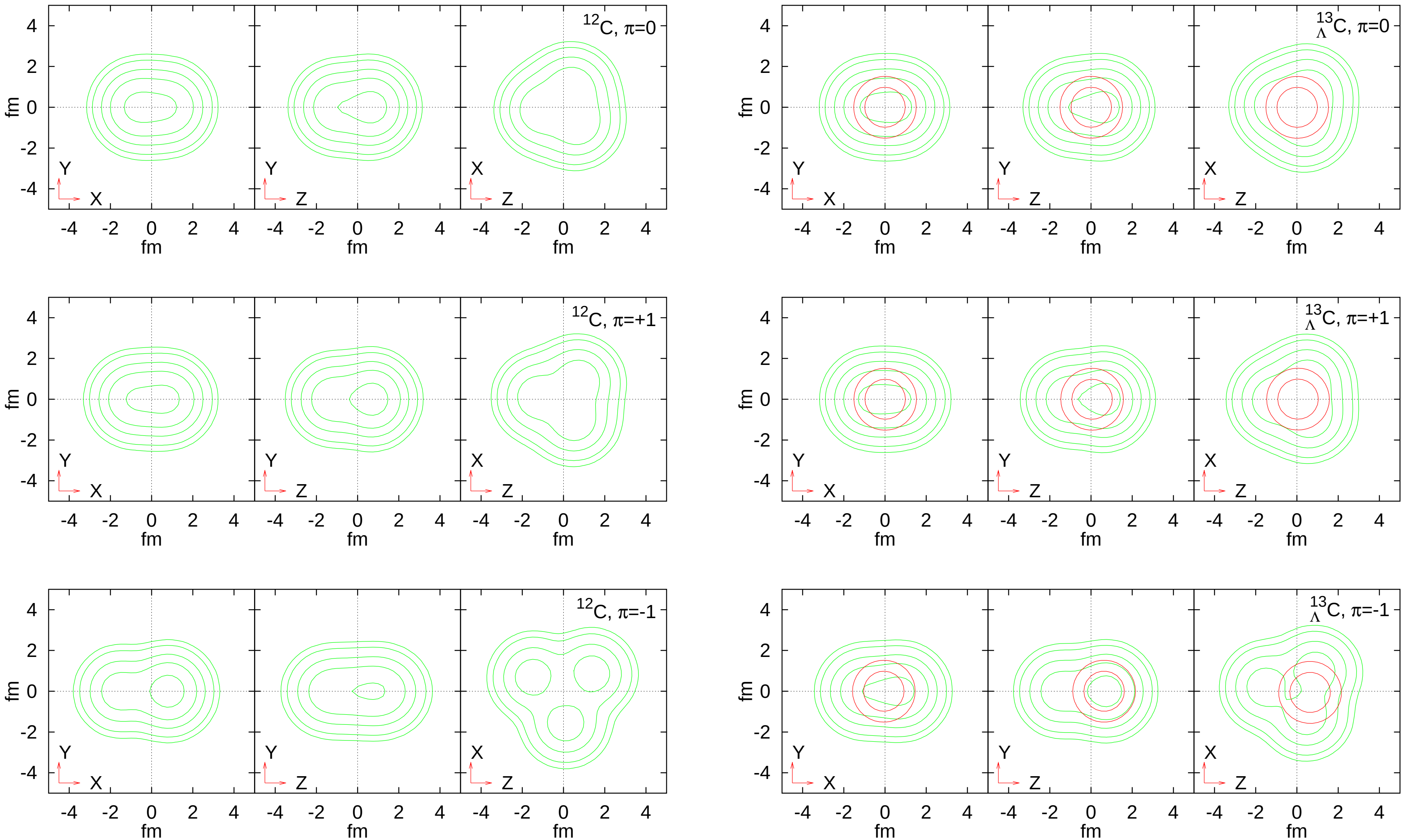
⋆ AMD with Double Parity Projection

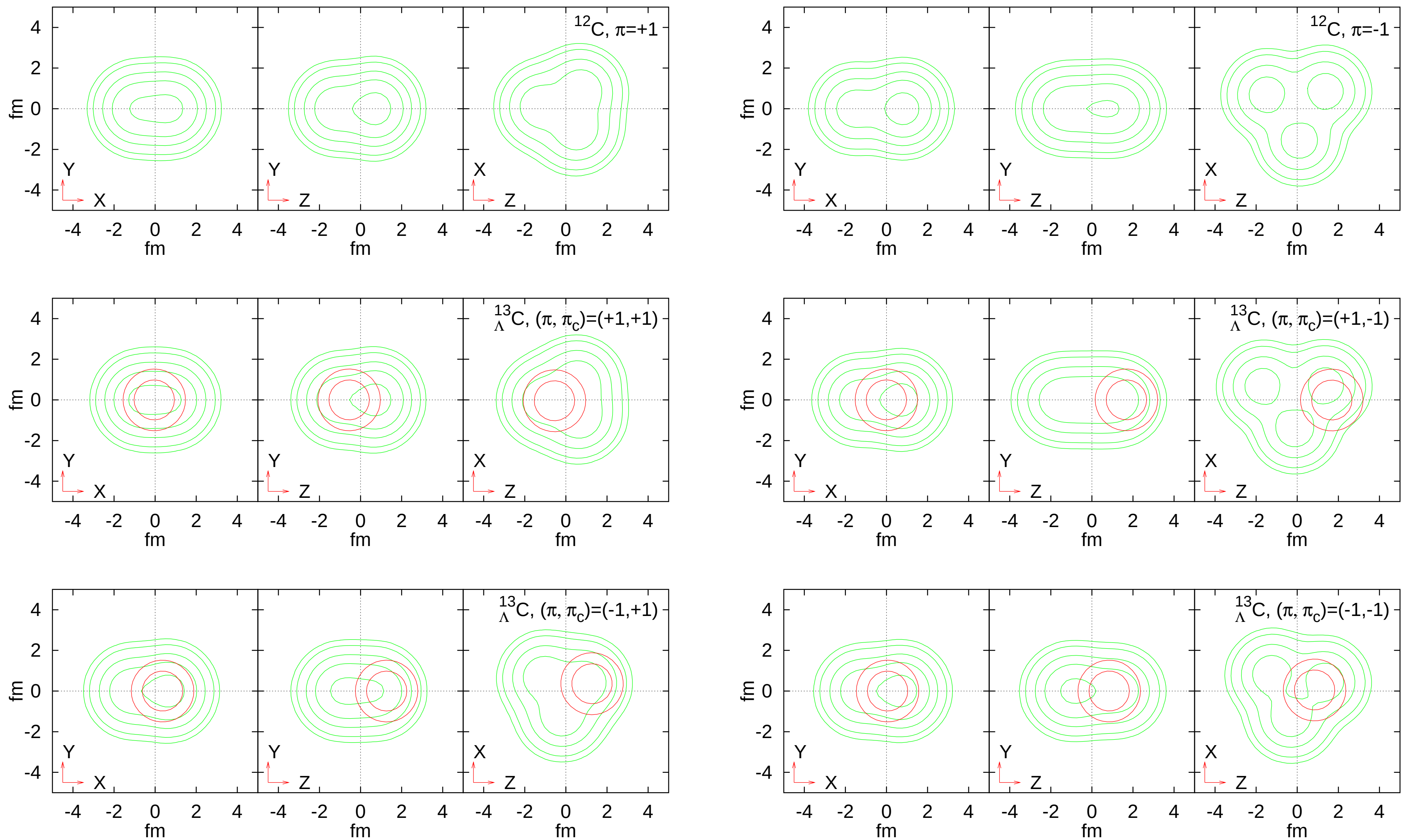
$$|\Psi> = |\Psi_{core}(Z)> \otimes|\psi_\Lambda(z)> +\pi|\Psi_{core}(-Z)> \otimes|\psi_\Lambda(-z)>$$
$$+ \pi_c|\Psi_{core}(-Z)> \otimes|\psi_\Lambda(z)> +\pi\pi_c|\Psi_{core}(Z)> \otimes|\psi_\Lambda(-z)>$$



⋆ Parities of
Core and the Total System
is Projected by Adding
the Core Reflected States
before Variation (Cooling).
→ Λ Parity is projected automatically.

