Two-neutron Decay of ^{16}Be in a Three-body Model

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Direct Reactions with Exotic Beams
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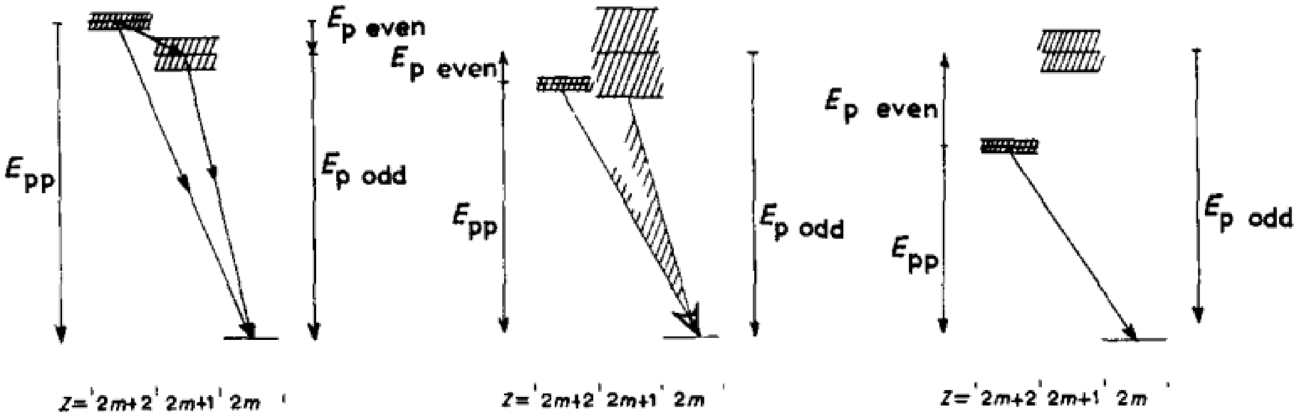
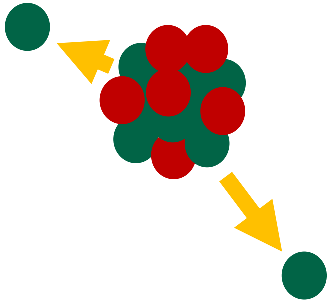
Diproton decay history

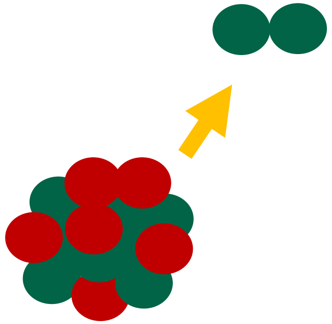
Sequential 2p decay

Diproton decay



V.I. Goldansky, Nucl. Phys. **19** 482 (1960)

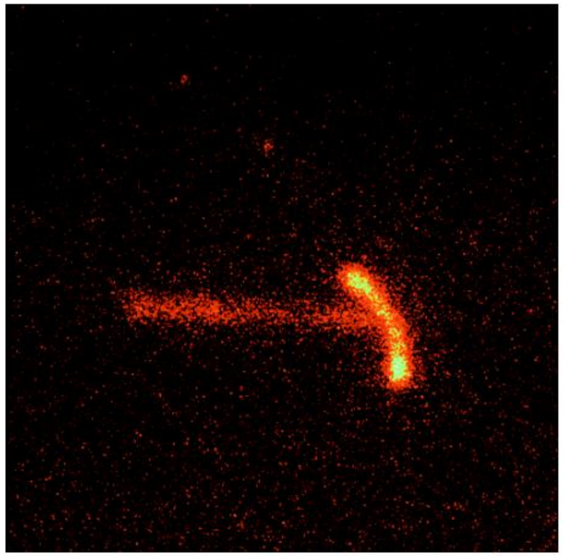




First observation of diproton decay was in ^{45}Fe, independently at both GANIL and GSI

J. Giovinazzo, et. al., PRL **89** 102501 (2002)

M. Pfützner, et. al., Eur. Phys. J A **14** 279 (2002)

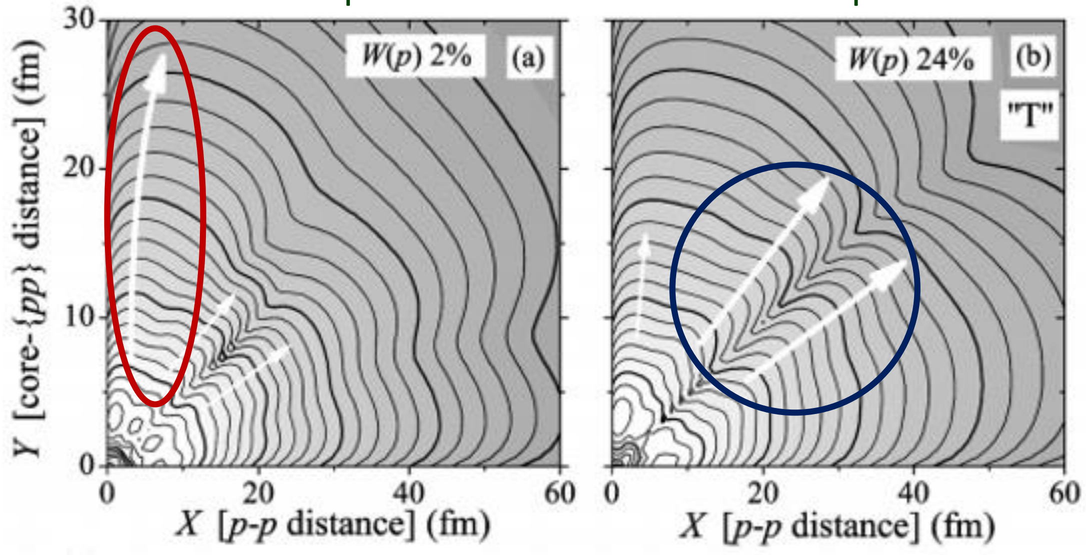


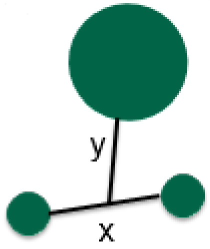
K. Miernik, et. al., PRL **99** 192501 (2007)

