Measuring neutron-unbound states with MoNA-LISA

Neutron decay measurements of ^{11}Li and ^{12}Be

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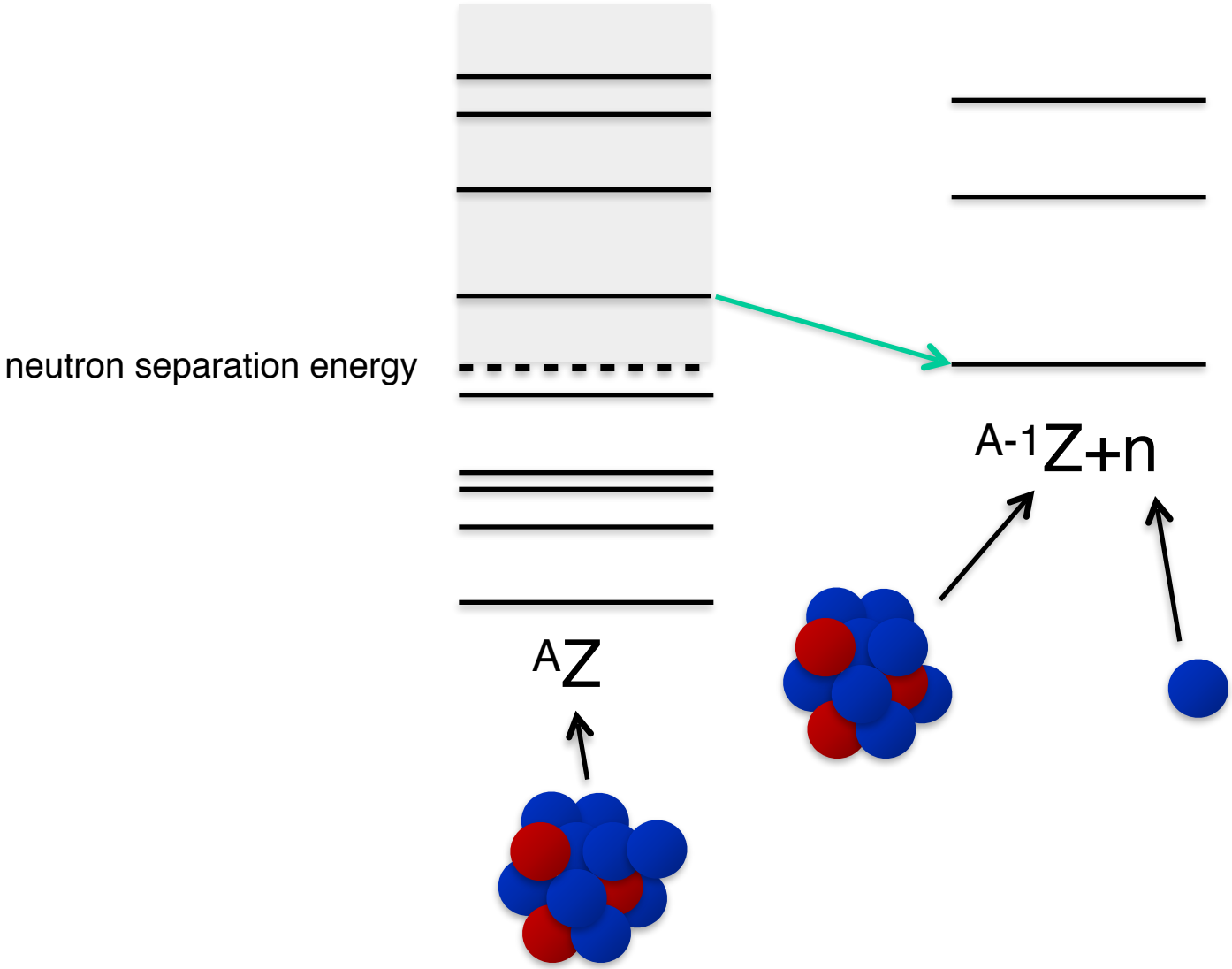
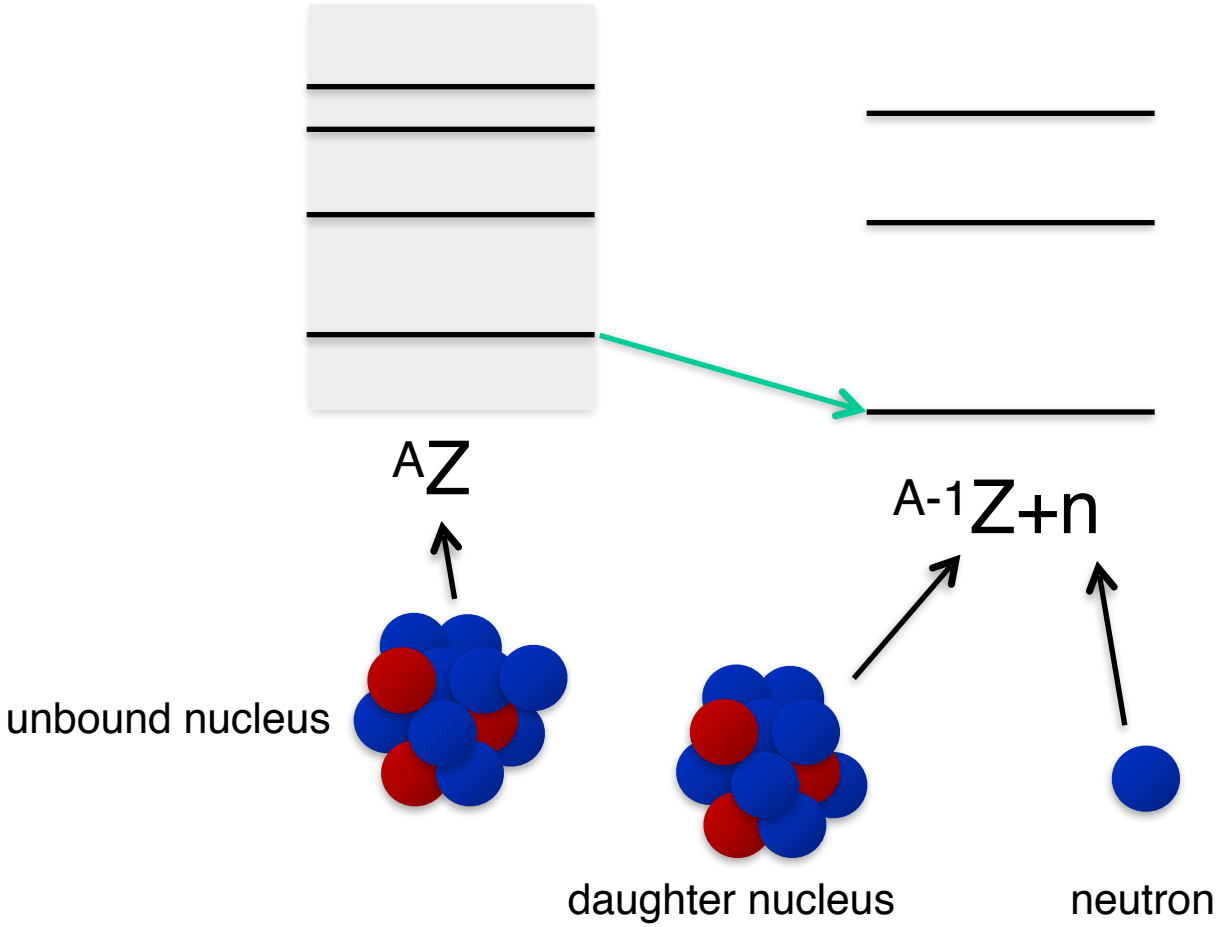
ISAC Theory Forum

15 December 2014

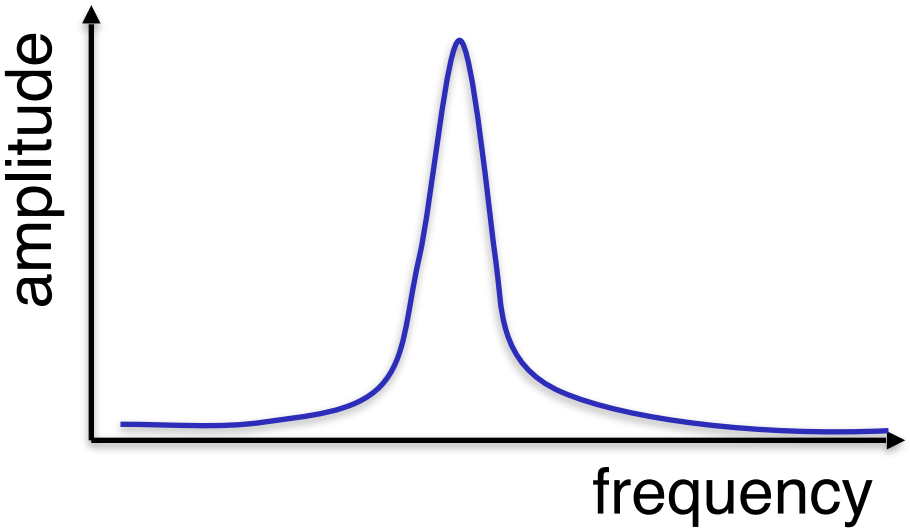
Neutron unbound states



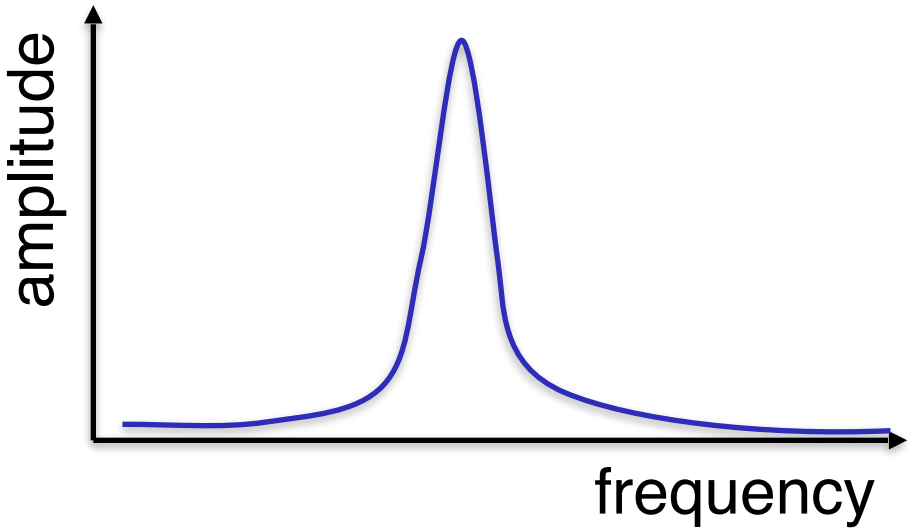
Neutron unbound nuclei

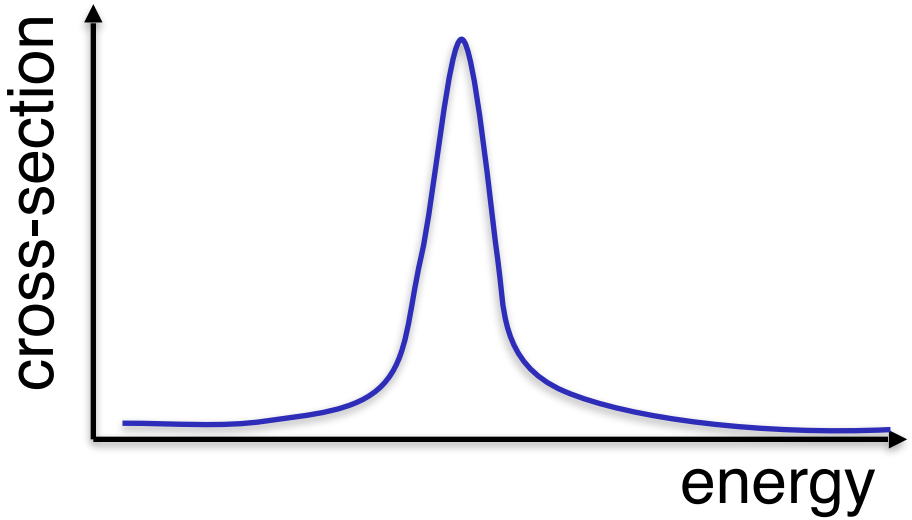


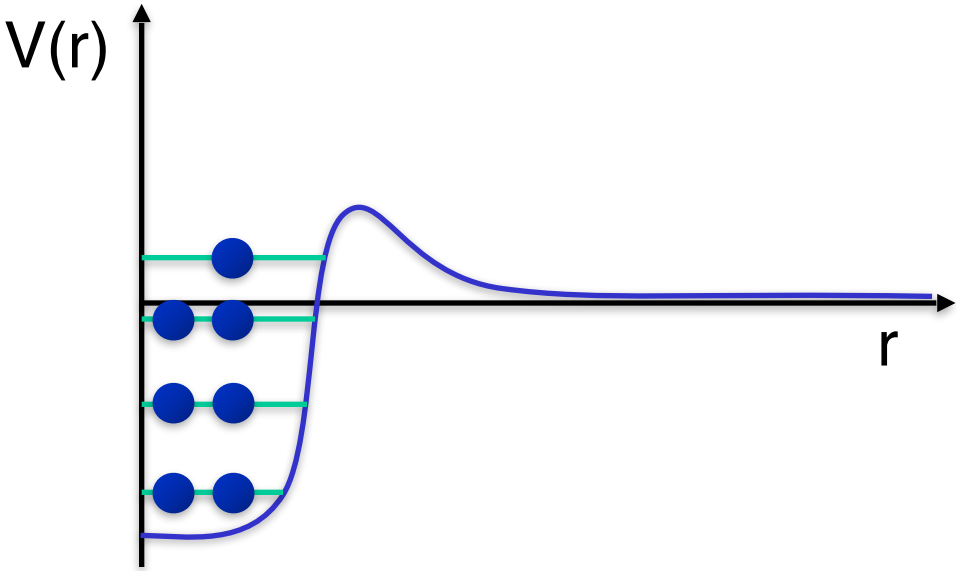
What is a resonance?



What is a resonance?



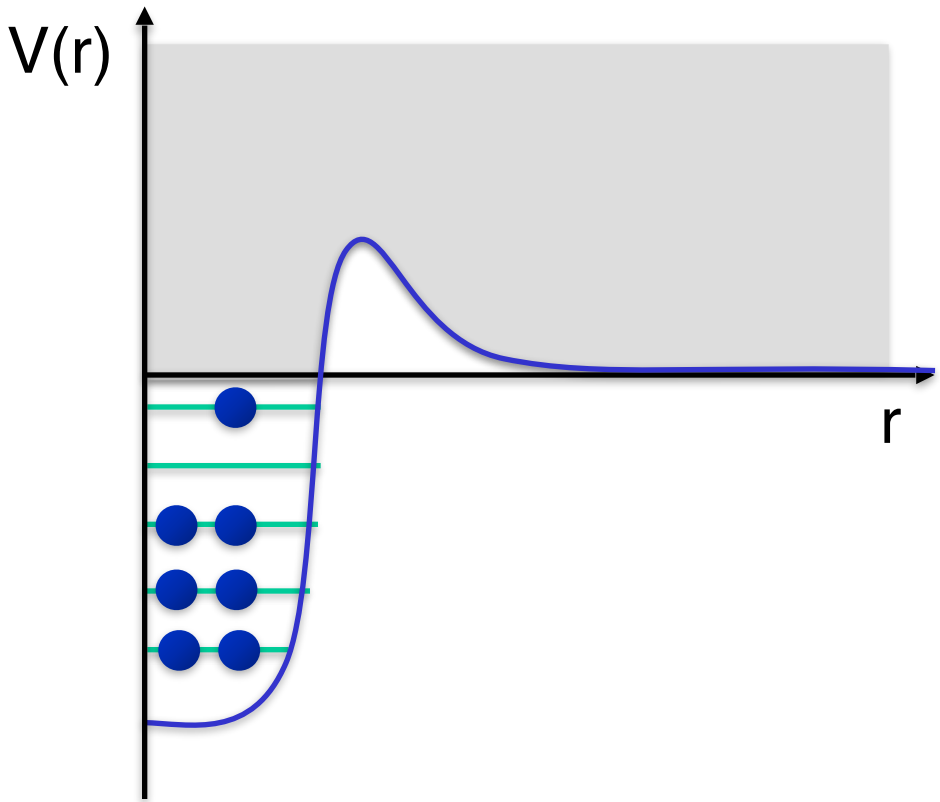




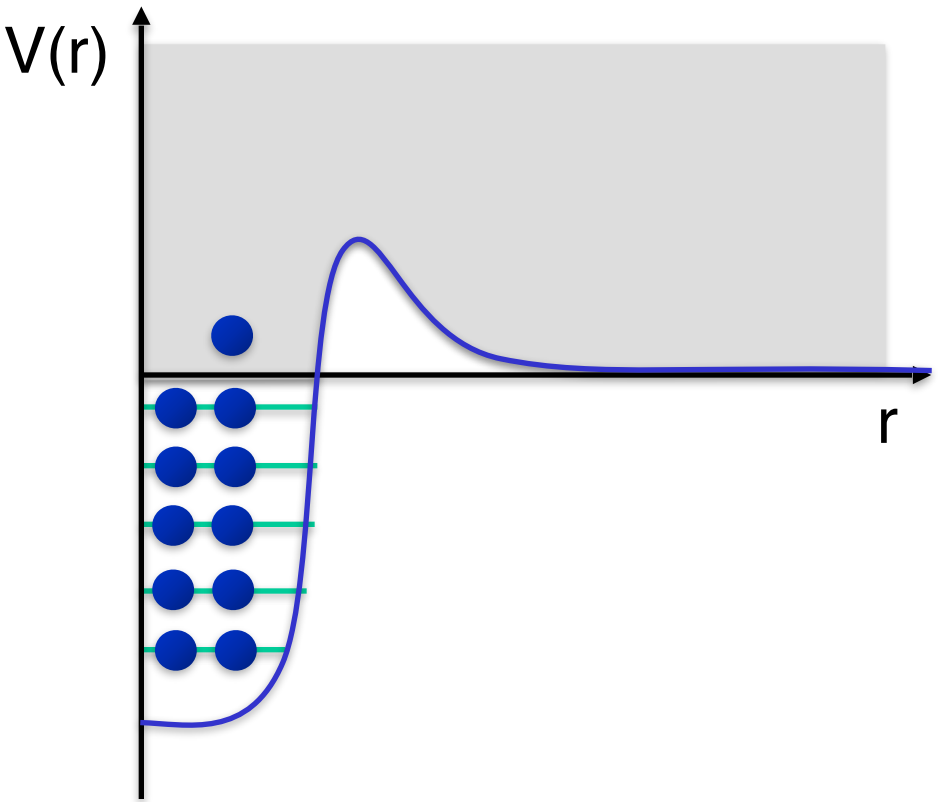
$$\sigma(E; E_0, \Gamma) \propto \frac{\Gamma^2}{(E - E_0)^2 + \Gamma^2}$$

Breit-Wigner distribution

Why study unbound nuclei?