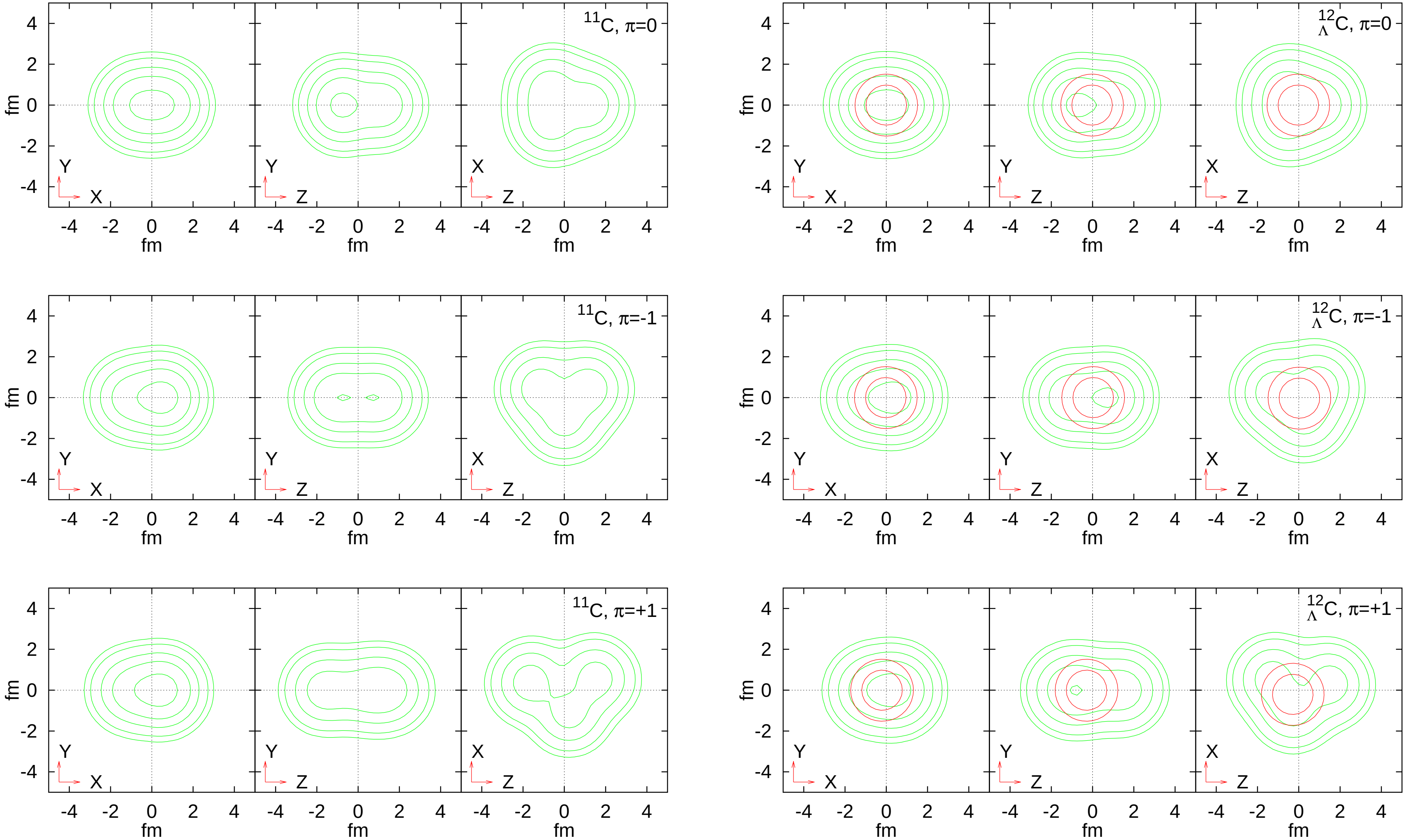
- **Densities: ^{12}C and $^{13}_{\Lambda}$C**