Decay models probe internal structure

The decay mode of ^{45}Fe (diproton or three-body) changes based on the underlying composition of the system

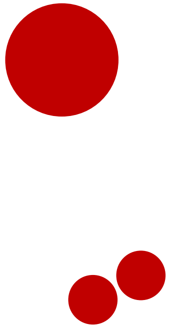
2% p^2 24% p^2

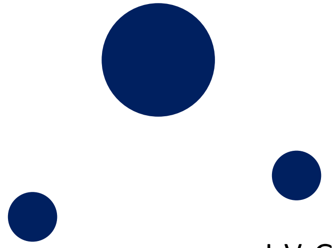




Diproton Decay

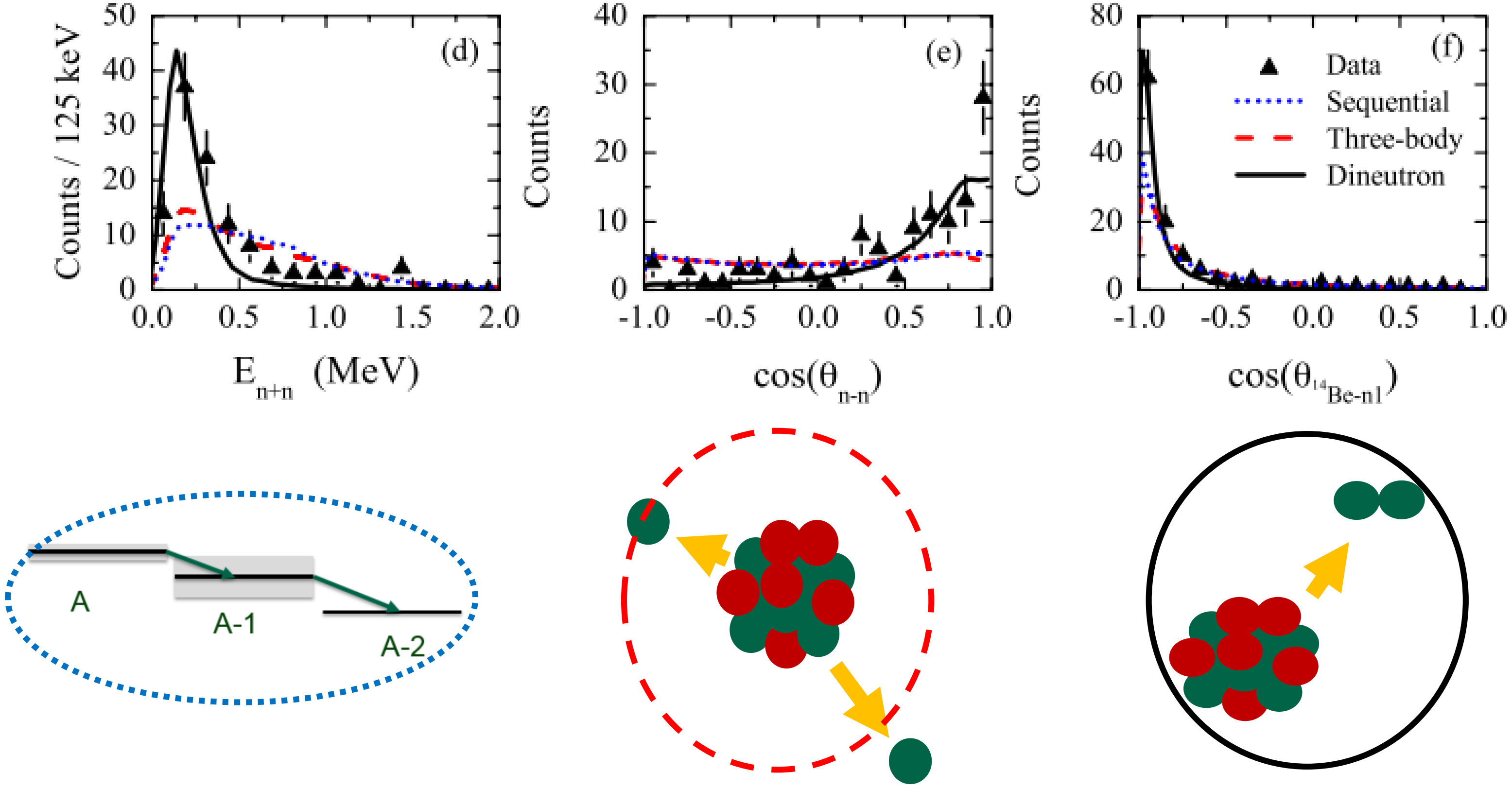
Three-body Decay



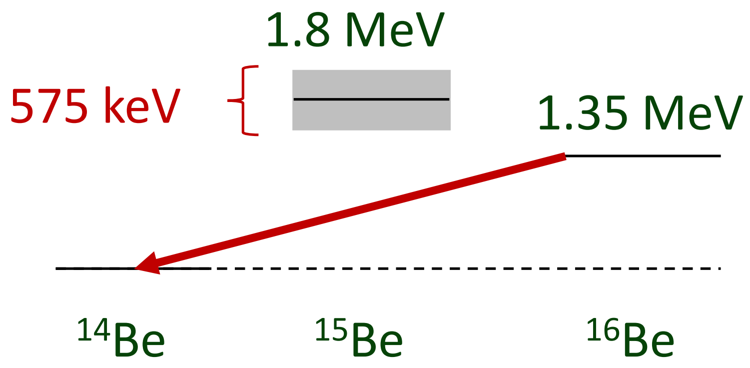


L.V. Grigorenko and M.V. Zhukov, PRC **68** 054005 (2003)