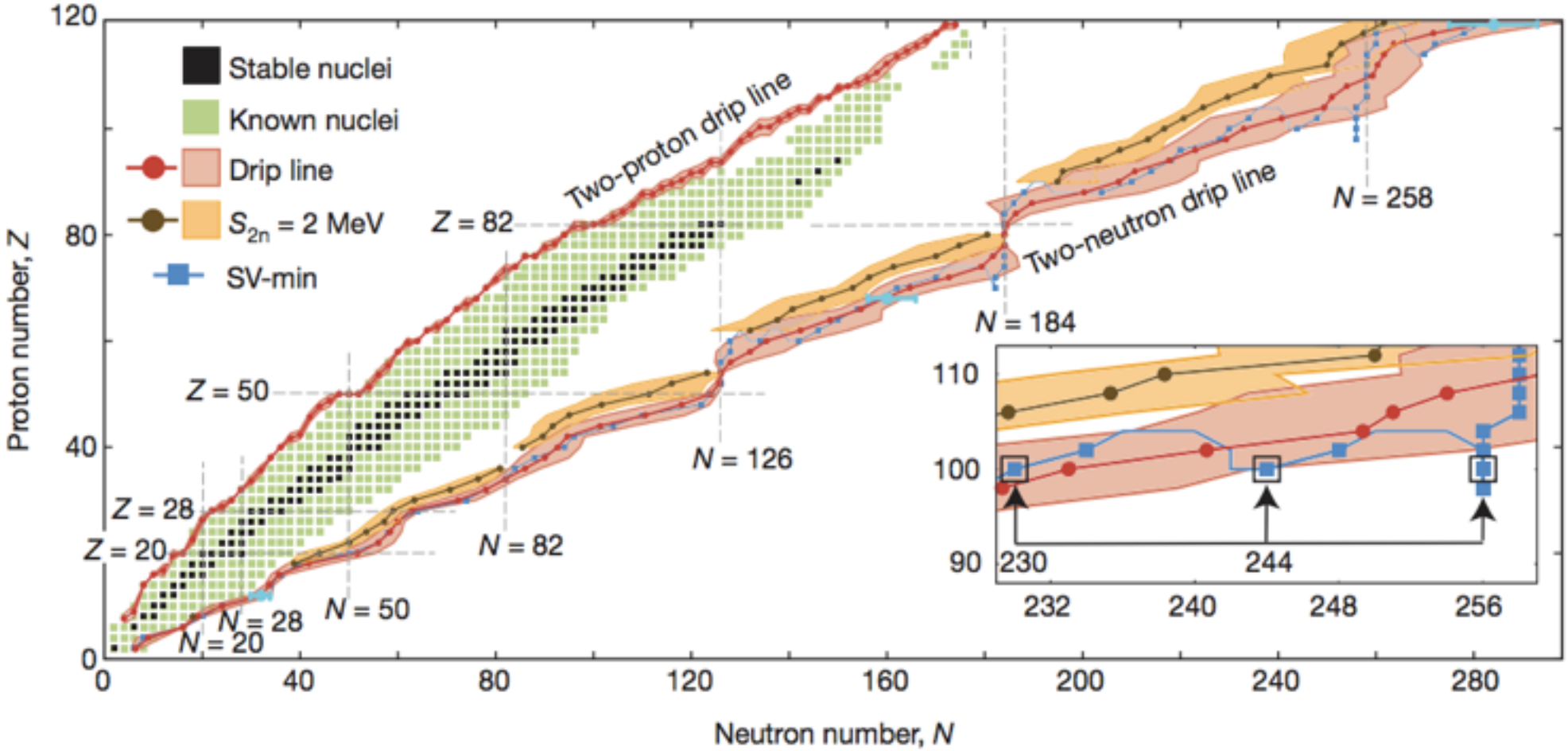


bound nucleus



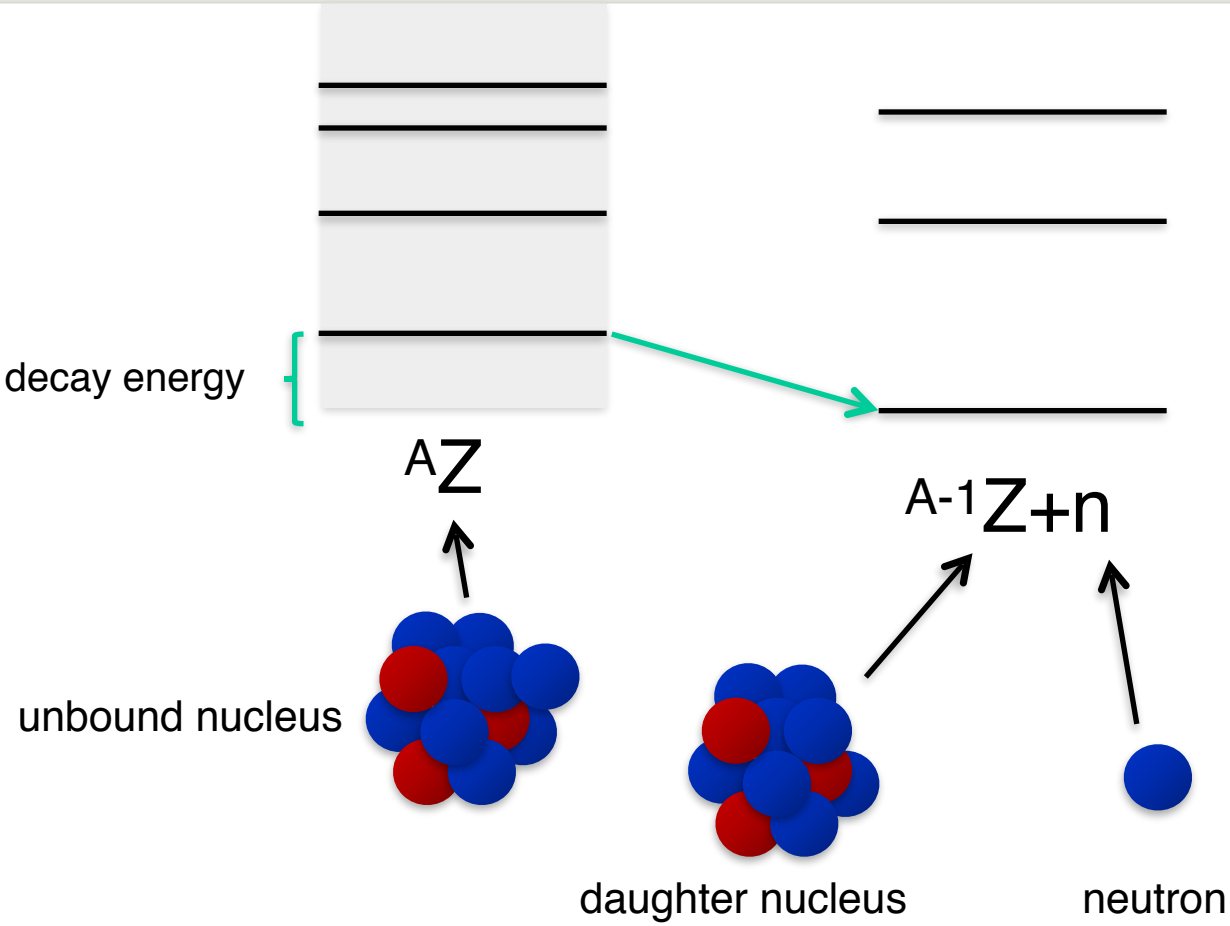
unbound nucleus

Dripline nuclei



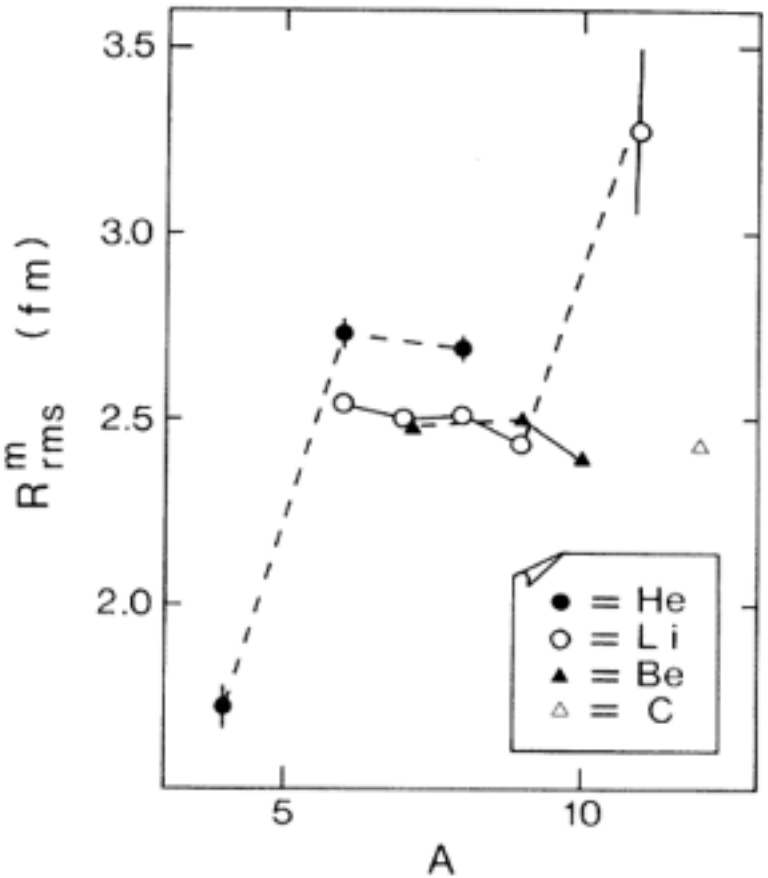
Erler, et al., *Nature* **486**, 509

Experimental measurements

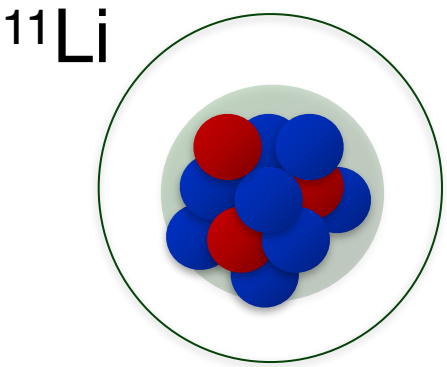


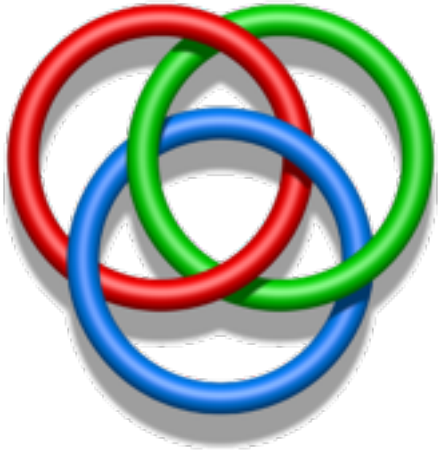
$$E_d = \sqrt{(P_f^\mu + P_n^\mu)^2} - M_n - M_f$$

^{11}Li: An overview

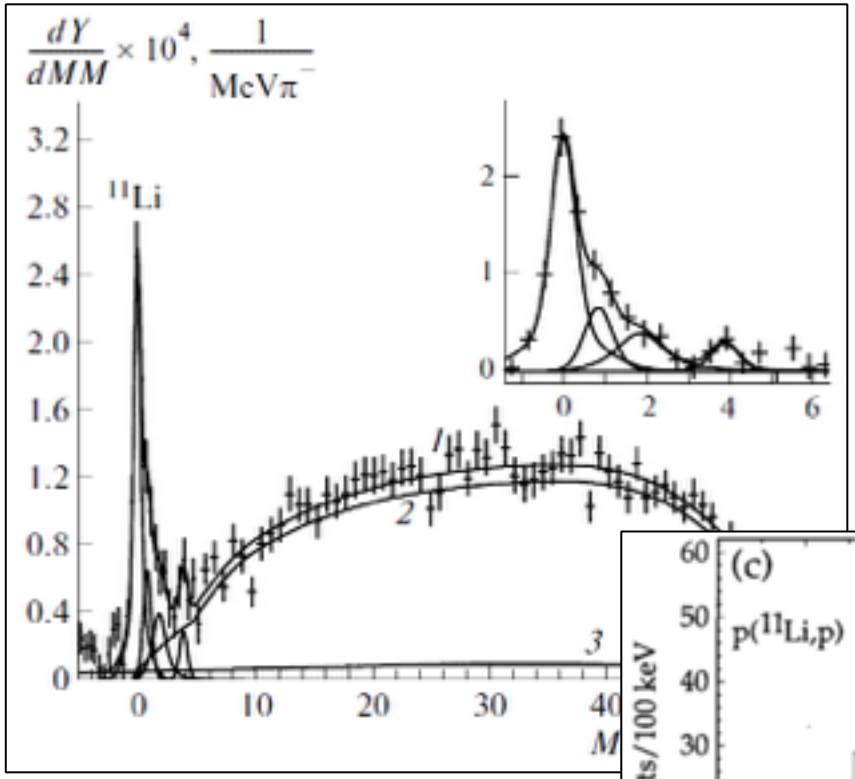


Tanihata, et al., PRL **55**:24, 2676 (1985)