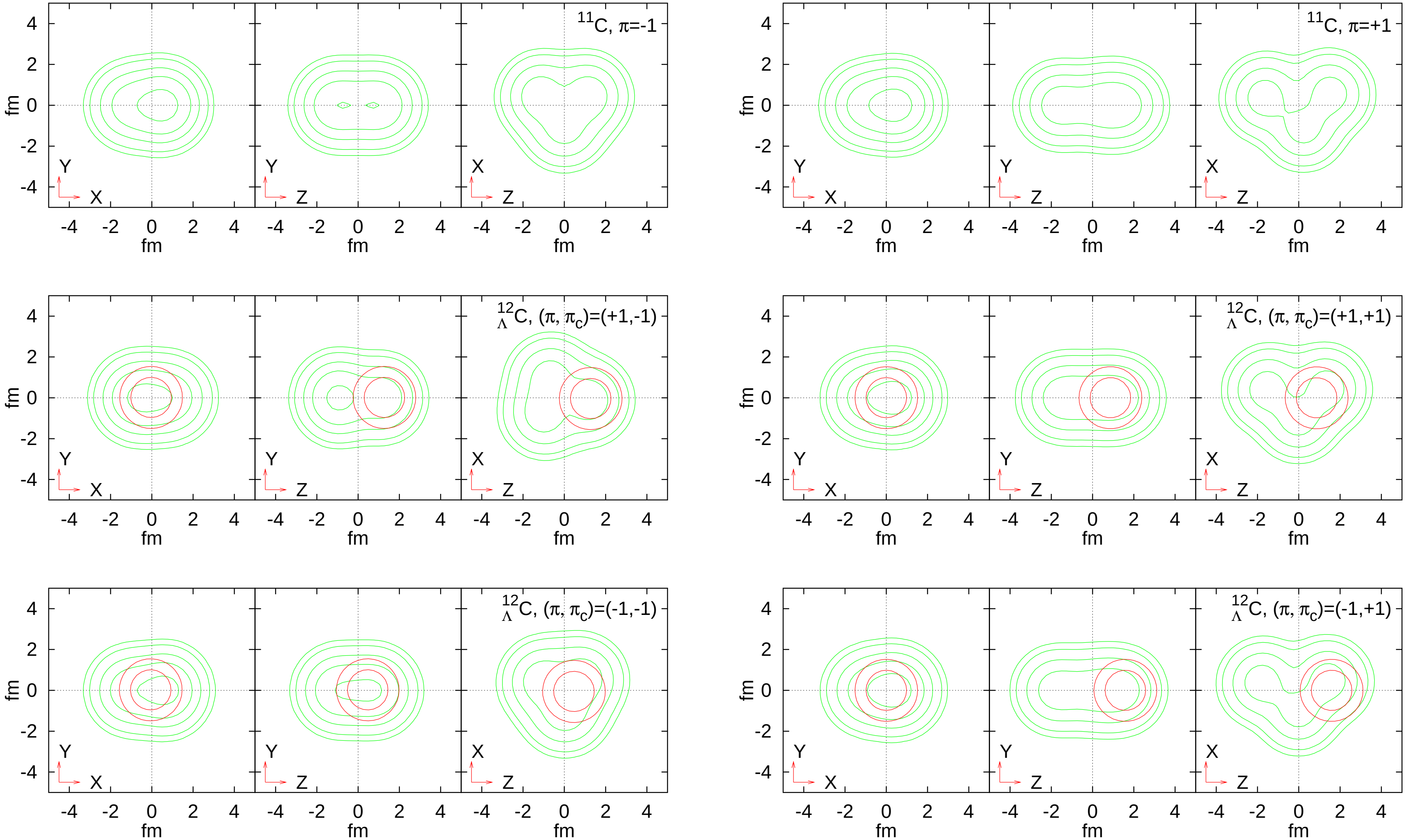




- Usual Parity Projection Mixes Up Core Parity Exc. and p_Λ Exc.
- DPP helps to separate Core Exc. and p_Λ Exc.