First observation of a dineutron decay, ^{16}Be

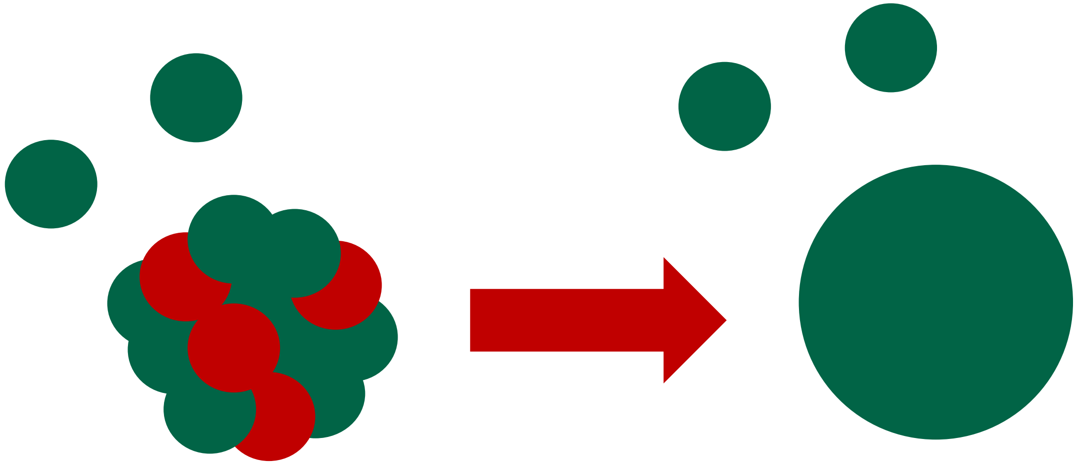


^{16}Be is an ideal candidate for dineutron decay



A. Spyrou, et. al., PRL **108** 102501 (2012)
J. Snyder, et. al., PRC **88** 031303(R) (2013)

Solving the three-body problem

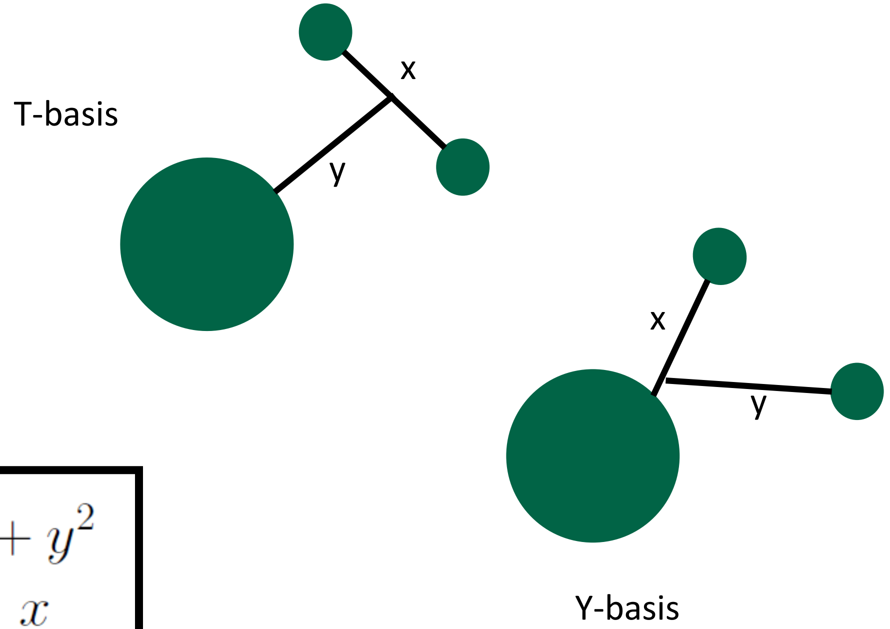


16-body problem

3-body problem

Now we can **exactly model** the degrees of freedom relevant to the decay

Jacobi and Hyperspherical Coordinates



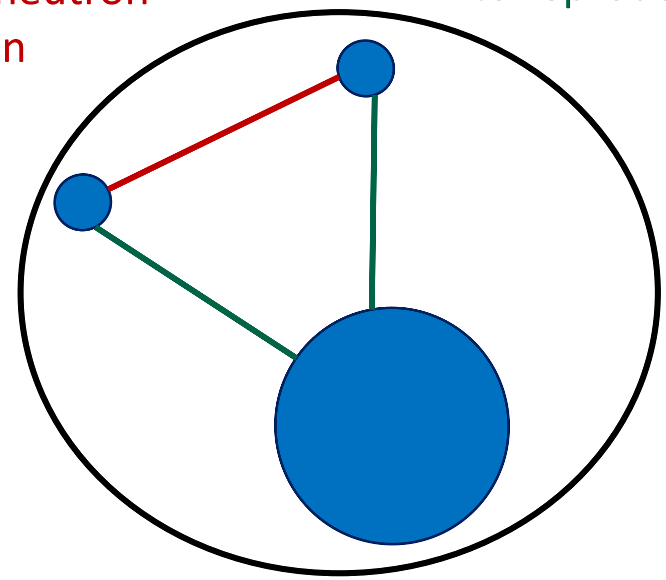
$$\rho^2 = x^2 + y^2$$

$$\tan\theta = \frac{x}{y}$$

Two- and three-body potentials

Neutron-neutron interaction

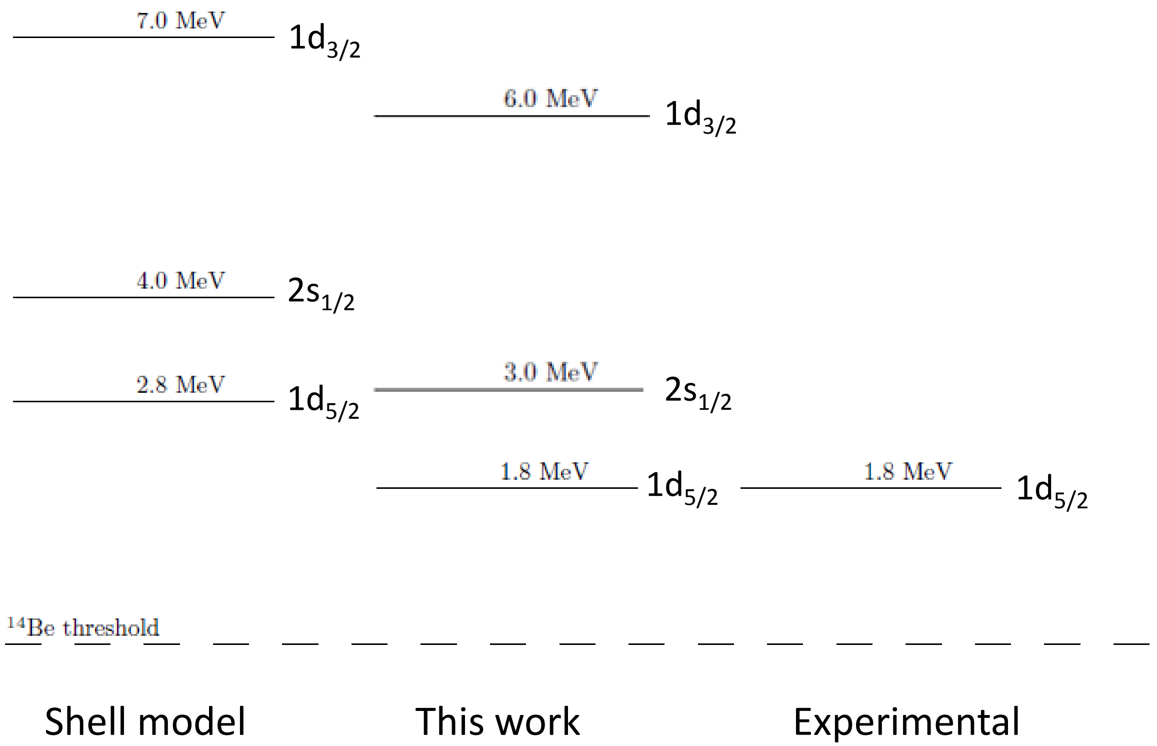
^{14}Be-n interaction to reproduce ^{15}Be



Three-body interaction reproduces the experimental resonance energy, takes into account the degrees of freedom missing in the model

D. Gogny, P. Pires, and R. De Tourreil, Phys. Lett. **32B** 7 (1970)

Structure of ^{15}Be



B.A. Brown, private communication (2013)

J. Snyder, et. al., PRC **88** 031303(R) (2013)

Hyperspherical harmonics basis expansion

$$\gamma = \{l, S, j, I, l_x, l_y\}$$