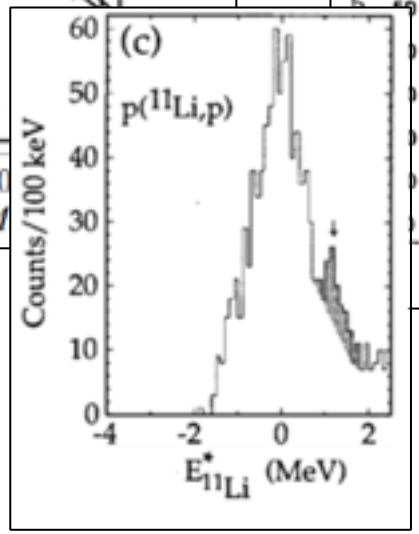




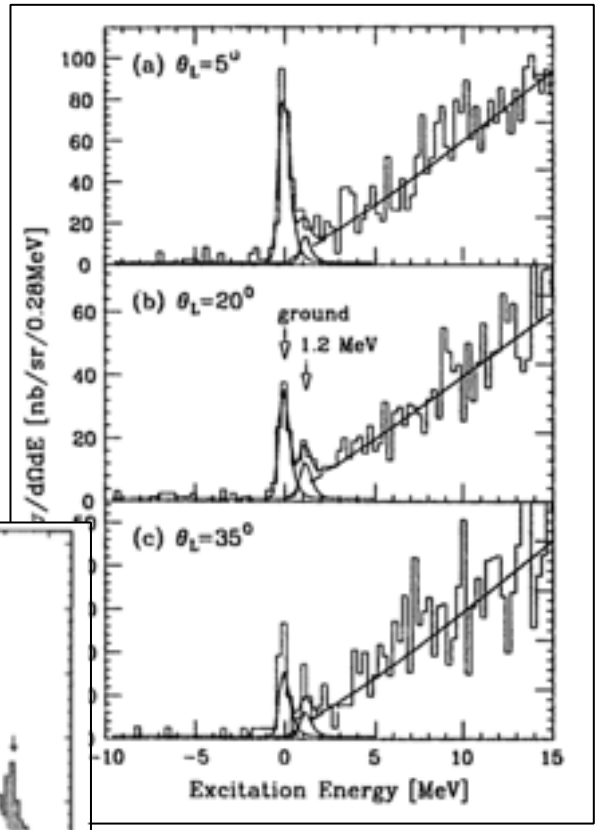
Background on ^{11}Li



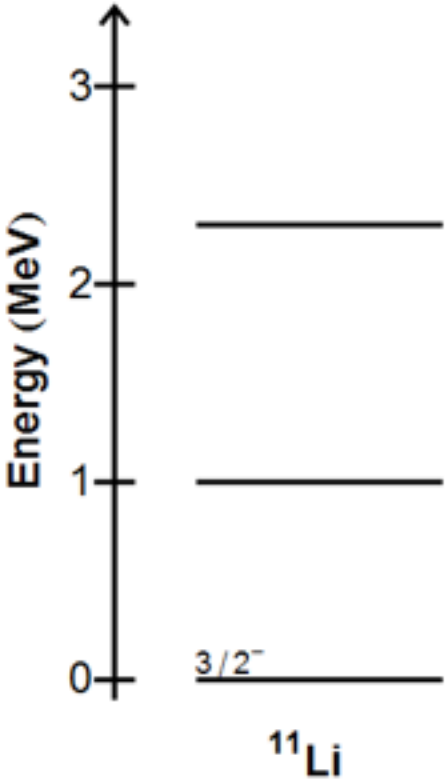
^{14}C(π⁻, pd)X



^{11}Li(p,p)



^{11}B(π⁻, π⁺)^{11}Li

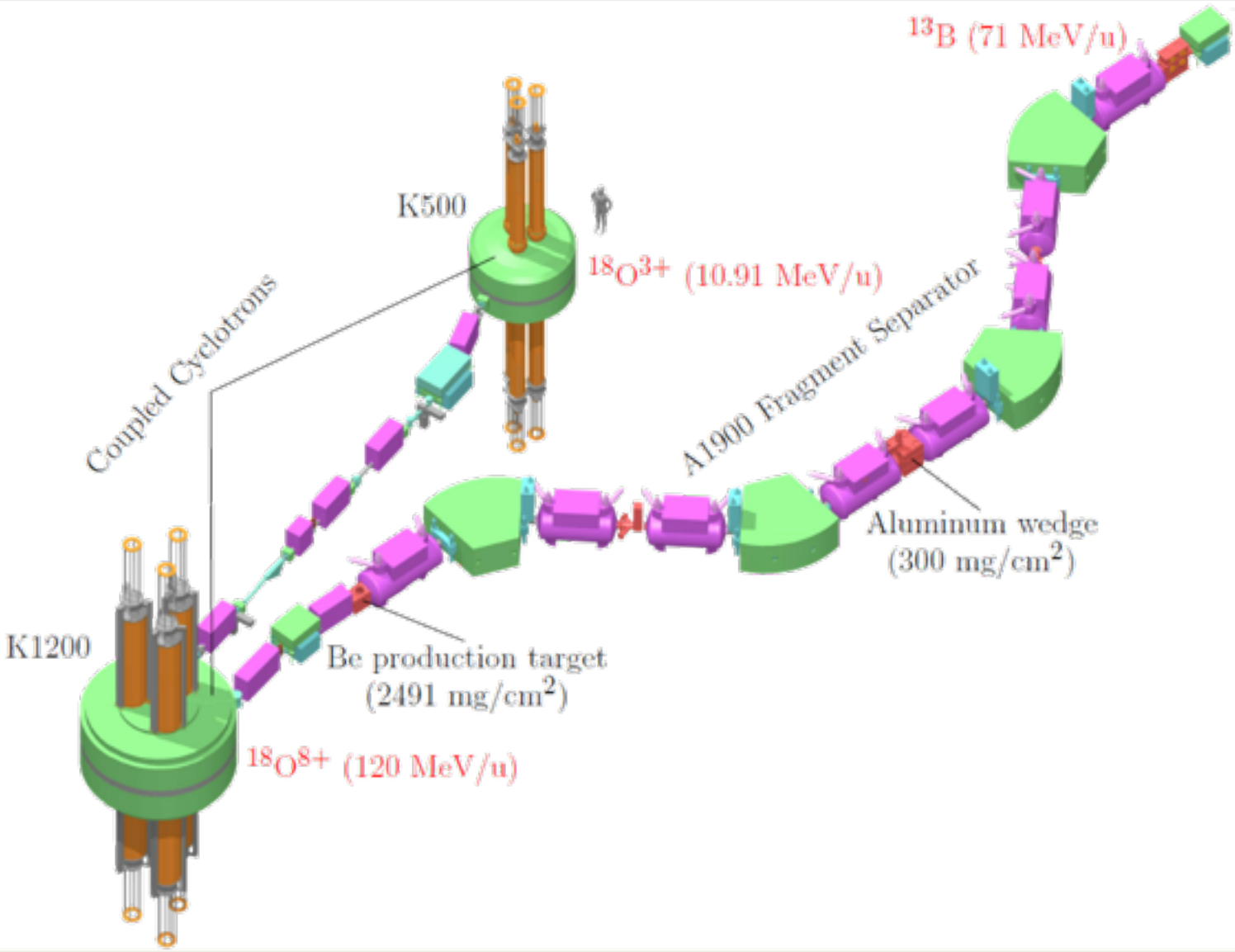


Korsheninnikov et al., PRC, **53**, R537 (1996)

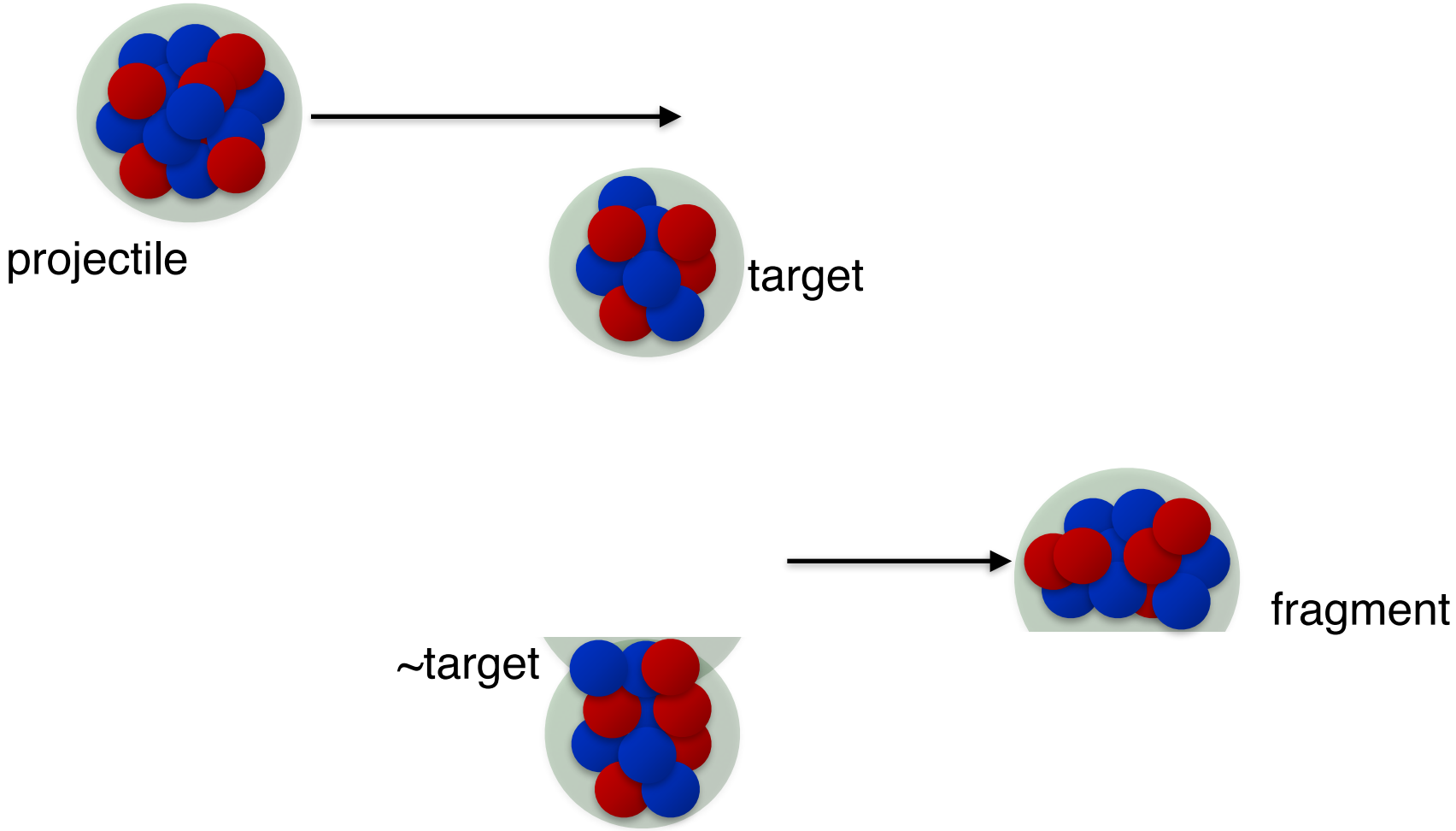
Kobayashi et al., NPA, **538**, 343 (1992)

Gurov et al., Bull. Russ. Aca. Sci., **740**, 433 (2010)