- Densities: ^{11}C and $^{12}_{\Lambda}$C





^{11}C, π=-1
^{11}C, π=+1
$^{12}_{\Lambda}$C, (π, π$_c$)=(+1,-1)
$^{12}_{\Lambda}$C, (π, π$_c$)=(+1,+1)
$^{12}_{\Lambda}$C, (π, π$_c$)=(-1,-1)
$^{12}_{\Lambda}$C, (π, π$_c$)=(-1,+1)
fm
Y X
Y Z
X Z

⋆ Results (Preliminary)

- Interactions

  ⋆ NN: Volkov No. 2 (B=H=0.125) & G3RS LS interaction

  ⋆ YN: Central One Range Gauss

- Wave Functions

  ⋆ Single Baryon wf: Gaussian with common ν

  ⋆ Baryon Spins are fixed to have z or $-z$ direction

  ⋆ Superposition of Slater Determinants given with
  Cooling (Parity Non-Projected), Total Parity Projected Cooling,
  and Double Parity Projected Cooling

  ⋆ In Double Parity Projection, following "COREs" are considered.
  ${}^{5}_{\Lambda}$He (${}^{9}_{\Lambda}$Be) / ^{11}C (${}^{12}_{\Lambda}$C) / ^{12}C (${}^{13}_{\Lambda}$C)

  ⋆ Effects of Double Parity Projection is very small in normal nuclei.

- J^{π} Projection

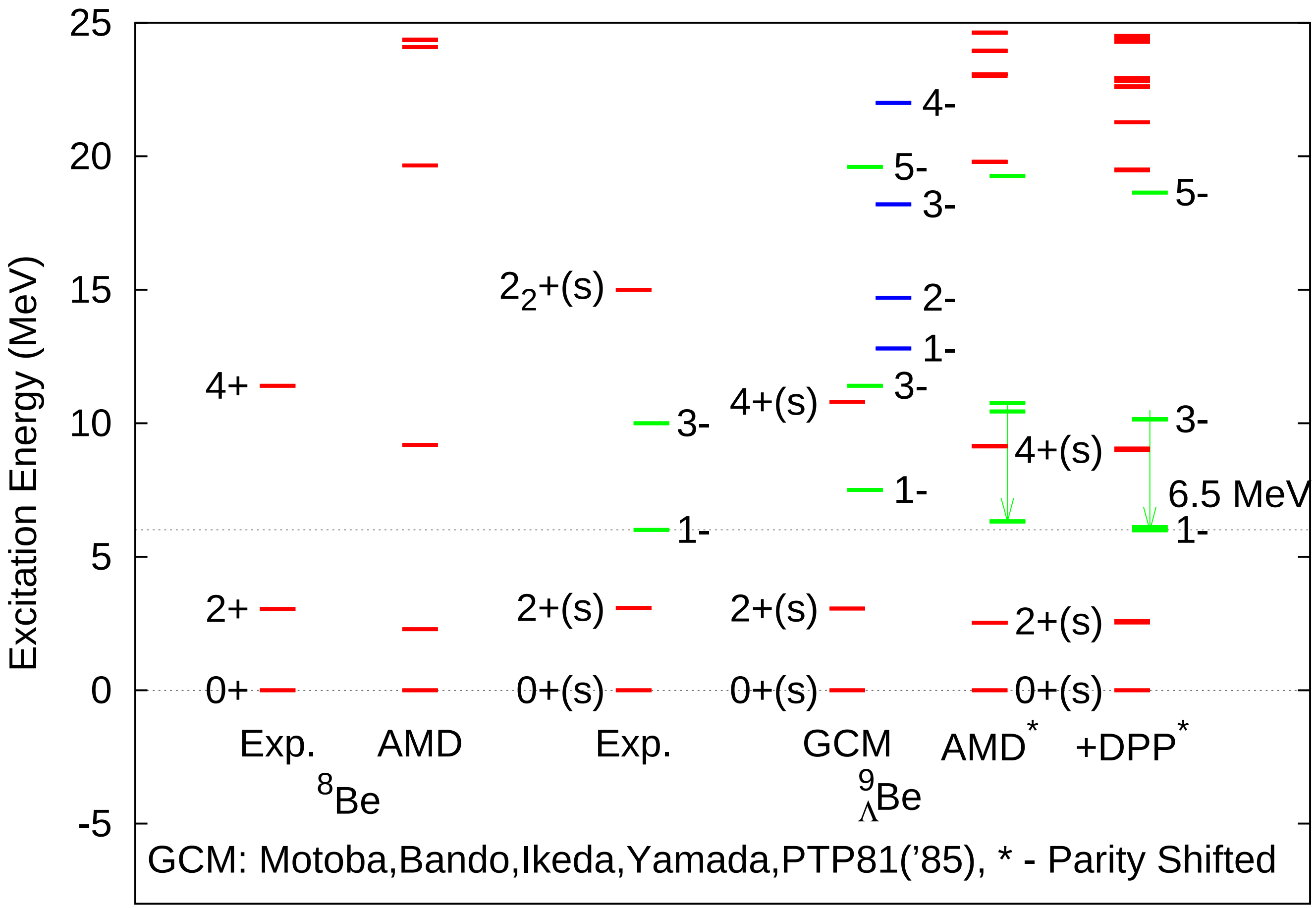
  ⋆ Numerically Performed (12×12×12)