$$-\frac{\hbar^2}{2\mu}\left[\frac{1}{\rho^5}\frac{\partial}{\partial\rho}\left(\rho^5\frac{\partial}{\partial\rho}\right)+\frac{1}{\rho^2\sin^2 2\theta}\frac{\partial}{\partial\theta}\left(\sin^2 2\theta\frac{\partial}{\partial\theta}\right)-\frac{L_x^2}{\rho^2\sin^2\theta}-\frac{L_y^2}{\rho^2\cos^2\theta}\right]\Psi^{JM}+\sum_{j>i=1}^{3}V_{ij}(\rho\Omega_5\sigma_1\sigma_2\xi)\Psi^{JM}=E\Psi^{JM}$$

The wave function is now separable

$$\Psi^{JM}=\frac{1}{\rho^{5/2}}\sum_{K\gamma}\chi^J_{K\gamma}(\rho)\mathcal{Y}^{JM}_{K\gamma}(\Omega_5\sigma_1\sigma_2\xi)$$

We have an eigenfunction of the angular part of the Hamiltonian

$$\mathcal{Y}^{JM}_{K\gamma}(\Omega_5\sigma_1\sigma_2\xi)=\varphi_K^{l_x l_y}(\theta)\left\{\left([Y_{l_x}\otimes Y_{l_y}]_\ell\otimes[X_{\sigma_1}\otimes X_{\sigma_2}]_S\right)_j\otimes\phi_I\right\}_{JM}$$

$$\left(-\frac{\hbar^2}{2m}\left[\frac{d^2}{d\rho^2}-\frac{(K+\frac{3}{2})(K+\frac{5}{2})}{\rho^2}\right]-E\right)\chi^J_\gamma(\rho)+\sum_{\gamma'}V_{\gamma\gamma'}(\rho)\chi^J_{\gamma'}(\rho)=0$$

Only have a radial equation to solve for each value of K

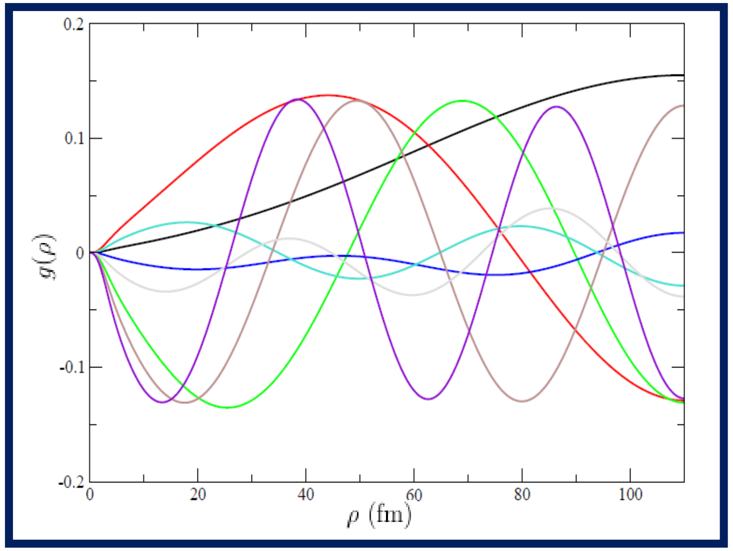
Using scattering boundary conditions: $\chi^L_{\gamma\gamma_i}(\kappa\rho)\rightarrow\frac{i}{2}\left[\delta_{\gamma\gamma_i}H^-_{K+3/2}(0,\kappa\rho)-\boldsymbol{S}^L_{\gamma\gamma_i}H^+_{K+3/2}(0,\kappa\rho)\right]$