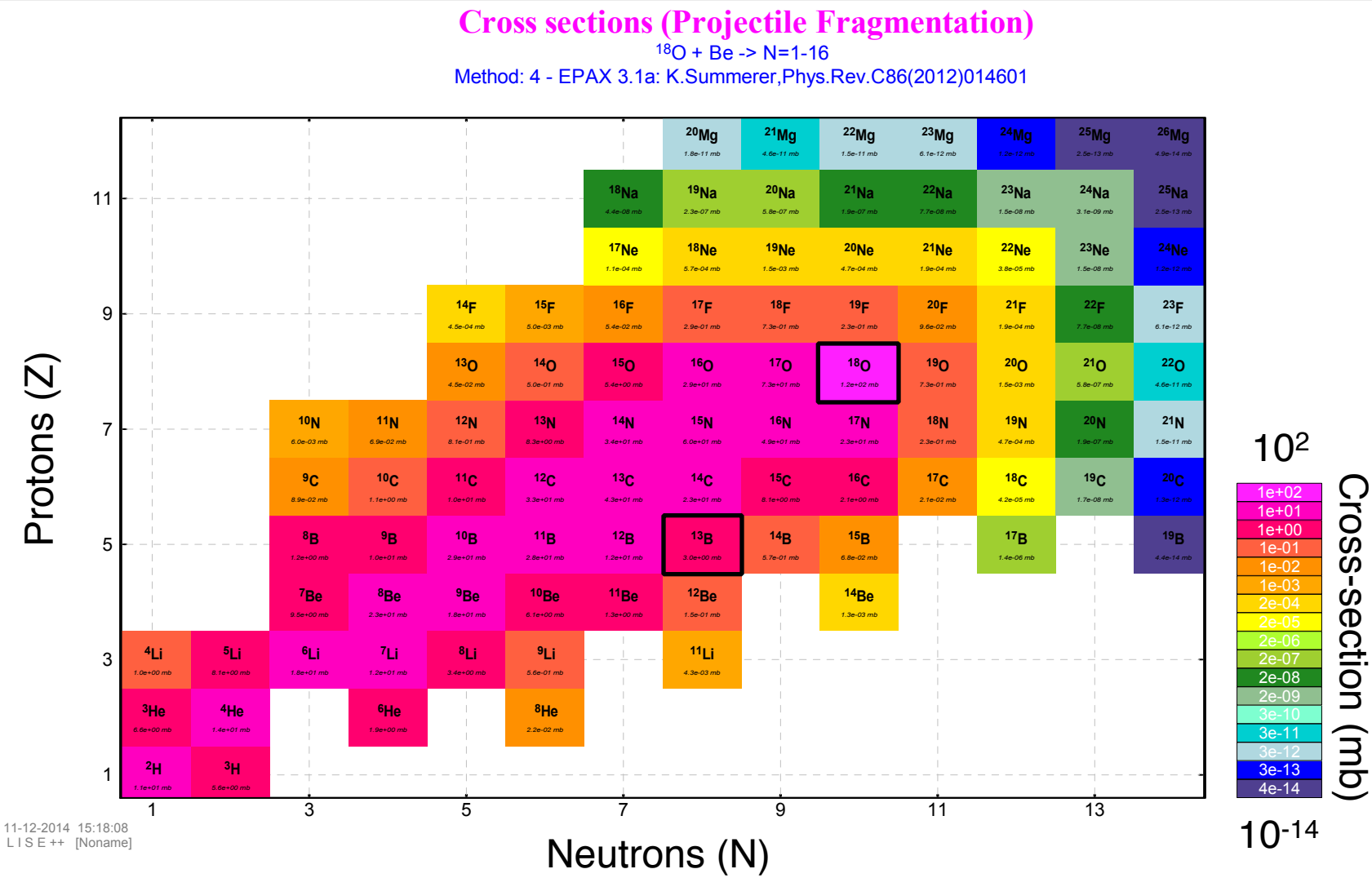
Beam production at NSCL



Projectile fragmentation

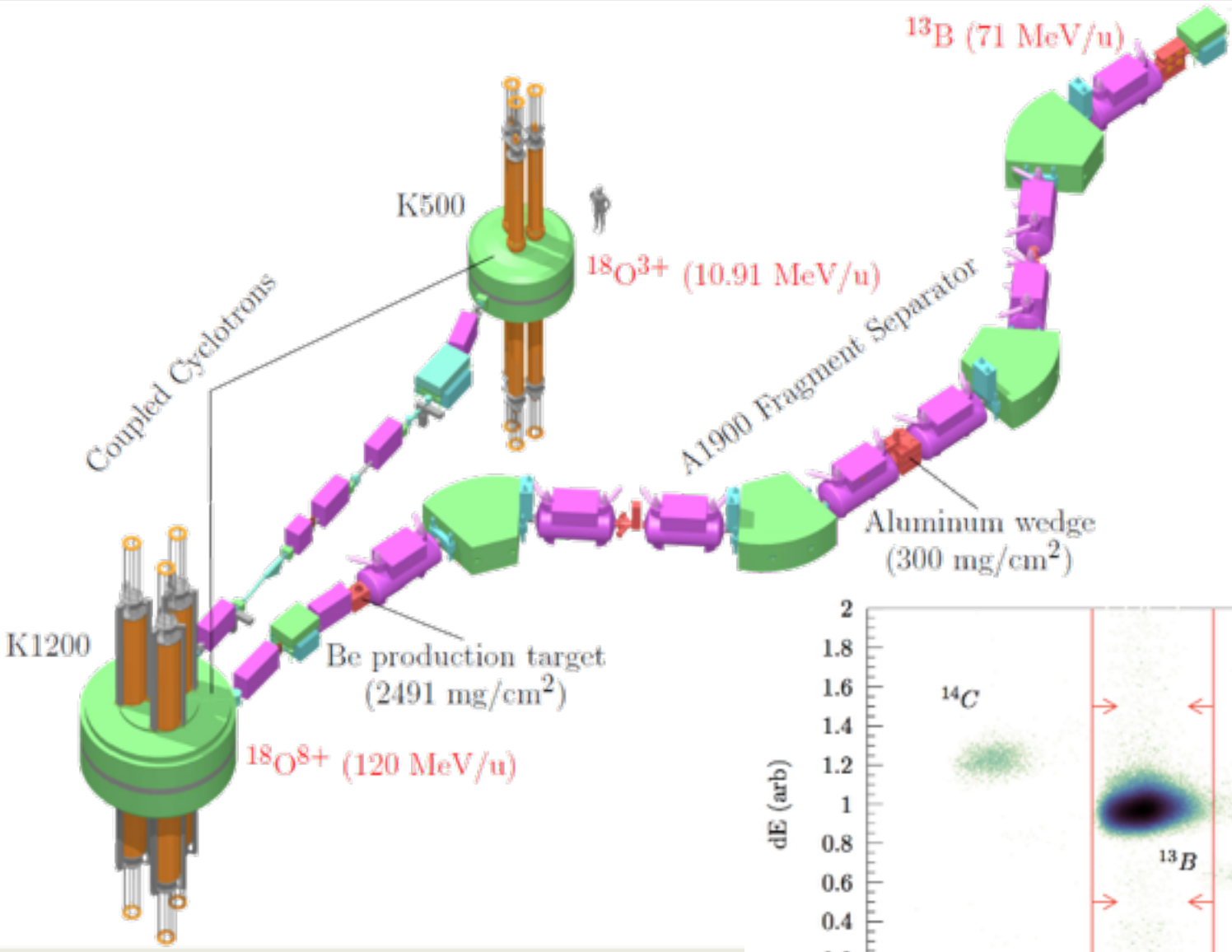


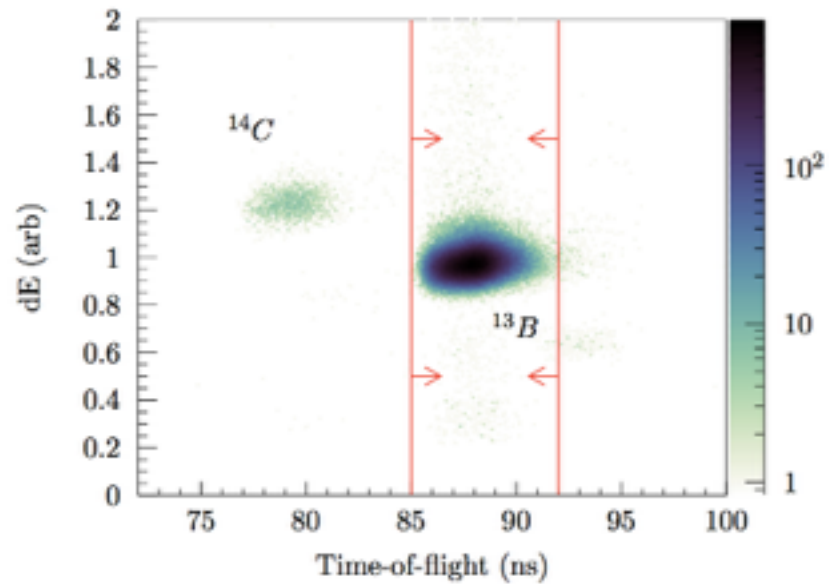
Projectile Fragmentation



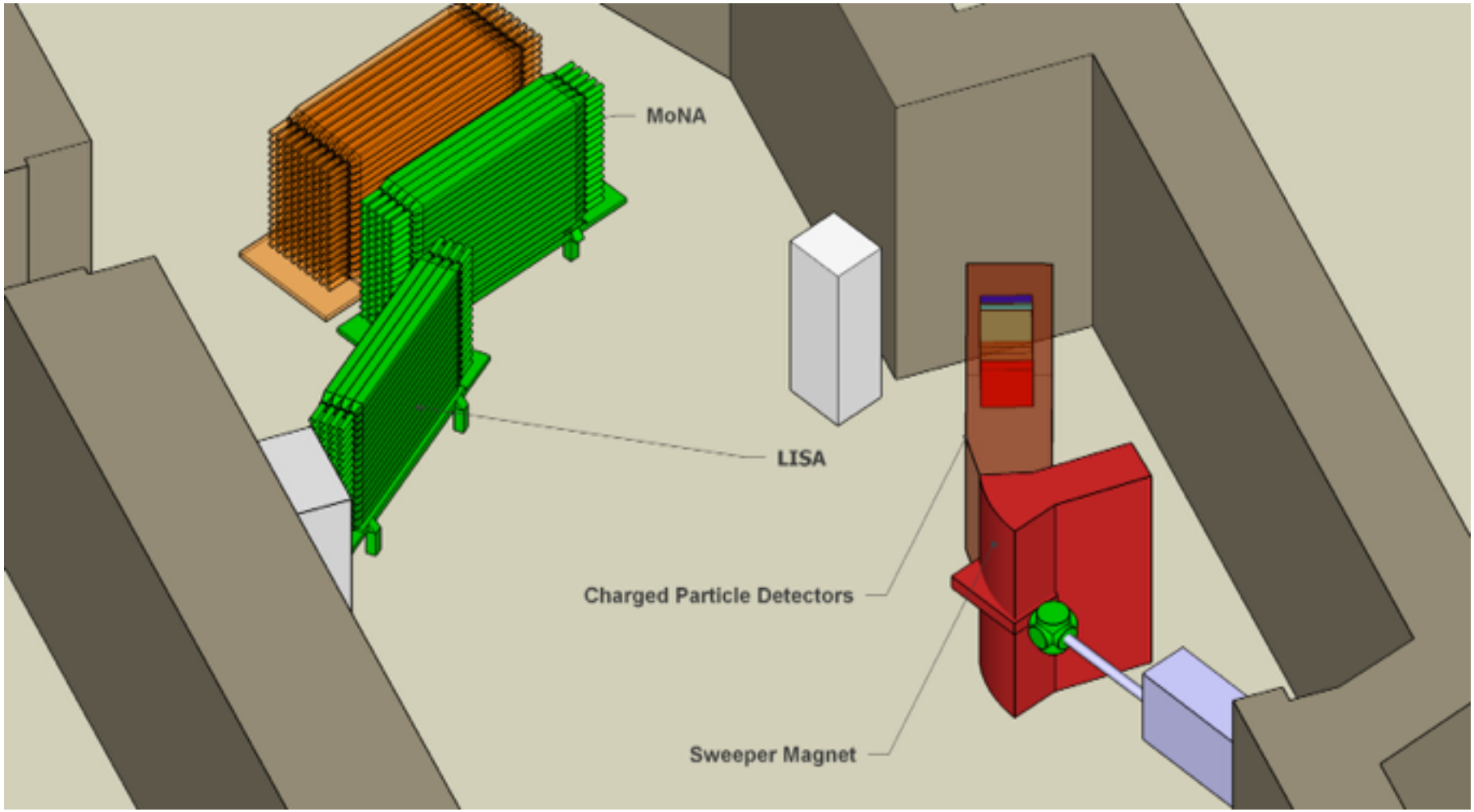
LISE++ calculation

Beam production at NSCL

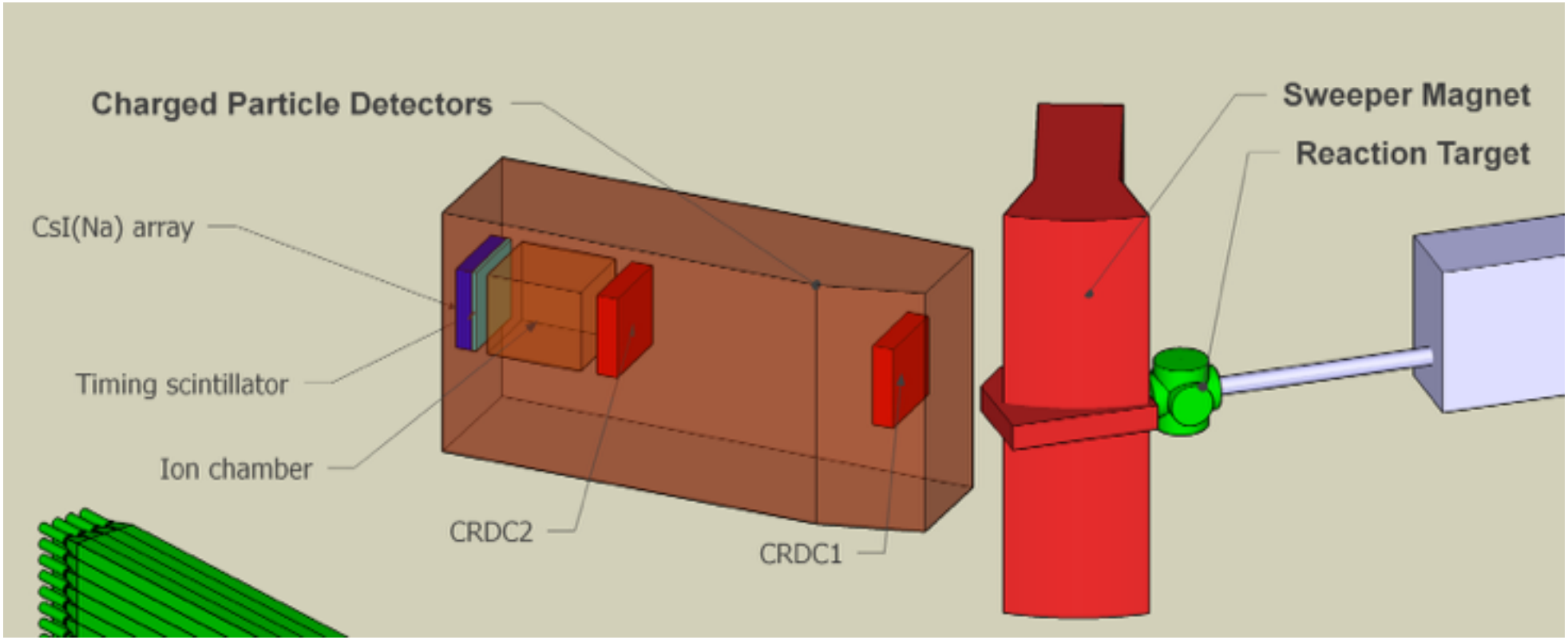




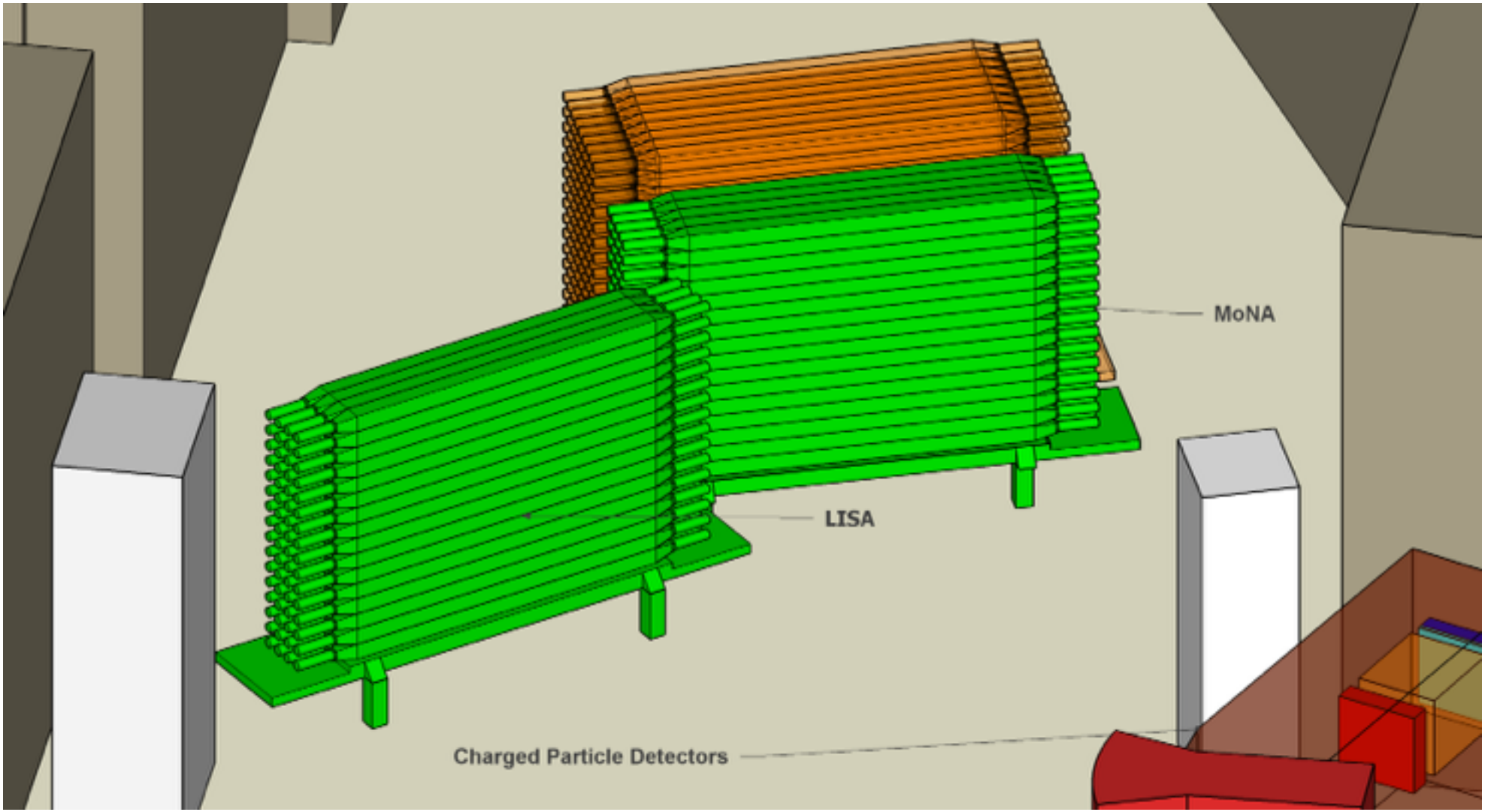
Experimental layout



Experimental set-up: fragments



Experimental set-up: neutrons



Interpretation through simulation

Physical reality + Experimental limitations = Data

Data - Experimental limitations = Physics

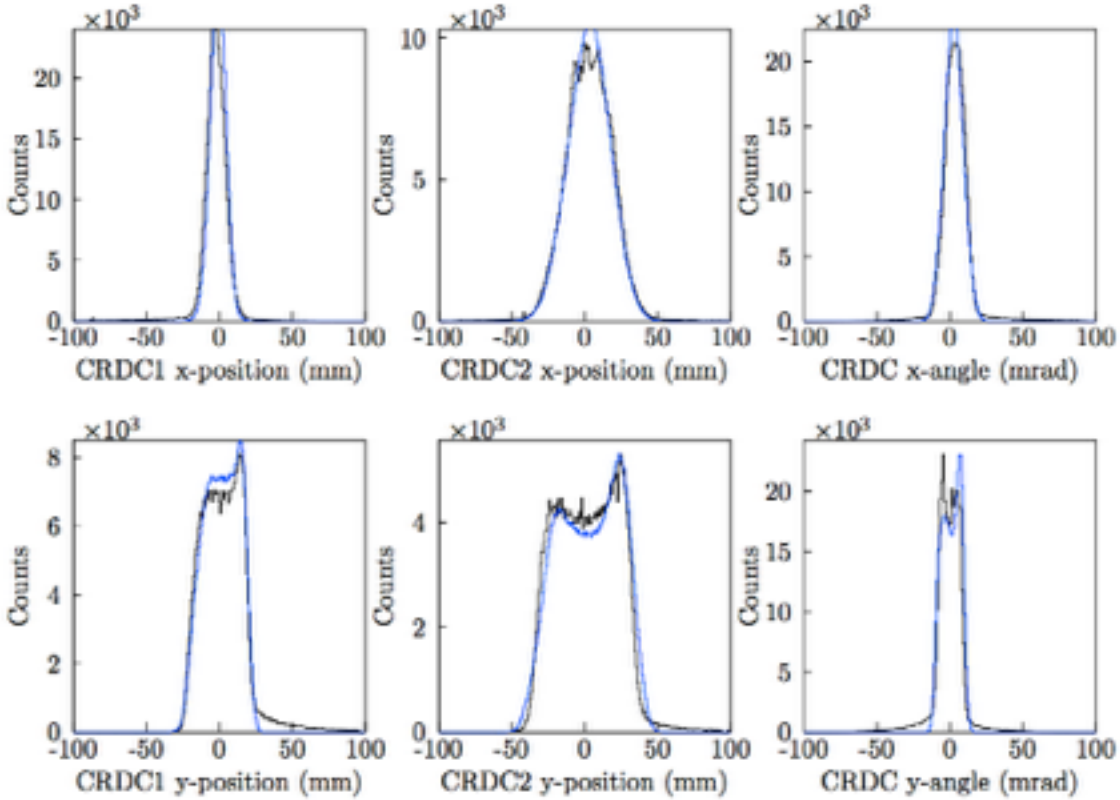
Interpretation through simulation

Physical reality + Experimental limitations = Data

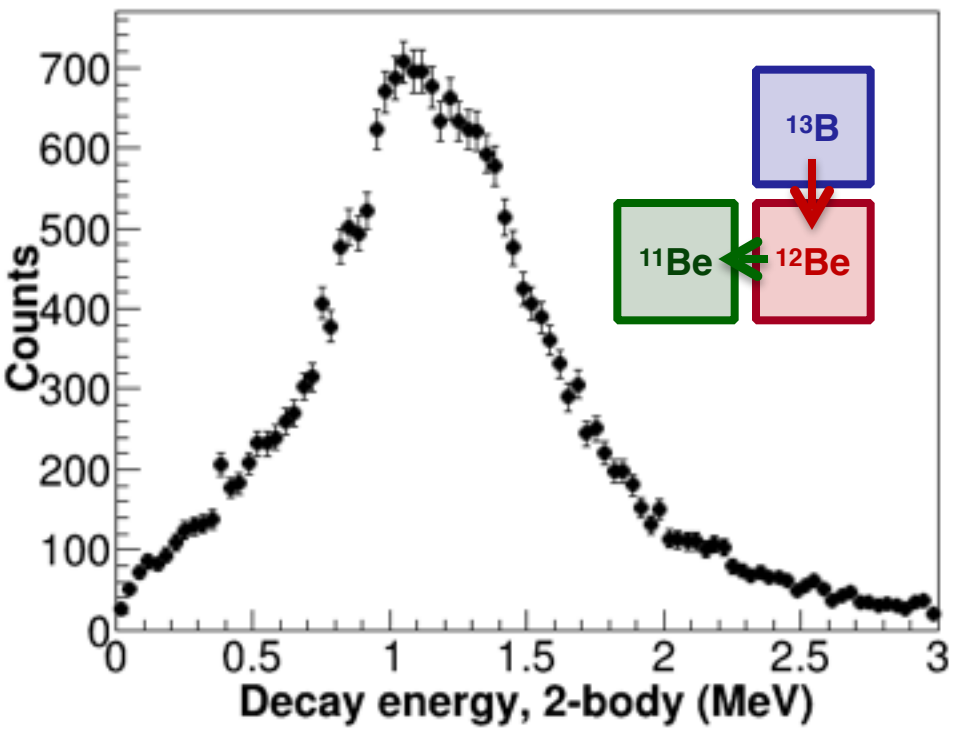
Physics + Simulation = Simulated data

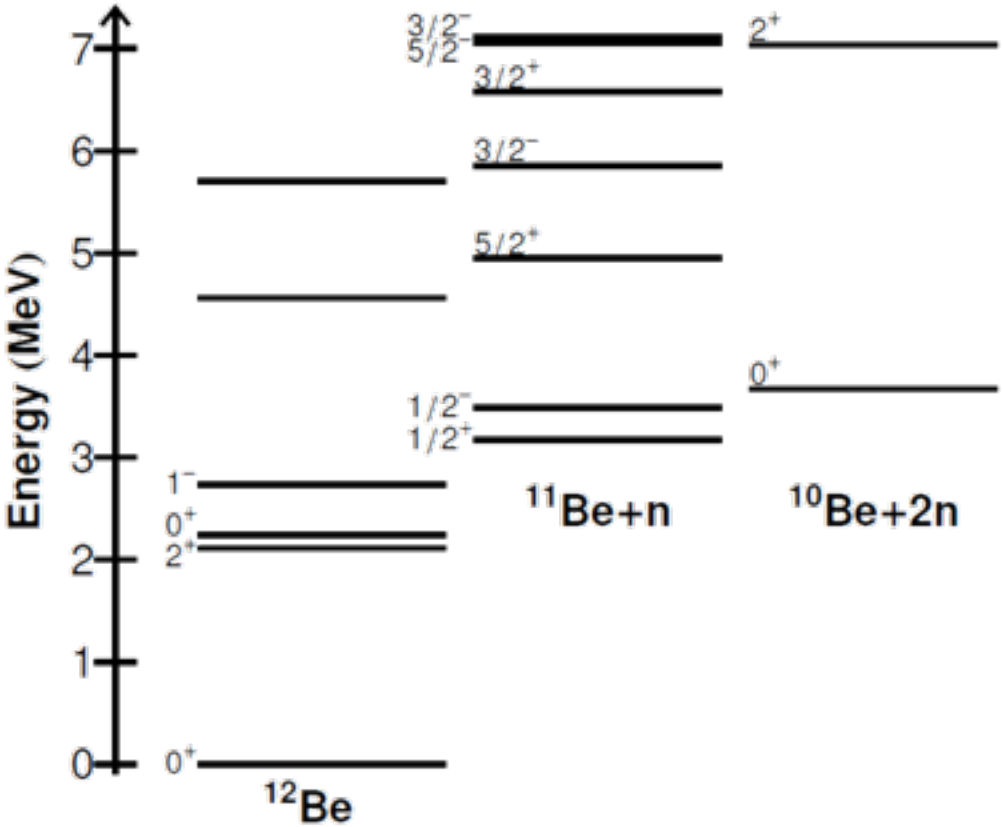
Simulation

- Beam profile
- Reaction dynamics