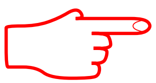
  ⋆ For the same K but different J, D functions are Orthogonalized on the Mesh Points by using the Schmidt Method

				BE(core)		$S(\Lambda)$		
	m	LS	YN	Exp.	AMD	Exp.	AMD	+DPP
^{8}Be, $^{9}_{\Lambda}$Be	0.51	1000	-40	56.5	55.4	6.7	6.4	6.6
^{11}C, $^{12}_{\Lambda}$C	0.56	1100	-40	73.4	71.9	11.2	11.1	11.8
^{12}C, $^{13}_{\Lambda}$C	0.59	1800	-35	92.3	93.0	11.7	10.5	11.2

Notes: No Spin-Dependent YN Int. are included.

- Excitation Spectra (I): $^{9}_{\Lambda}$Be

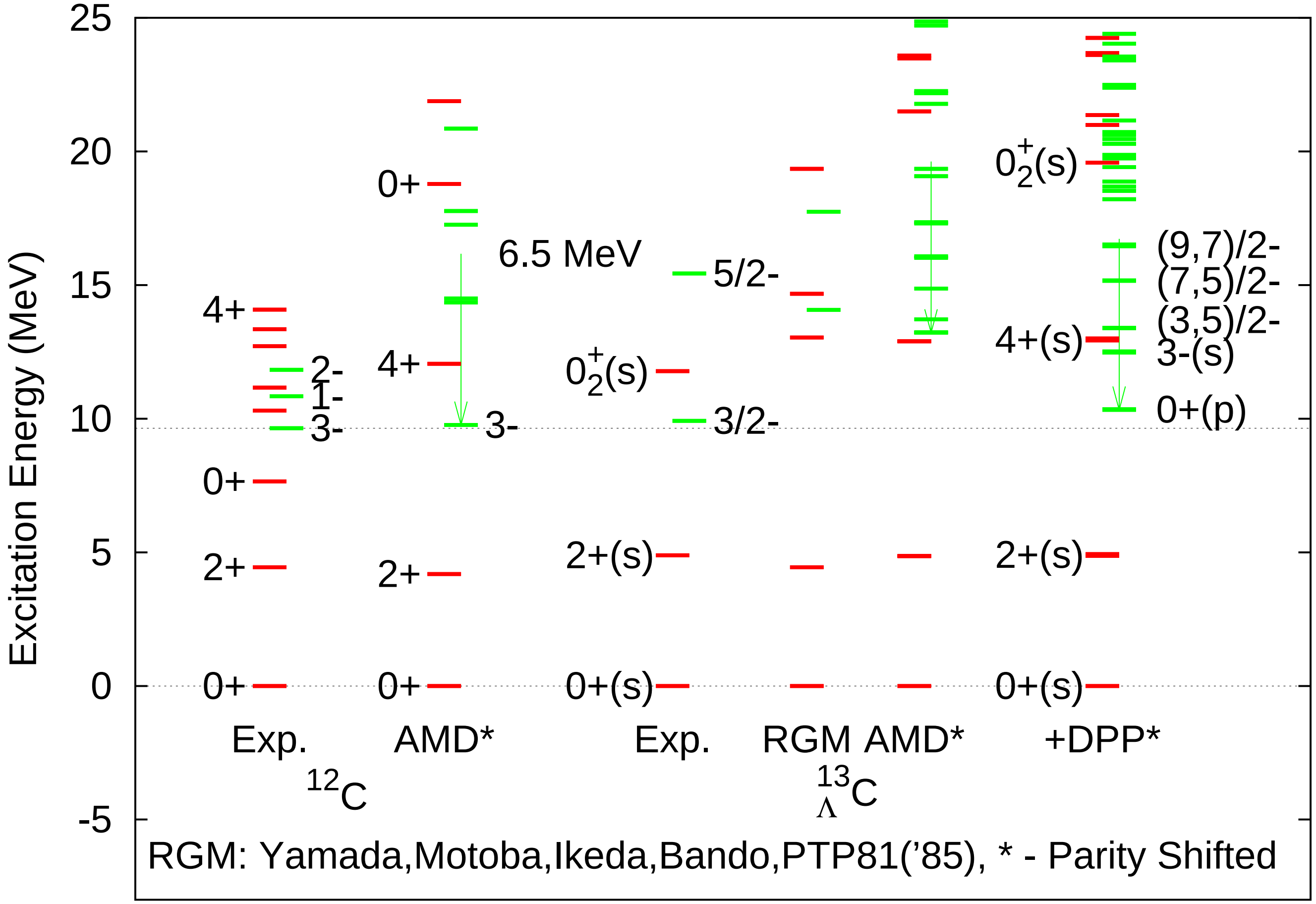




⋆ ^{8}Be core → Already Symmetric → No DPP Effect (not shown)

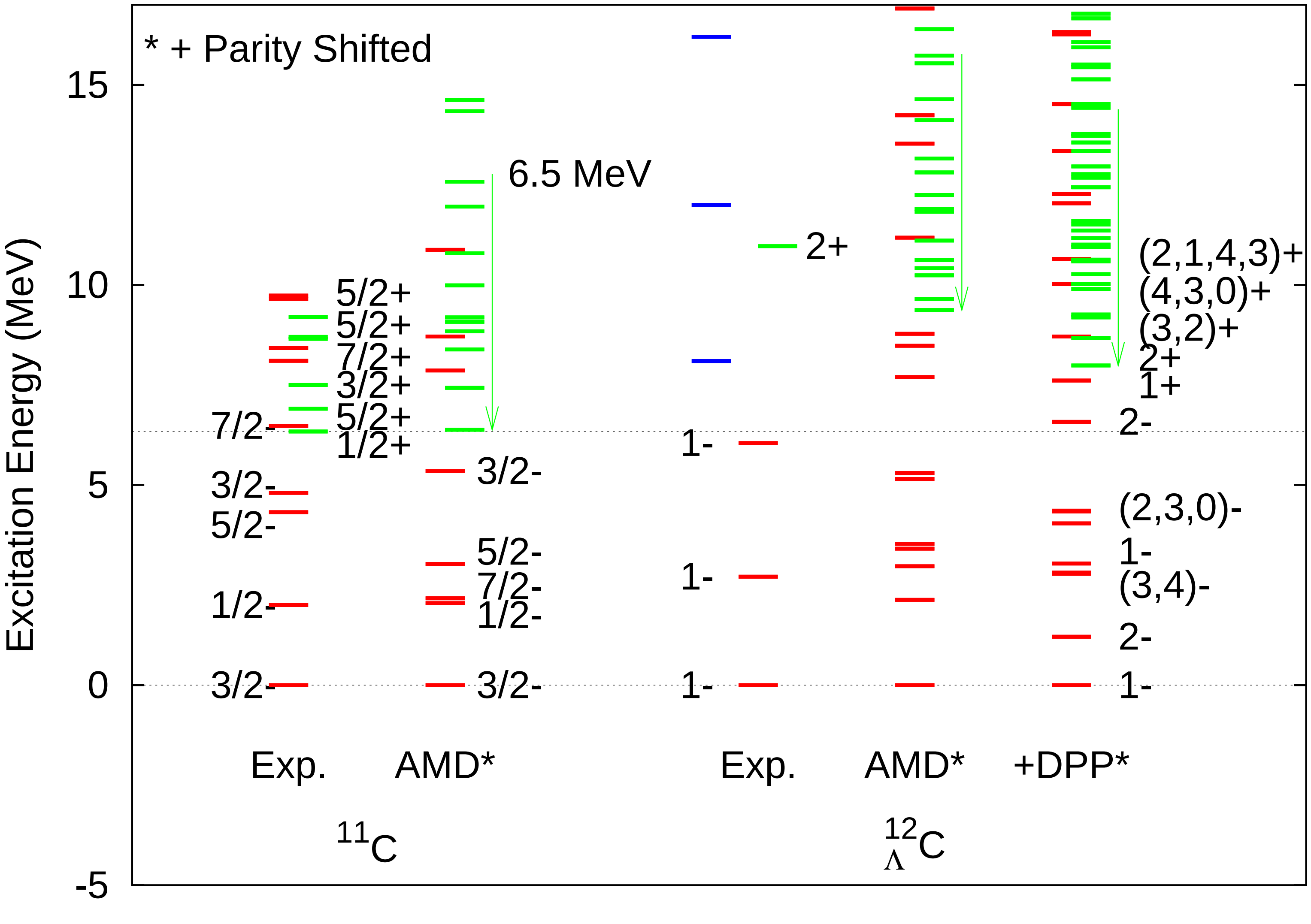
⋆ $^{5}_{\Lambda}$He core → Already Accounted in AMD