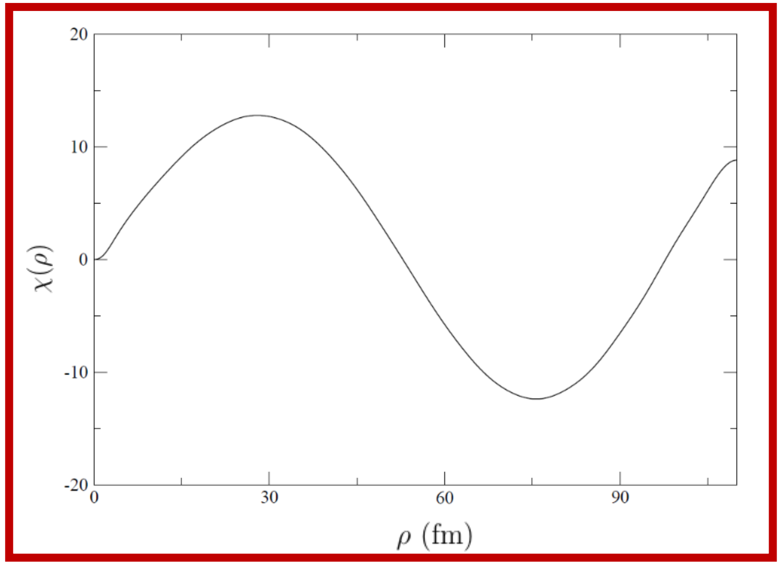
I.J. Thompson and F.M. Nunes, *Nuclear Reactions for Astrophysics*, (Cambridge University Press, Cambridge, 2009)

Hypersperical R-matrix method

$$\beta = \frac{w'(a)}{w(a)}$$

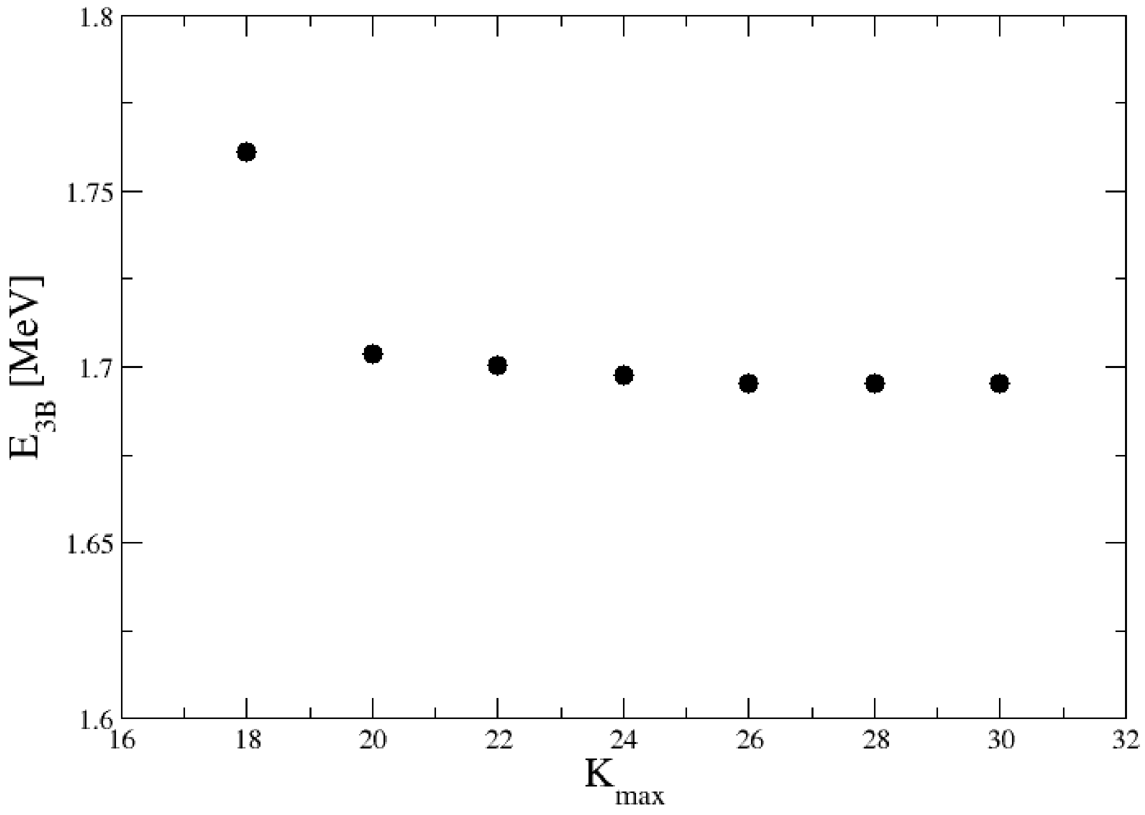
- To solve the hyperspherical radial equation:
  - Solve the uncoupled problem in a box, size *a*
  - Creates an orthogonal basis inside of the box by fixing the logarithmic derivatives at the boundary of the box
  - Solve the coupled scattering problem in the box
  - Match to the scattering solution outside of the box





I.J. Thompson and F.M. Nunes, *Nuclear Reactions for Astrophysics*, (Cambridge University Press, Cambridge, 2009)