- Fragment tracking
- Detector acceptances and resolutions
- Neutron interactions in MoNA-LISA
  - Cross-talk
- **Decay energy distribution**



$^{12}Be^{*} \rightarrow {}^{11}Be + n$ decay energy



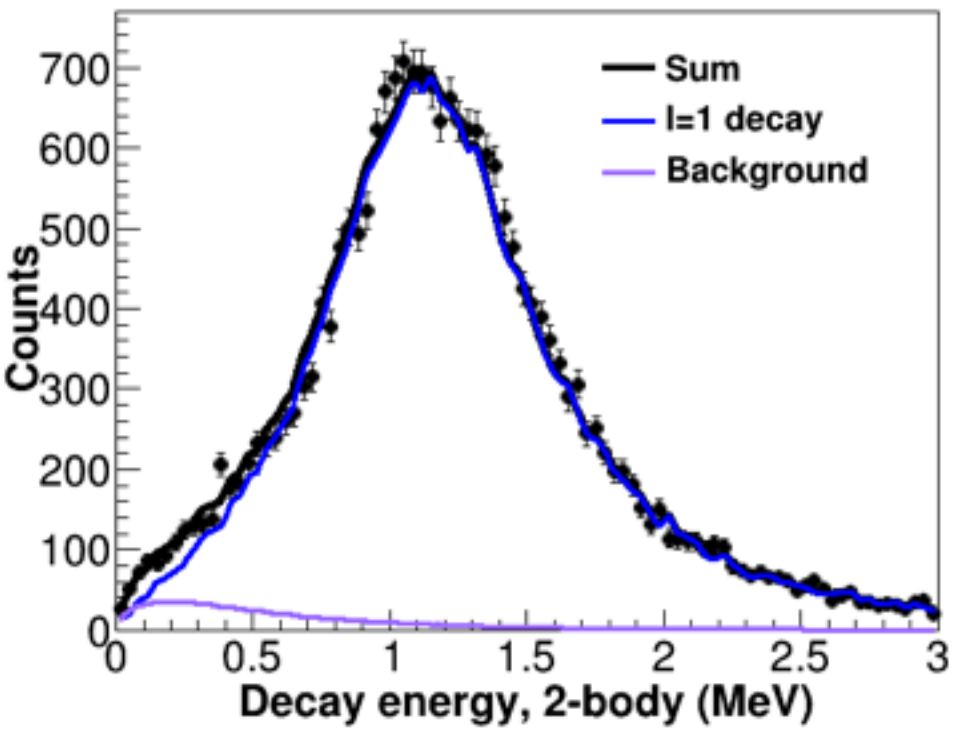


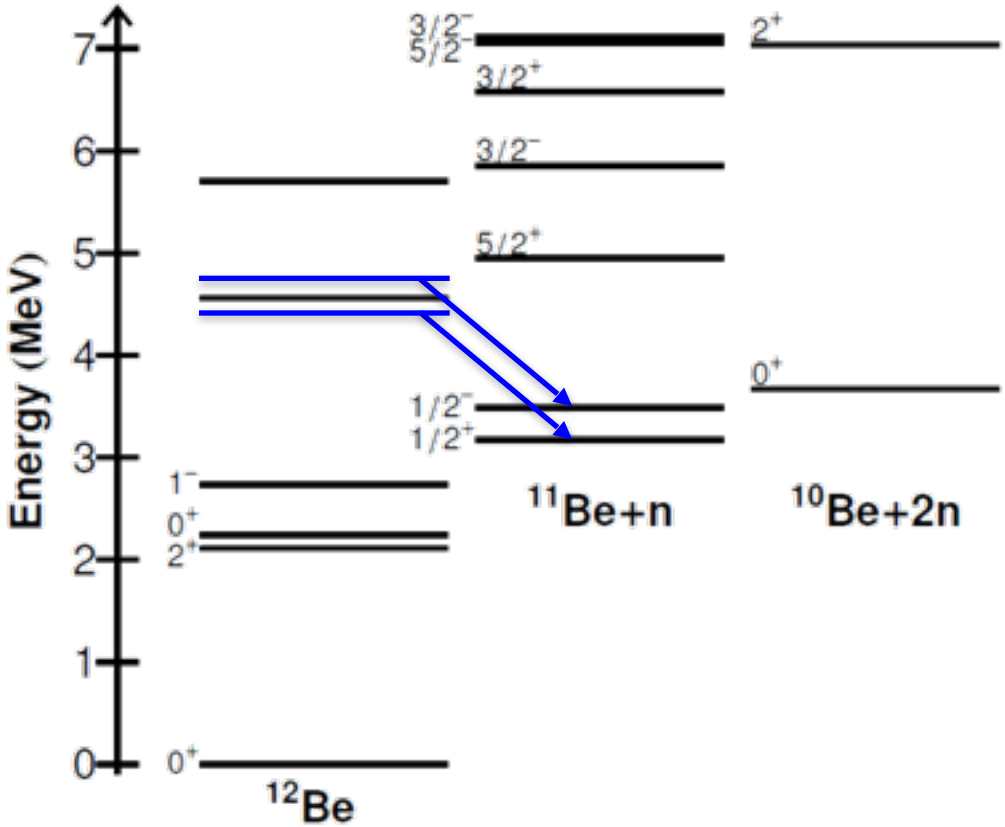
Smith et al., PRC, **90**, 024309 (2014)

$^{12}Be^{*} \rightarrow {}^{11}Be+n$ decay energy

E_d = 1243±20 keV

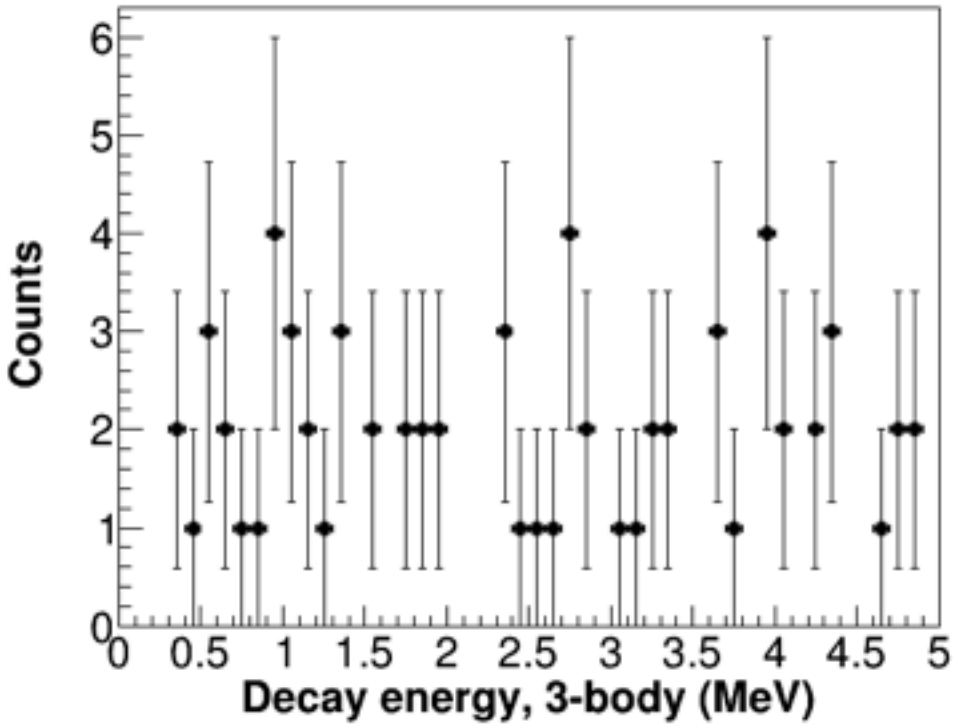
Γ = 634±50 keV

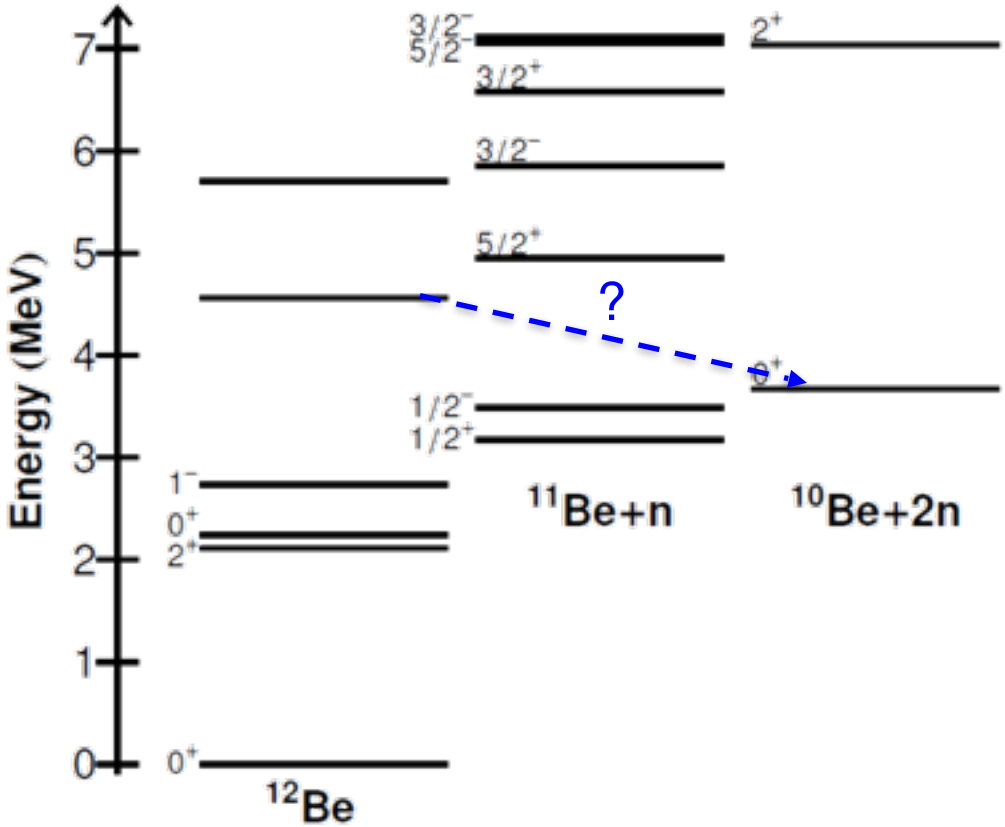




Smith et al., PRC, **90**, 024309 (2014)

$^{12}Be^{*} \rightarrow {}^{10}Be+2n$ decay energy





Smith et al., PRC, **90**, 024309 (2014)

Spin and parity in ^{12}Be

- Requires L=1 decay to $1/2^+$, $1/2^-$
- Population: 1p knockout from ^{13}B ground state of $3/2^-$
- Very little 2n decay

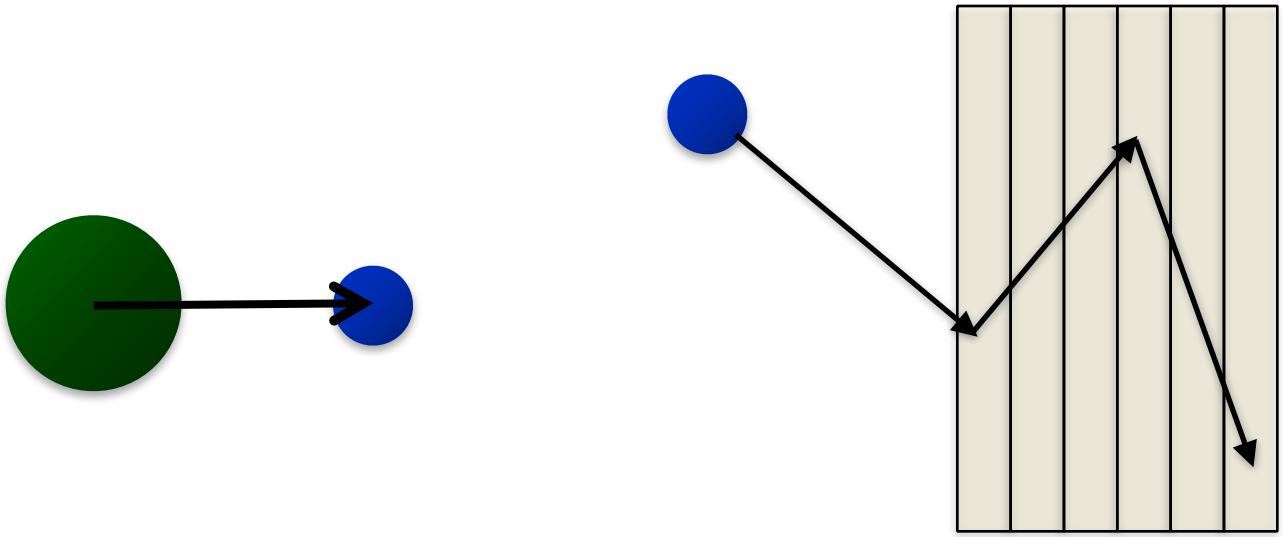
- Spin: 0, 1, 2
- Eliminates 0^-
- Negative parity