- Excitation Spectra (II): $^{13}_{\Lambda}$C



☞ $\star$ ^{12}C core $\rightarrow$ $E^*(3^-) = 9.6$ MeV (Cluster Exc.) $\sim \varepsilon(p_\Lambda)$
$\cdots$ Splitting of Negative Parity States ($E^* \sim 15$ MeV)

- Excitation Spectra (III): $^{12}_{\Lambda}C$



${}^{12}_{\Lambda}$C: ^{11}C core $\rightarrow E^*(\pi = +1) < \varepsilon(p_\Lambda)$

- Negative Parity States
  - ⋆ Coupling of Core Exc. Negative Parity States and Λ Spin
- Positive Parity States
  - ⋆ Core Exc. Pos. Parity States ($E^* = (7-9)$ MeV, s_Λ)
  - ⋆ Possibly, Parity Mixing Intershell Coupling States ($E^* \gtrsim 10$ MeV)

⋆ Summary

⋆ We have developed(?) AMD with Double Parity Projection (DPP).

- ∘ Parities of Core and the Total System is Projected before Variation.
  $\rightarrow \pi(\Lambda)$ is also Projected automatically, then Λ can have a node in the p_Λ state.

⋆ DPP is not effective in normal nuclei, and hypernuclei having (intrinsically) reflection symmetric core.

⋆ For hypernuclei with core nuclei which can be (intrinsically) reflection asymmetric, DPP helps to separate Core Exc. and Single Particle Exc. of Λ.

⋆ In ${}^{13}_{\Lambda}$C, Core$(3^-) \otimes s_\Lambda$ State is expected to appear just above Core$(gs) \otimes p_\Lambda$ State.

⋆ In ${}^{12}_{\Lambda}$C, Core$(\pi = -1) \otimes s_\Lambda$ States are expected to appear at around $E^* = (7-9)$ MeV. $E^* = 11$ MeV State may have core excited components.

⋆ If the Exchange Current (two-body current) is important in (e, e') reaction, Core Excited Hypernuclear States may be formed more abundantly in $(e, e'K^+)$ reactions.

⋆ Detailed Analysis of the w.f. (Intershell Coupling), Extension of wf Space (GCM for core, spwf extension for Λ), Reliable YN Interactions, are necessary.