Convergence of the basis expansion



$$\Psi^{JM} = \frac{1}{\rho^{5/2}} \sum_{K\gamma} \chi^{J}_{K\gamma}(\rho) \mathcal{Y}^{JM}_{K\gamma}(\Omega_5 \sigma_1 \sigma_2 \xi)$$

$$\gamma = \{l, S, j, I, l_x, l_y\}$$

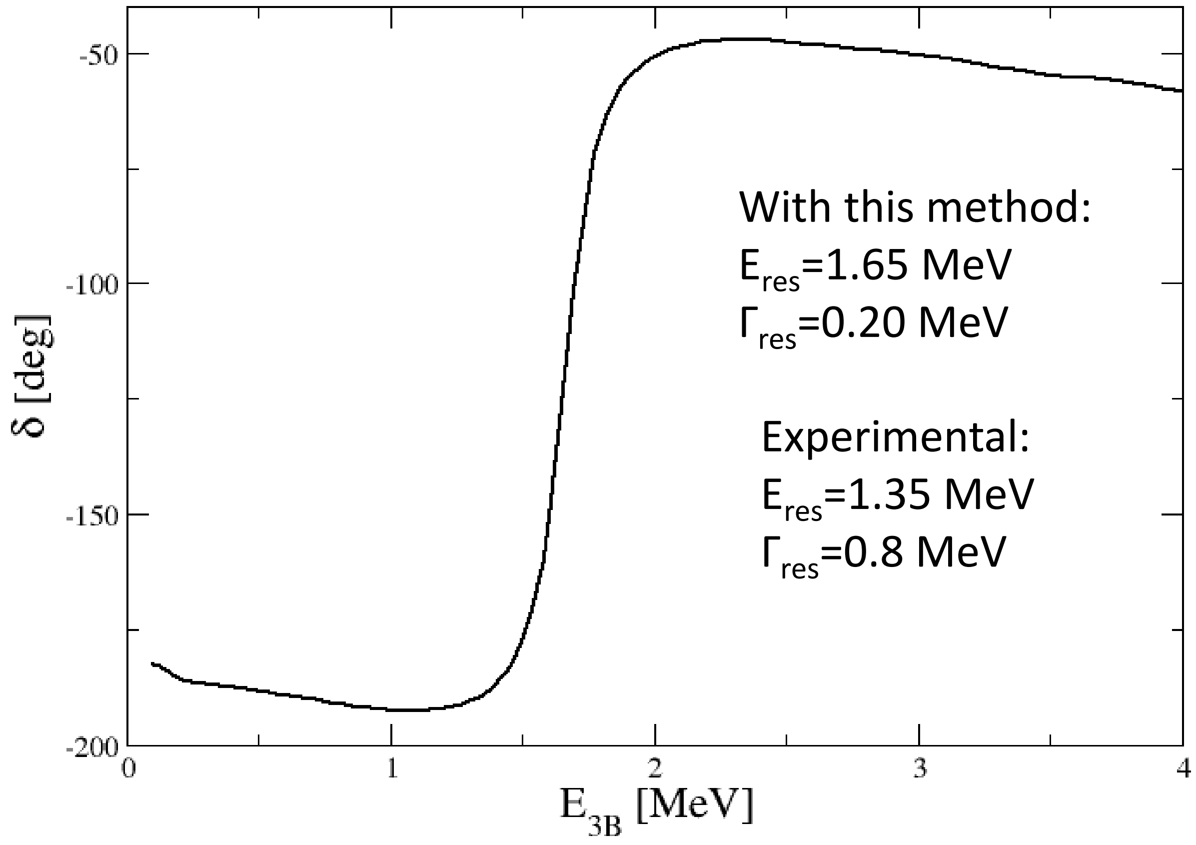
Also need to converge:

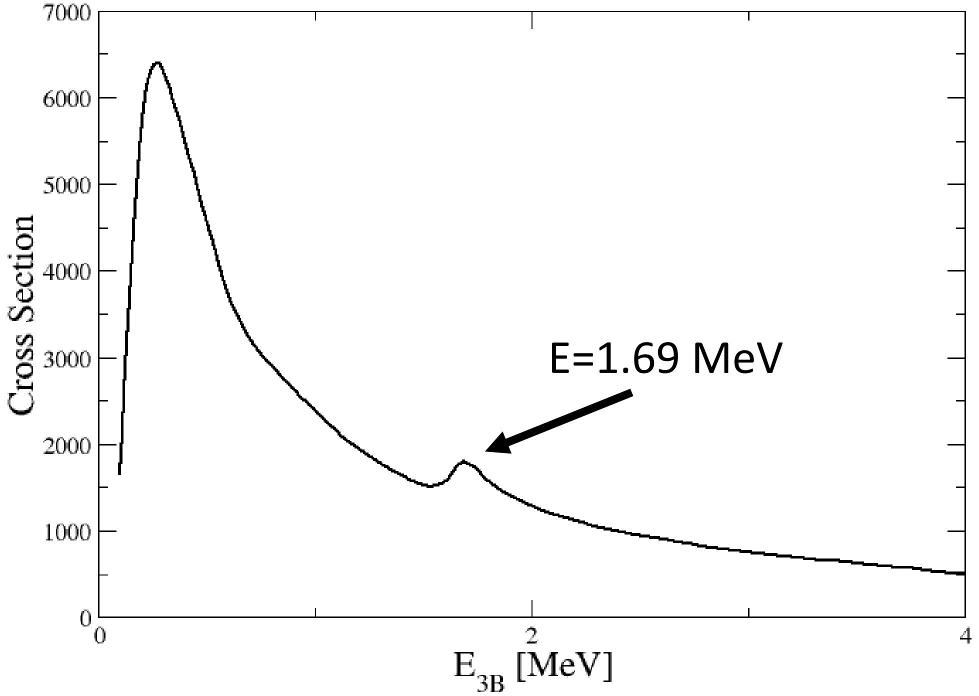
- Number of Jacobi polynomials for hyperangular discretization
- Number of hyperradial basis states, for the R-matrix calculation
- Size of the R-matrix box (depends on the number of hyperradial basis states)

Single channel resonance

After converging the system, we can look at single channel phase shifts to get an idea of the three-body resonance energy and single channel width.