Probable spin and parity:
1^-, 2^-

Smith et al., PRC, **90**, 024309 (2014)
Garrido et al., PRC, **86**, 024310 (2012)

From 1n decay to 2n decay

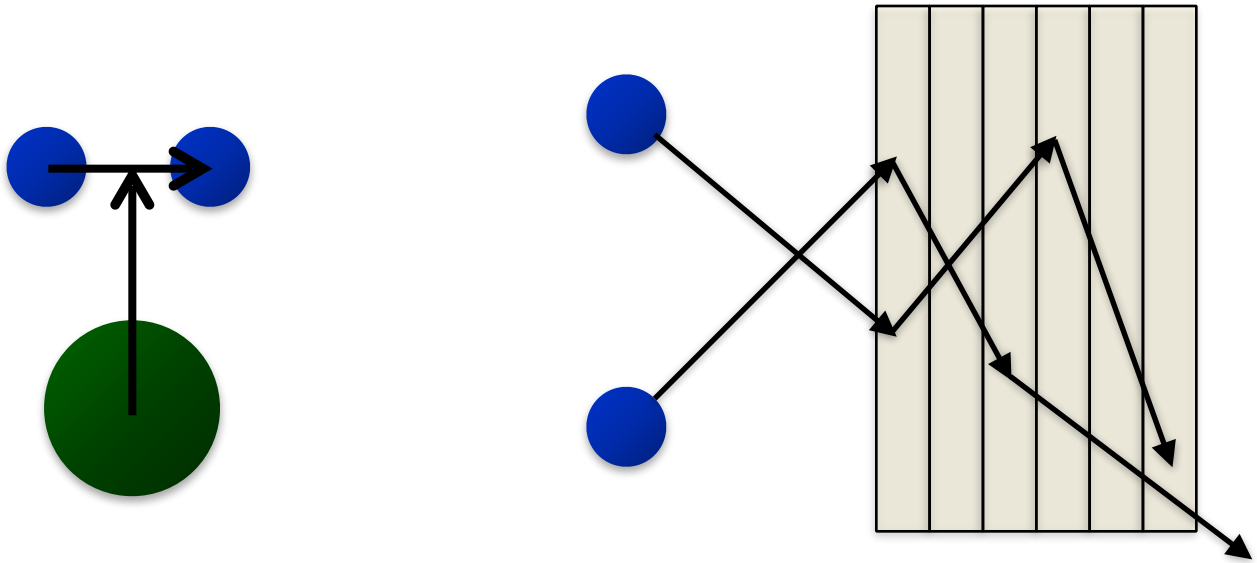
$$E_d = \sqrt{(P_f^\mu + P_n^\mu)^2} - M_n - M_f$$



$$\sigma(E; E_0, \Gamma) \propto \frac{\Gamma^2}{(E - E_0)^2 + \Gamma^2}$$

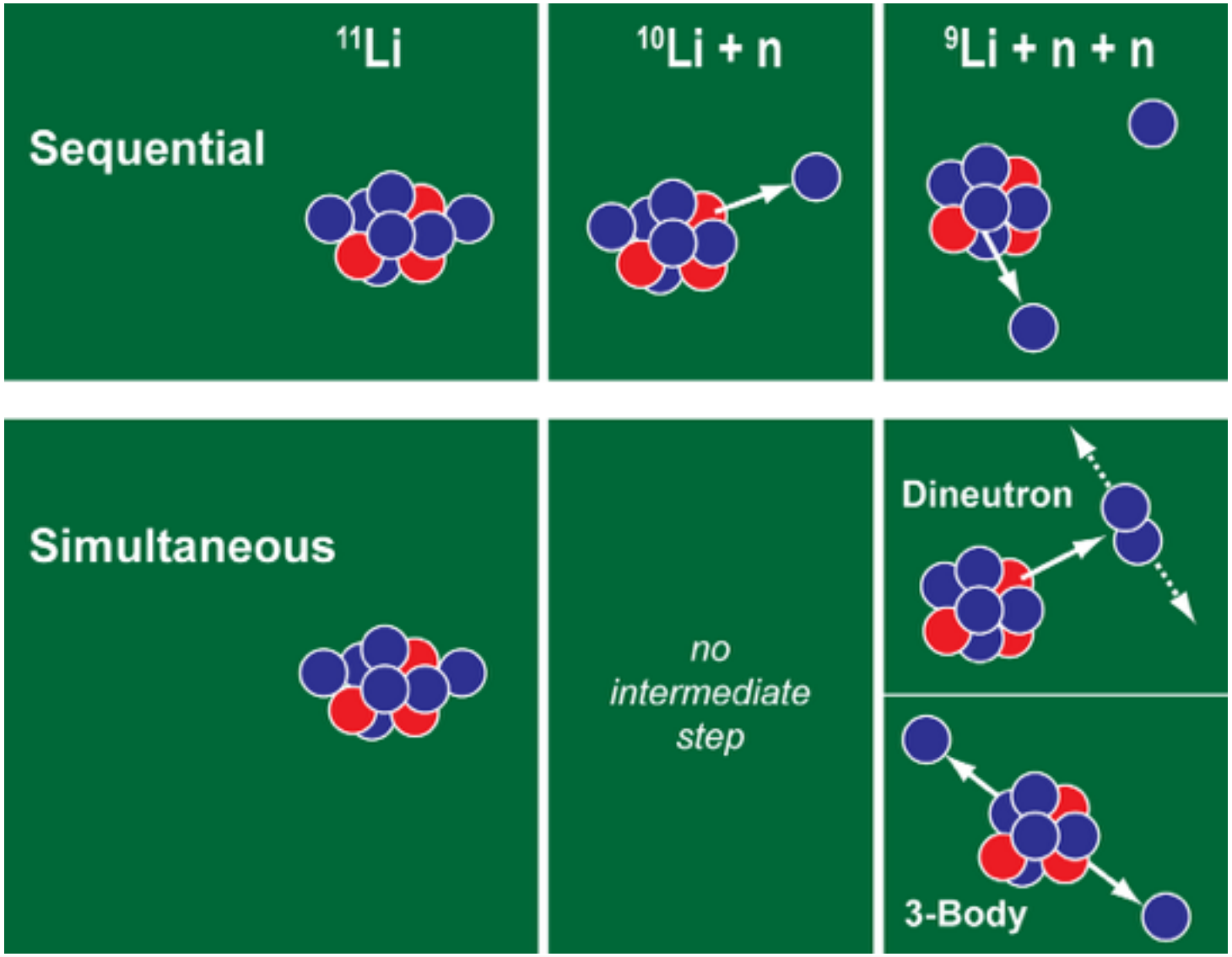
From 1n decay to 2n decay

$$E_d = \sqrt{(P_f^\mu + P_{n_1}^\mu + P_{n_2}^\mu)^2} - M_f - 2M_n$$



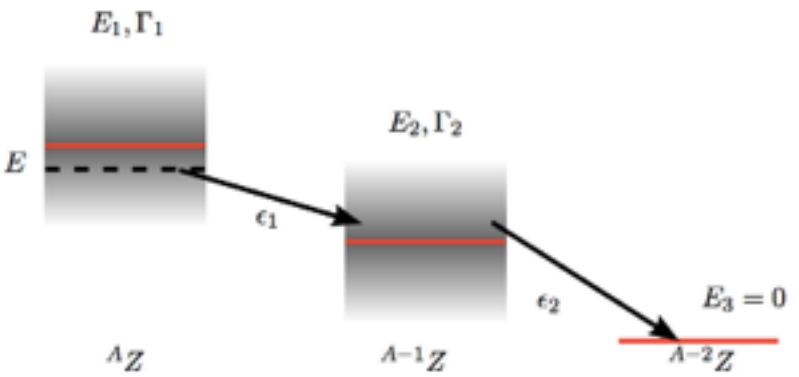
$$\sigma(E; E_0, \Gamma_0, E_1, \Gamma_1) = ???$$

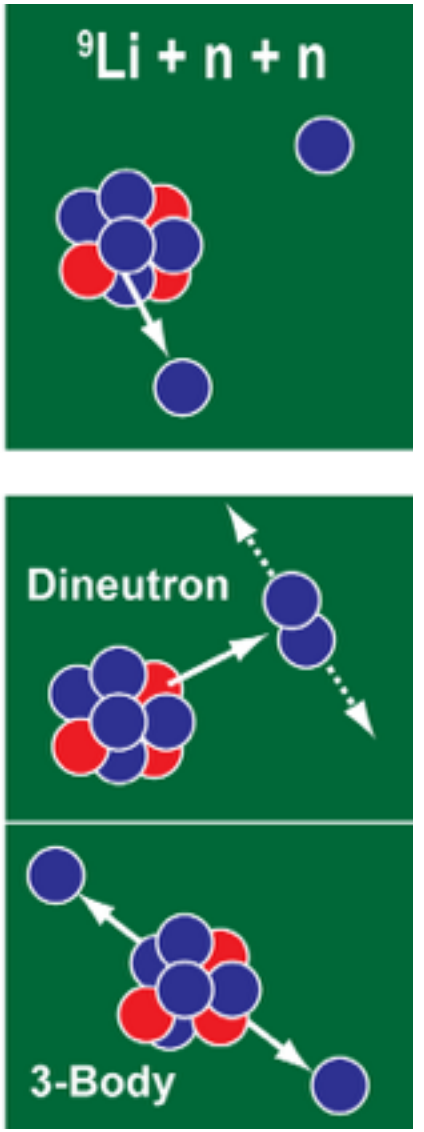
Two neutron correlations



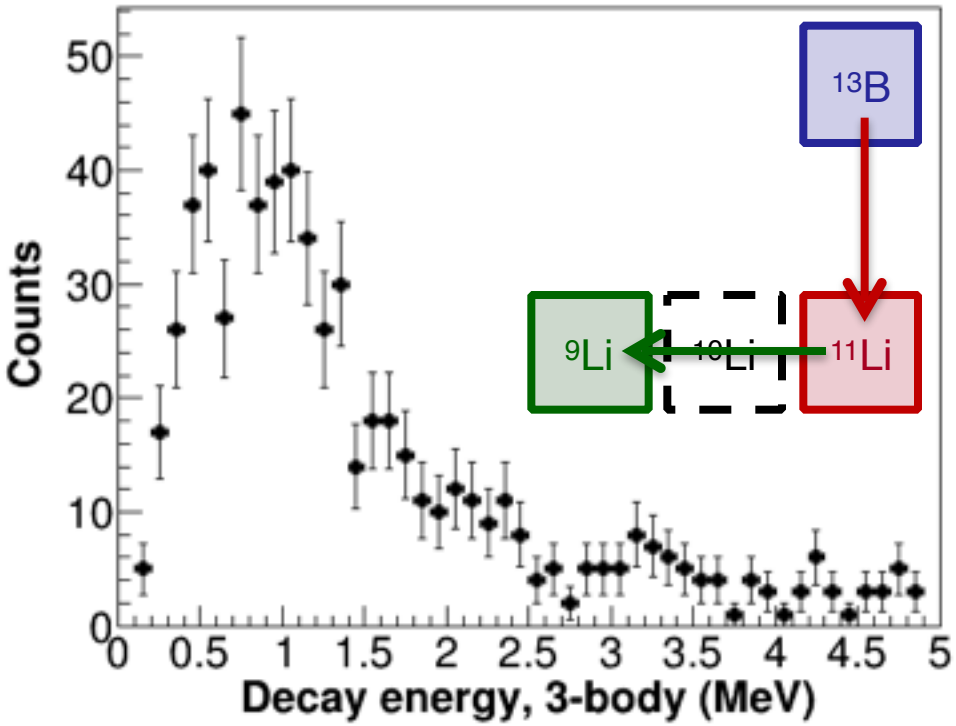
Two neutron correlations

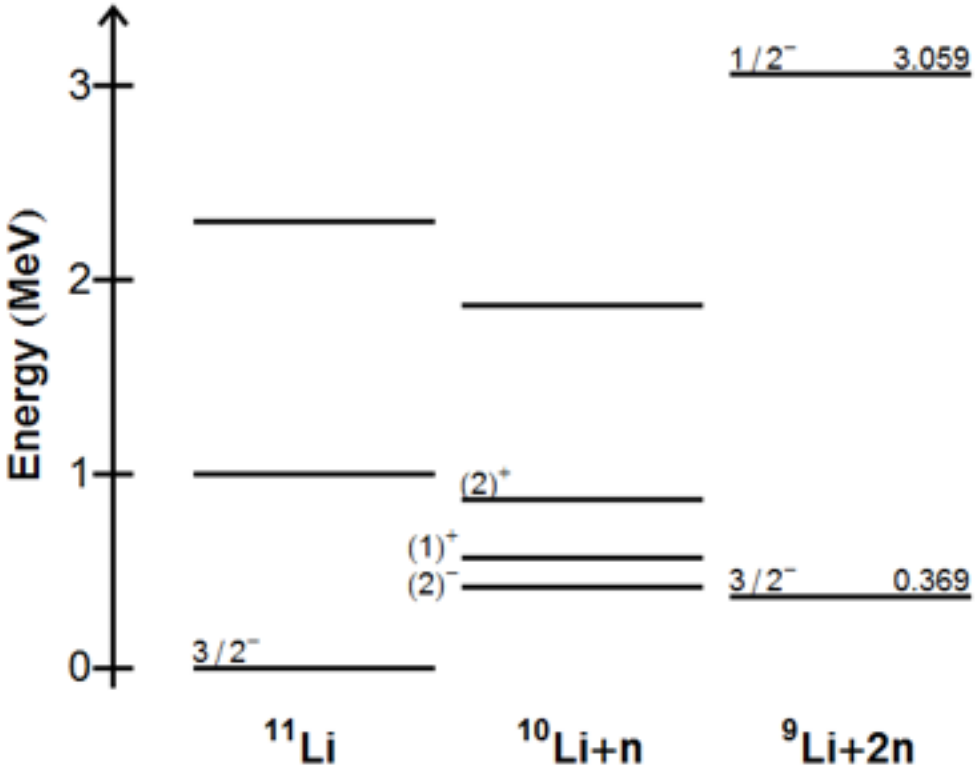
- **Sequential model**
  - continuum shell model formalism
  - input: central energies and widths
  - output: neutron energy distributions
  - neutrons: same orbital, paired to $J=0^+$
- **Dineutron model**
  - input: central energy and width
  - output: total energy and dineutron energy
  - assumes two L=0 decays
- **3-body model**
  - phase space decay
  - input: central energy and width
  - output: energies and angles of particles





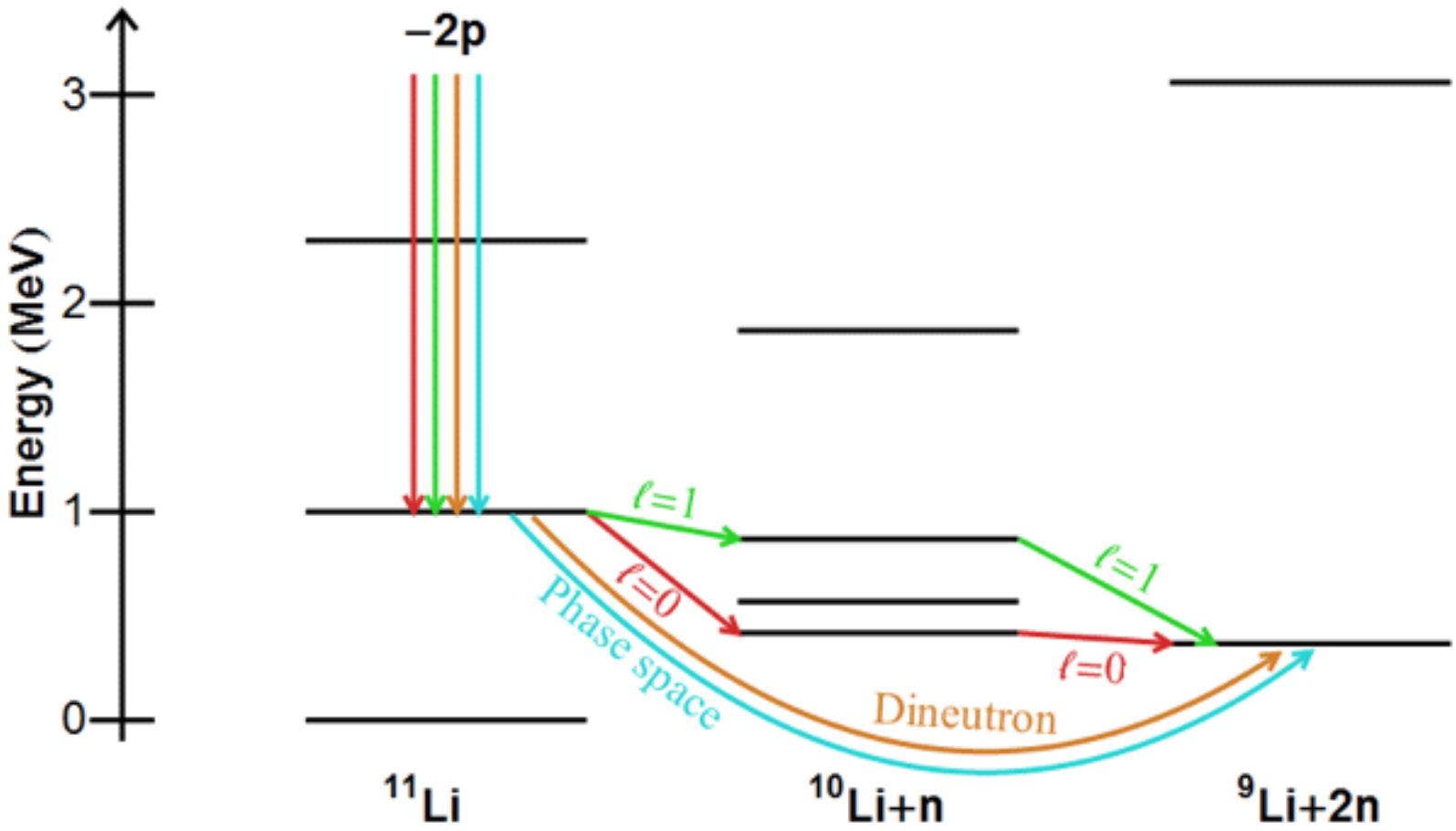
$^{11}Li^{*} \rightarrow {}^{9}Li+2n$ decay energy



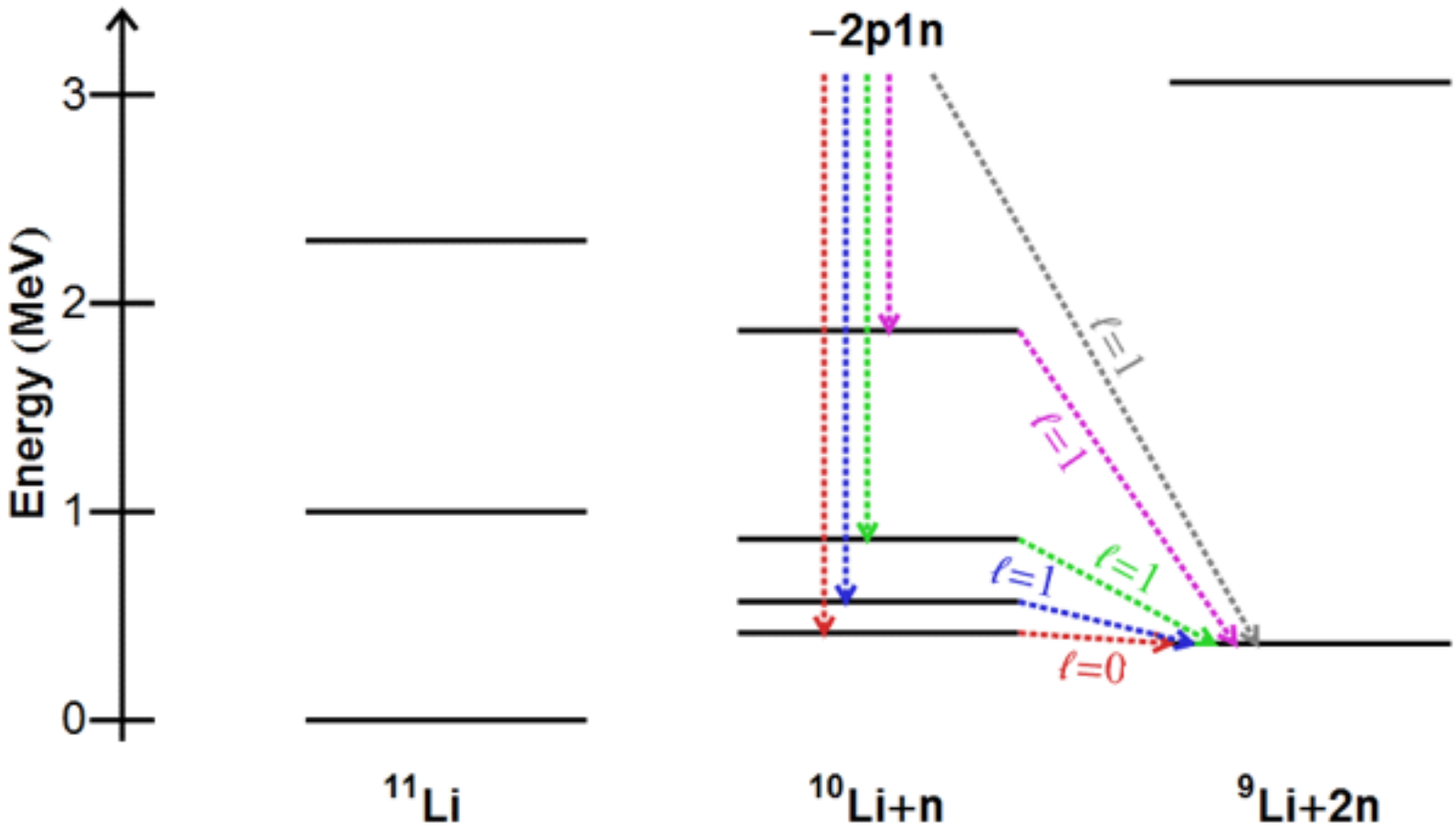


Smith et al., PLB, in review

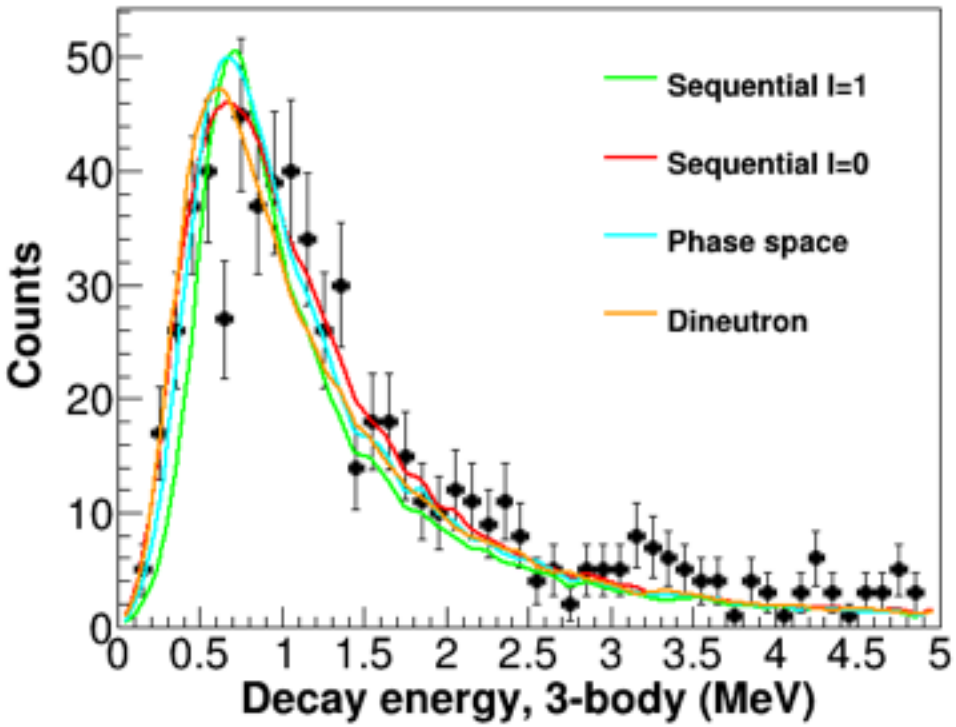
Potential decay paths – 2n

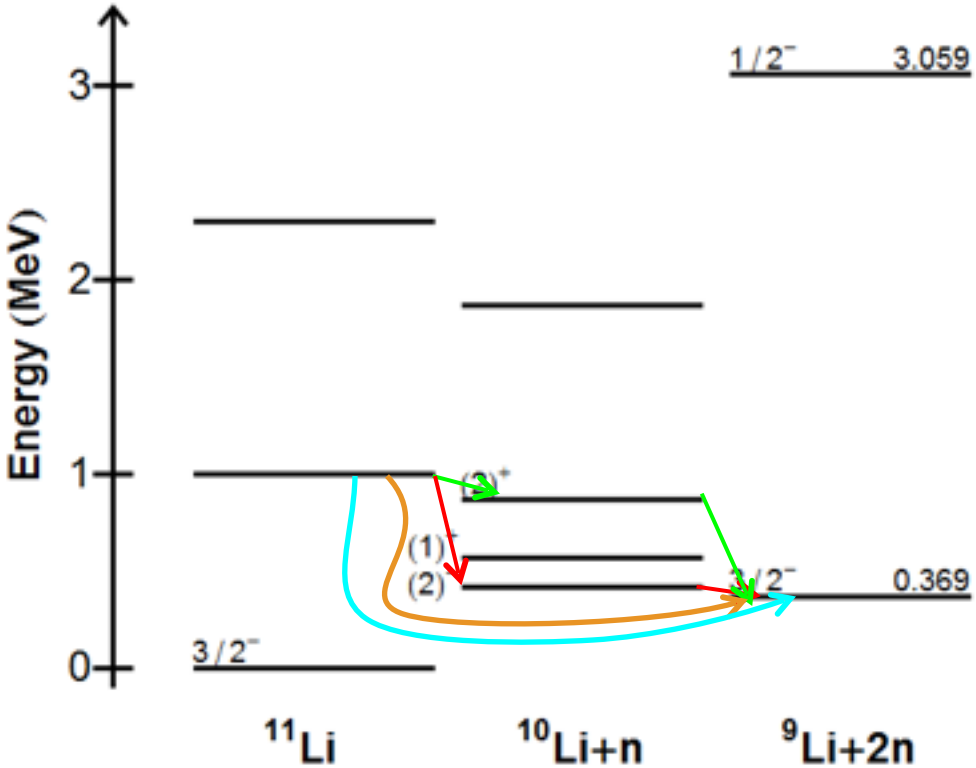


Potential decay paths – 1n



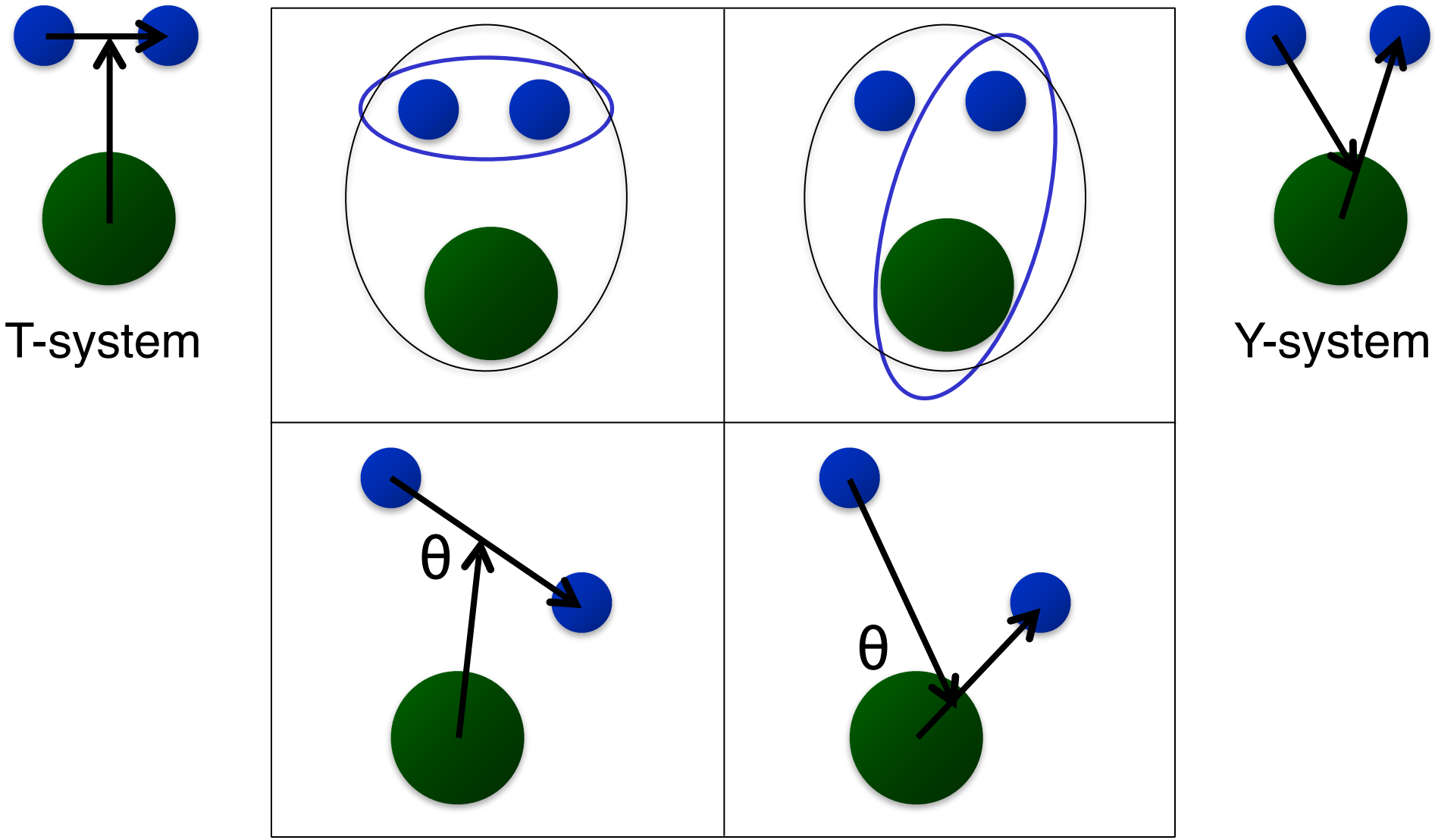
$^{11}Li^{*} \rightarrow {}^{9}Li+2n$ decay energy