K=0, L=0, lx= 0, ly=0

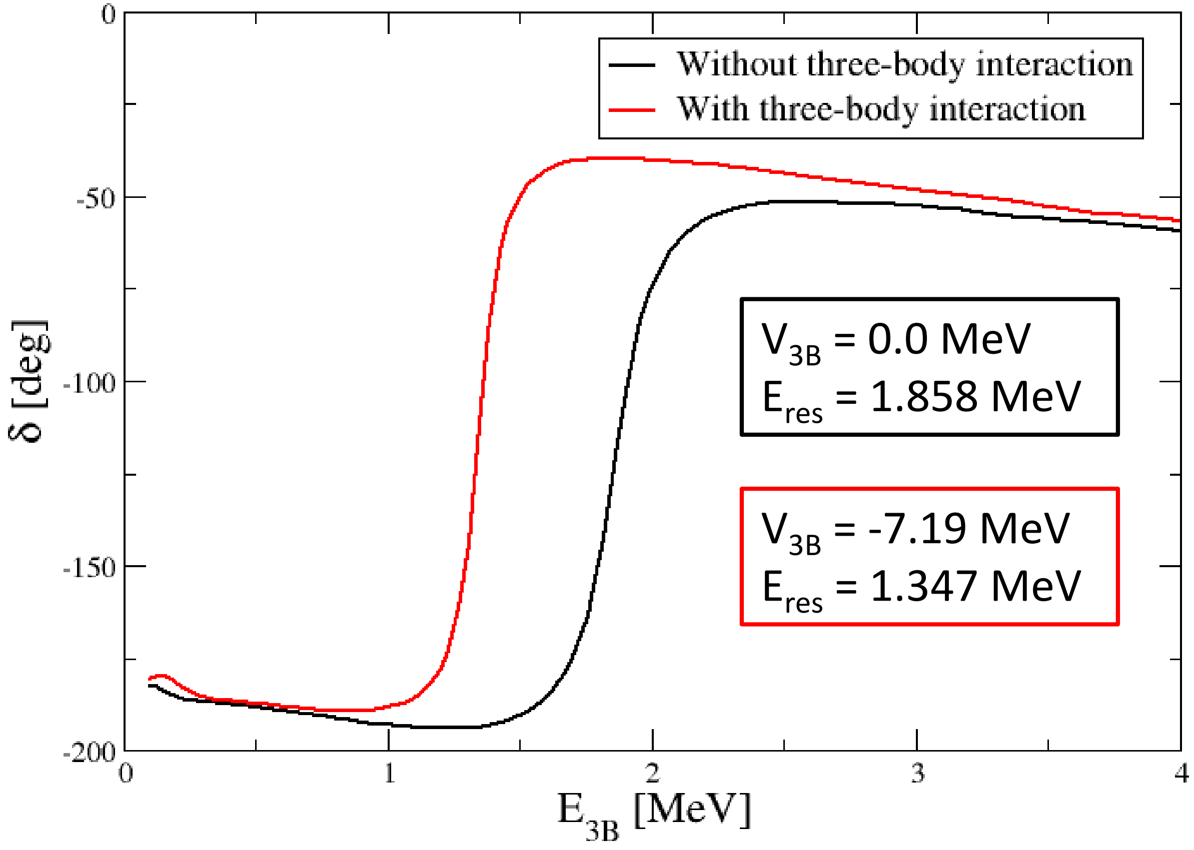




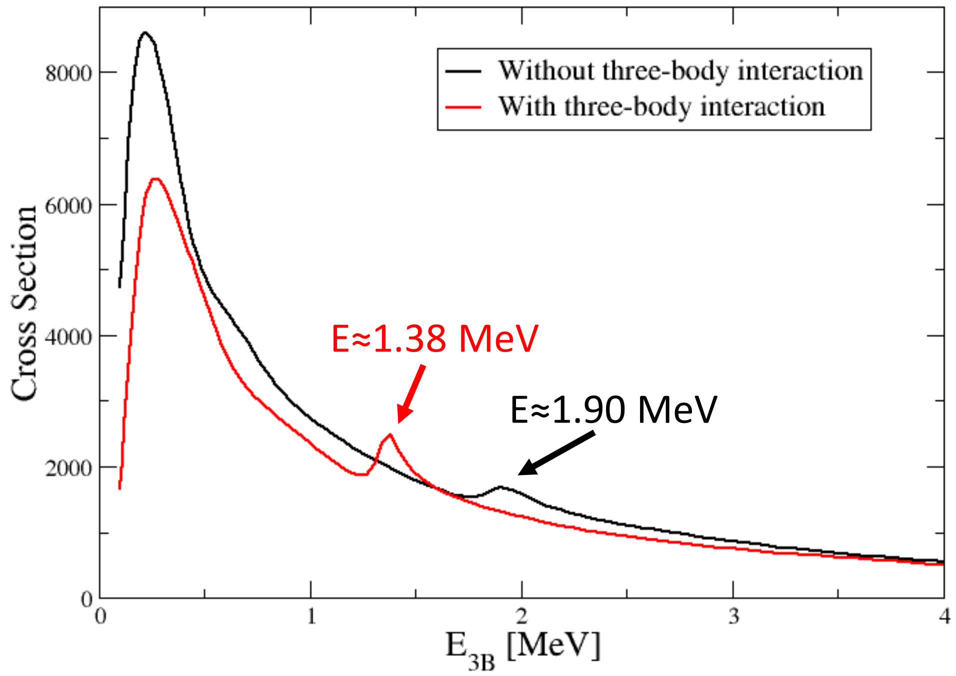
The three-body elastic cross section also indicates the location of the resonance.

Reproducing the experimental resonance energy

K=0, L=0, lx= 0, ly=0 E_{res} (exp) = 1.35 MeV



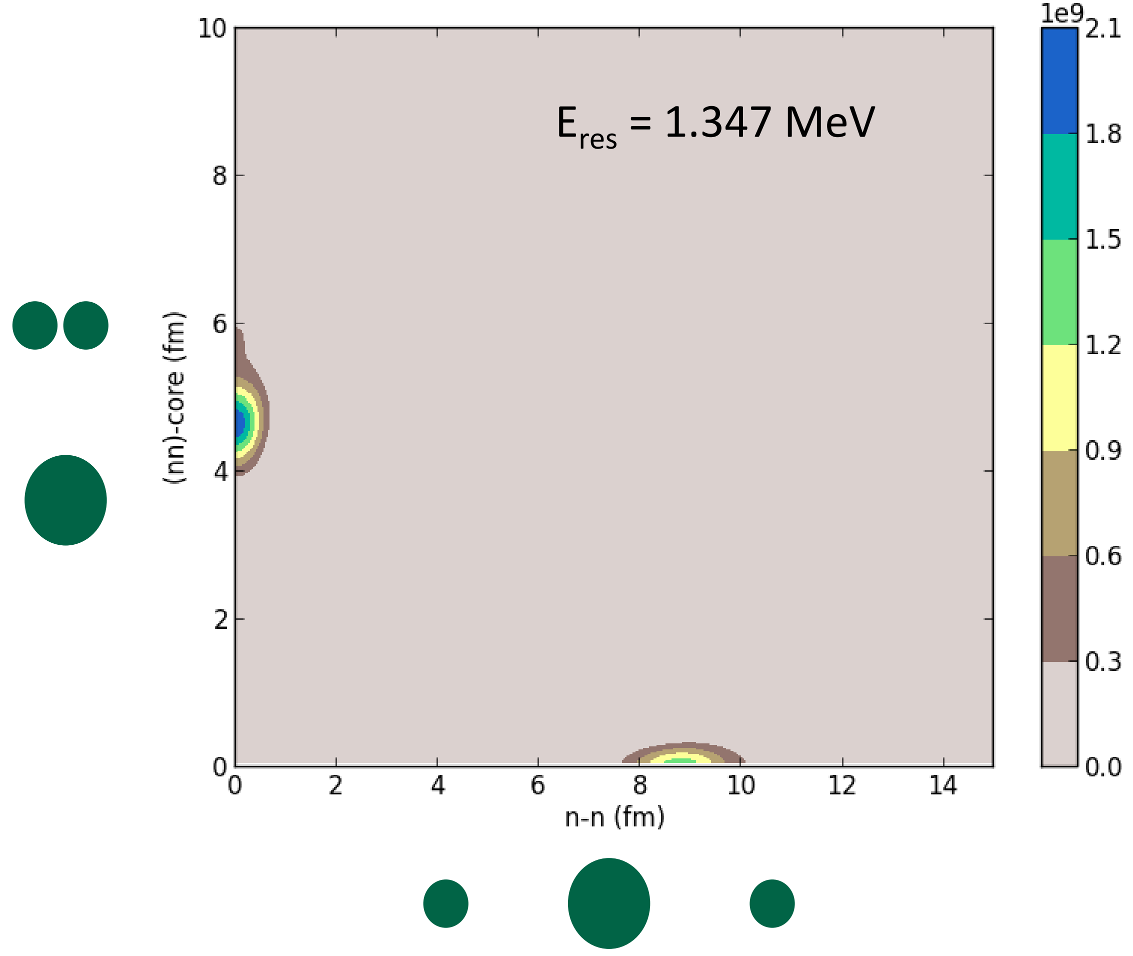
Total elastic cross section reinforces the resonance position across all channels

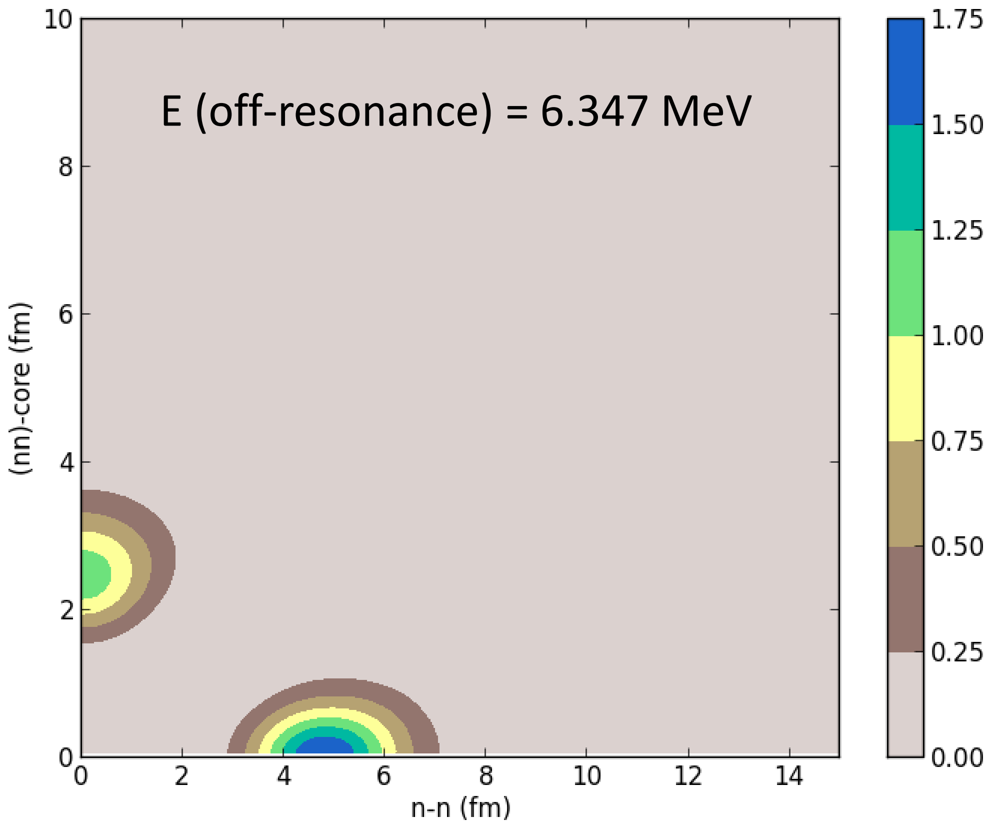


Three-body configuration and width

Preliminary

A dineutron decay of ^{16}Be was seen experimentally





Changes in the shape of the density distribution can be used to calculate the width of the system

Summary and outlook

- Using hypershperical coordinates and the R-matrix method, we constructed a three-body model for ^{16}Be.
- The density distribution favors a dineutron configuration over a helicopter configuration, consistent with experimental results.
- Changes in the structure of the density distribution can give a picture of the width of this state.
- The structure of ^{15}Be and strength of the nn interaction can be explored to see what is causing the strong dineutron.
- Comparisons with other methods are ongoing (with Simin Wang, MSU/NSCL).

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- Simin Wang (MSU/NSCL)
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