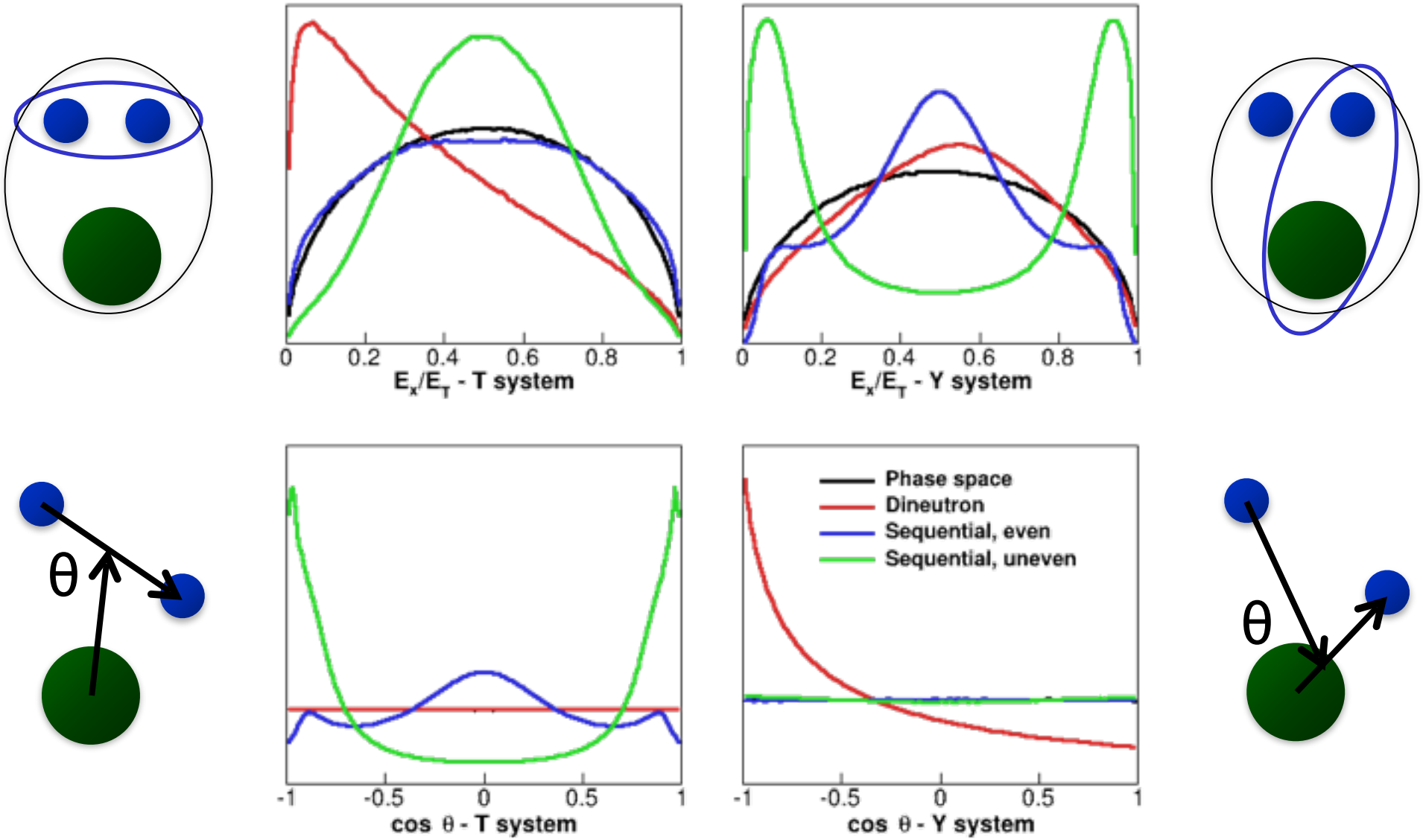


Smith et al., PLB, in review

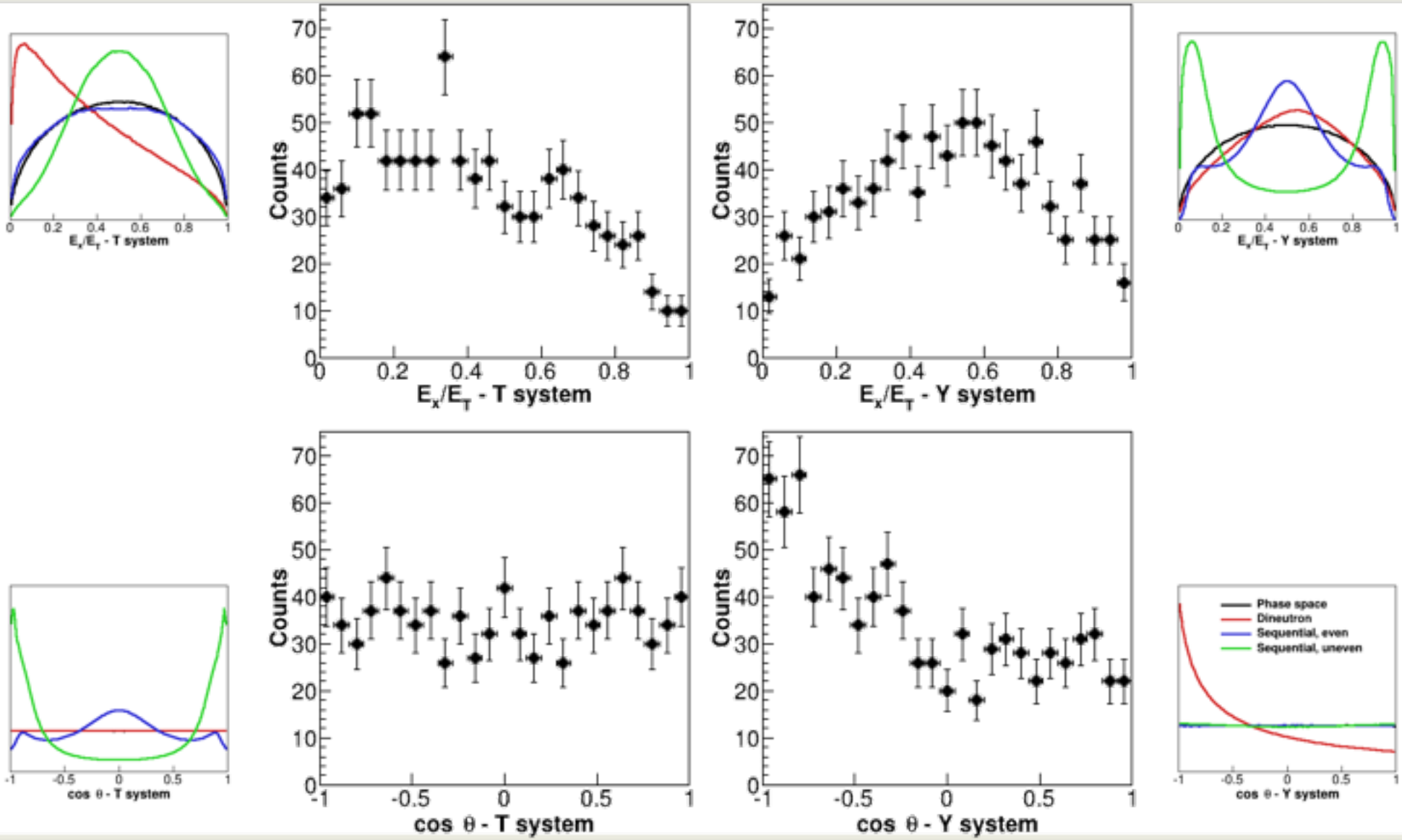
Jacobi plot definitions



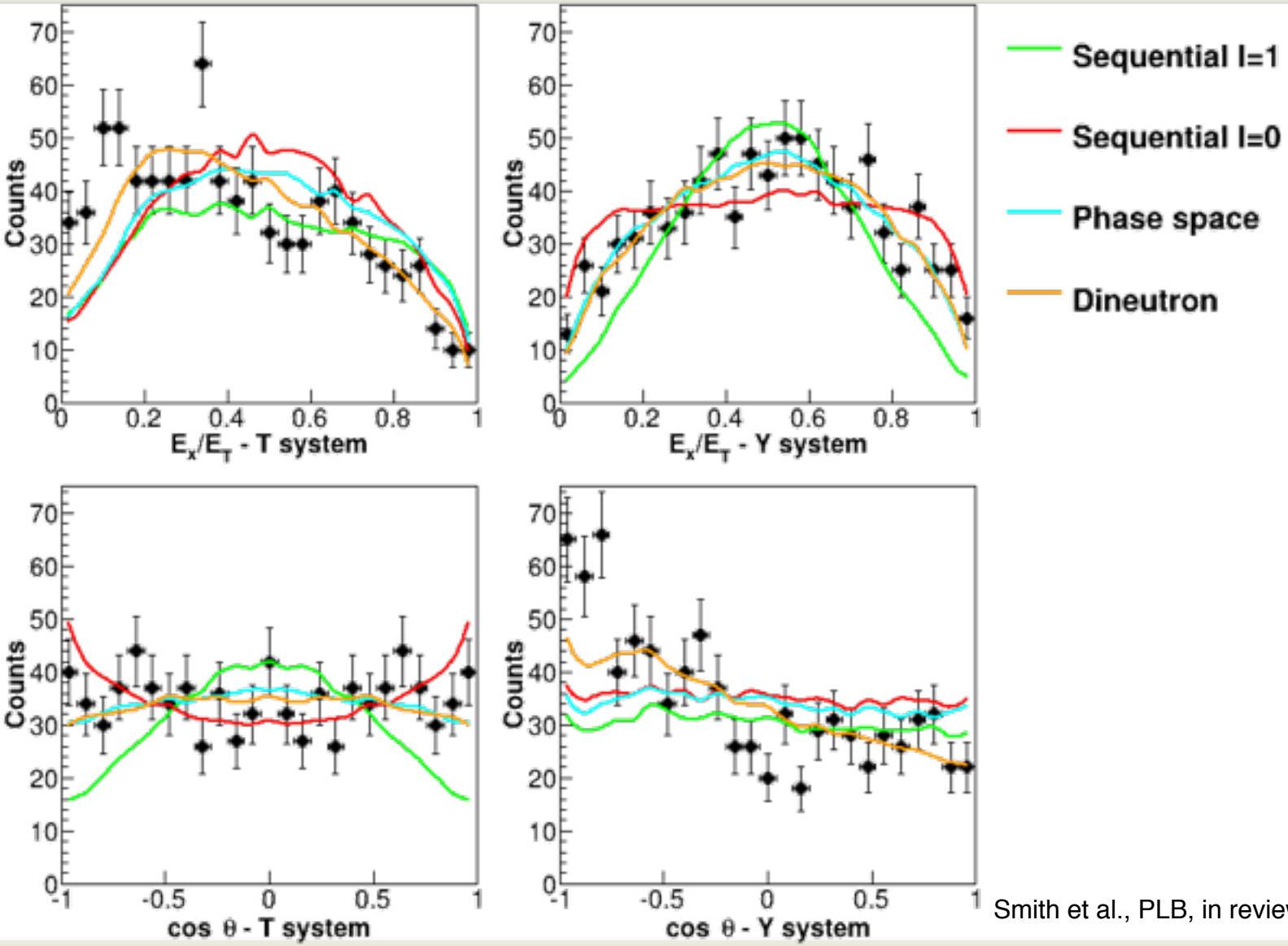
Jacobi plots



^{11}Li Jacobi plots

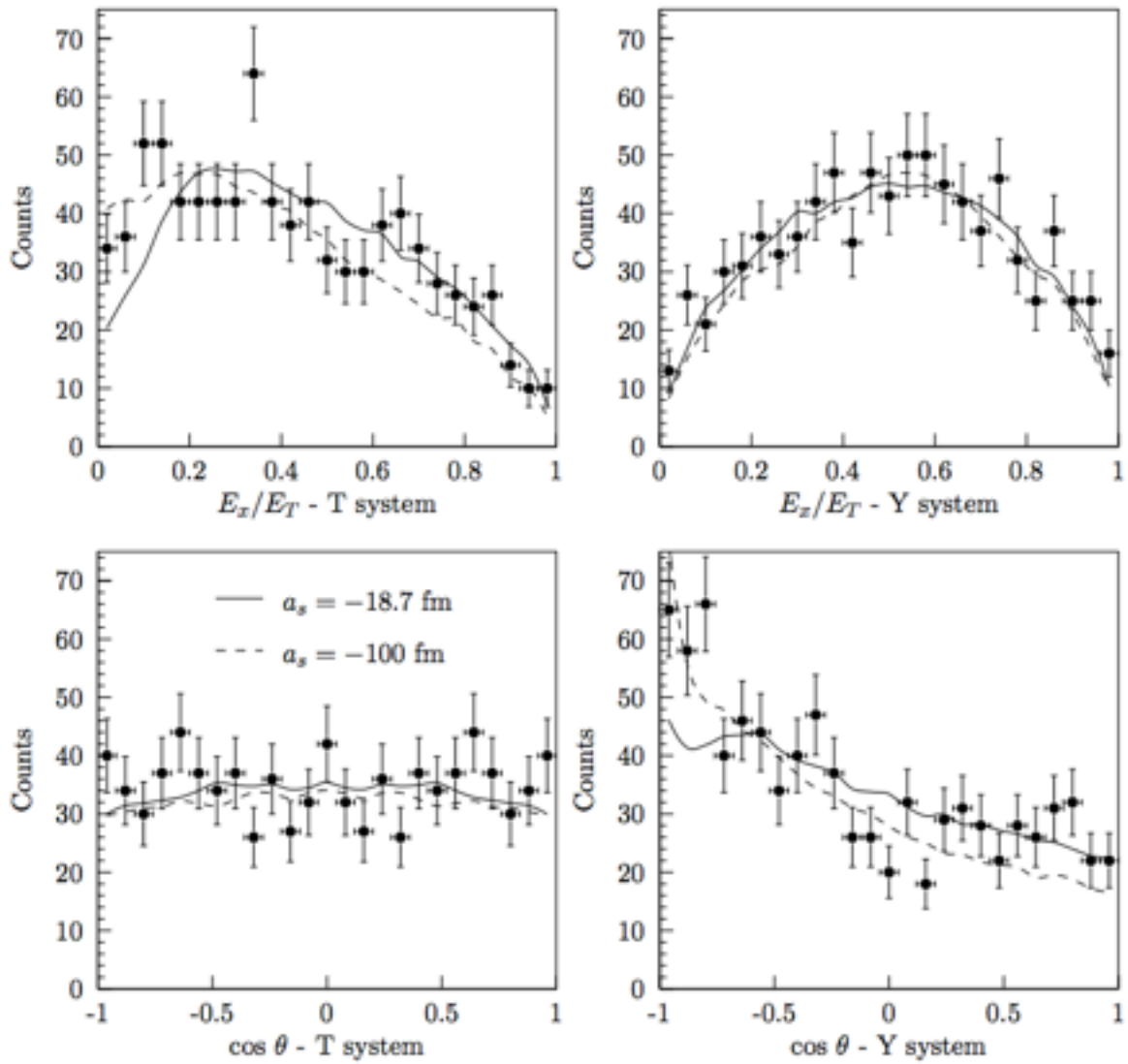


Jacobi plots



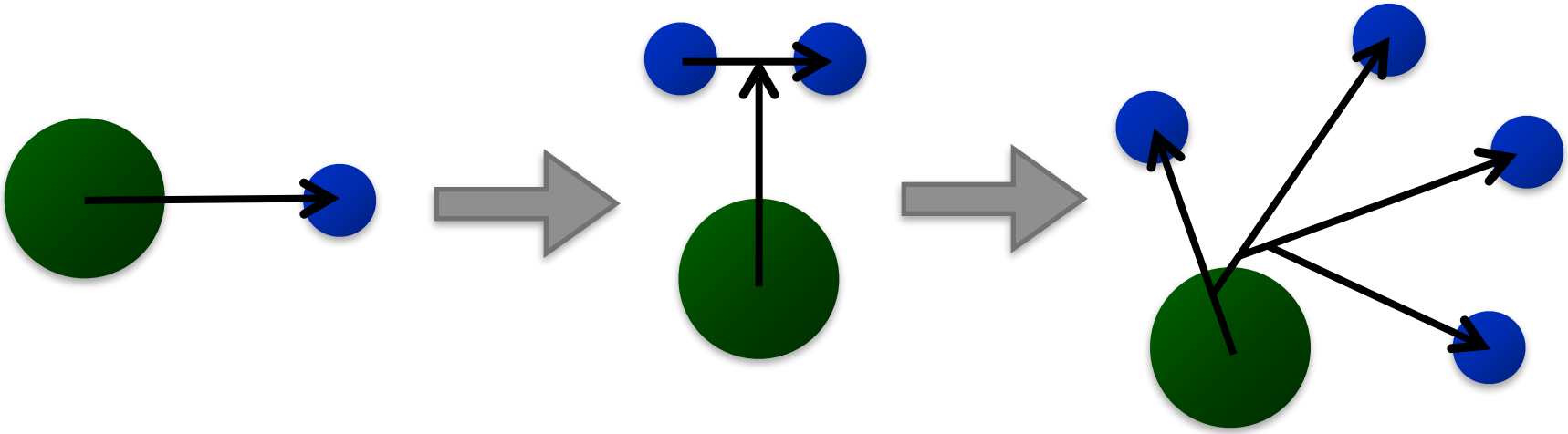
Smith et al., PLB, in review

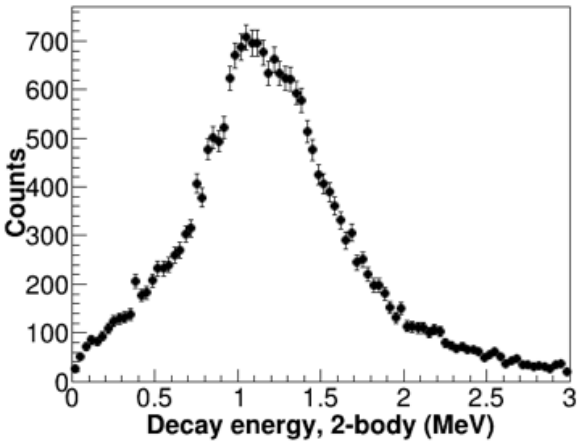
Jacobi plots

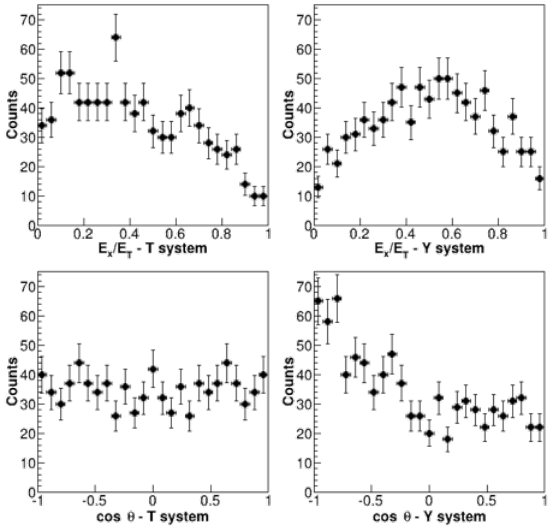


Smith et al., PLB, in review

Pushing particle decay farther







???

Future directions

- Combining neutron detectors with gamma, beta detectors
- Identification of unique particles (neutrons)
- Better models that track the entire decay
- Neutron-rich beams needed to reach the neutron drip line at higher Z

Acknowledgements

- **Local MoNA group**
  - Thomas Baumann, Greg Christian, Michael Jones, Zach Kohley, Shea Mosby, Jesse Snyder, Artemis Spyrou, Krystin Stiefel, Michael Thoennessen
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- **NSCL**
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Thank you