Decoupling with the Similarity Renormalization Group (SRG)

E.D.Jurgenson

Department of Physics
The Ohio State University

APS Division of Nuclear Physics
Newport News, VA
October 11-13, 2007

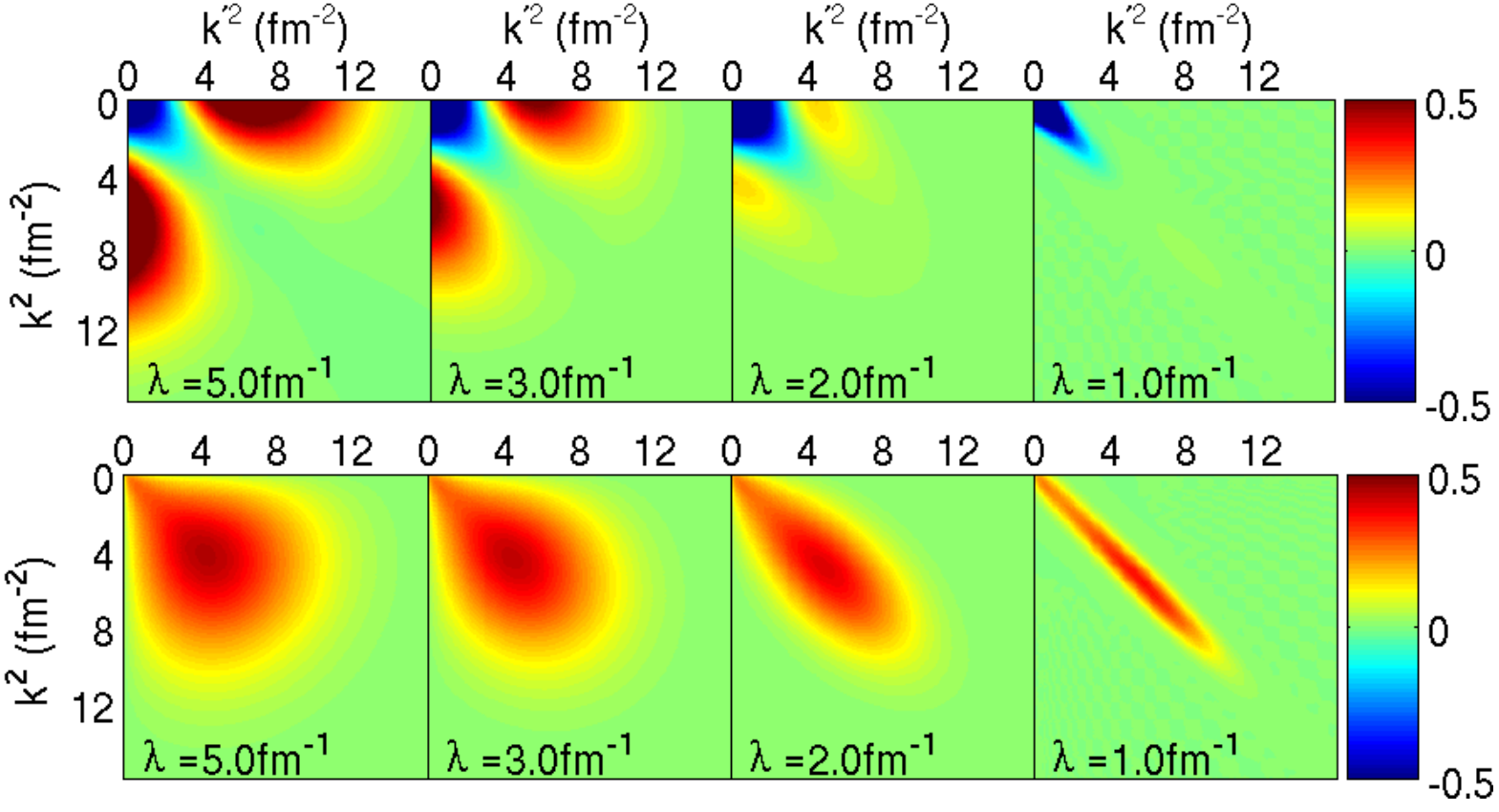
Work supported by NSF and UNIDEF/SciDAC (DOE)
Collaborators: E.R.Anderson, S.K.Bogner, R.J.Furnstahl, P.Maris, R.J.Perry, A.Schwenk, J.Vary

On the web: `http://www.physics.ohio-state.edu/~ntg/srg/`

What does the SRG do?

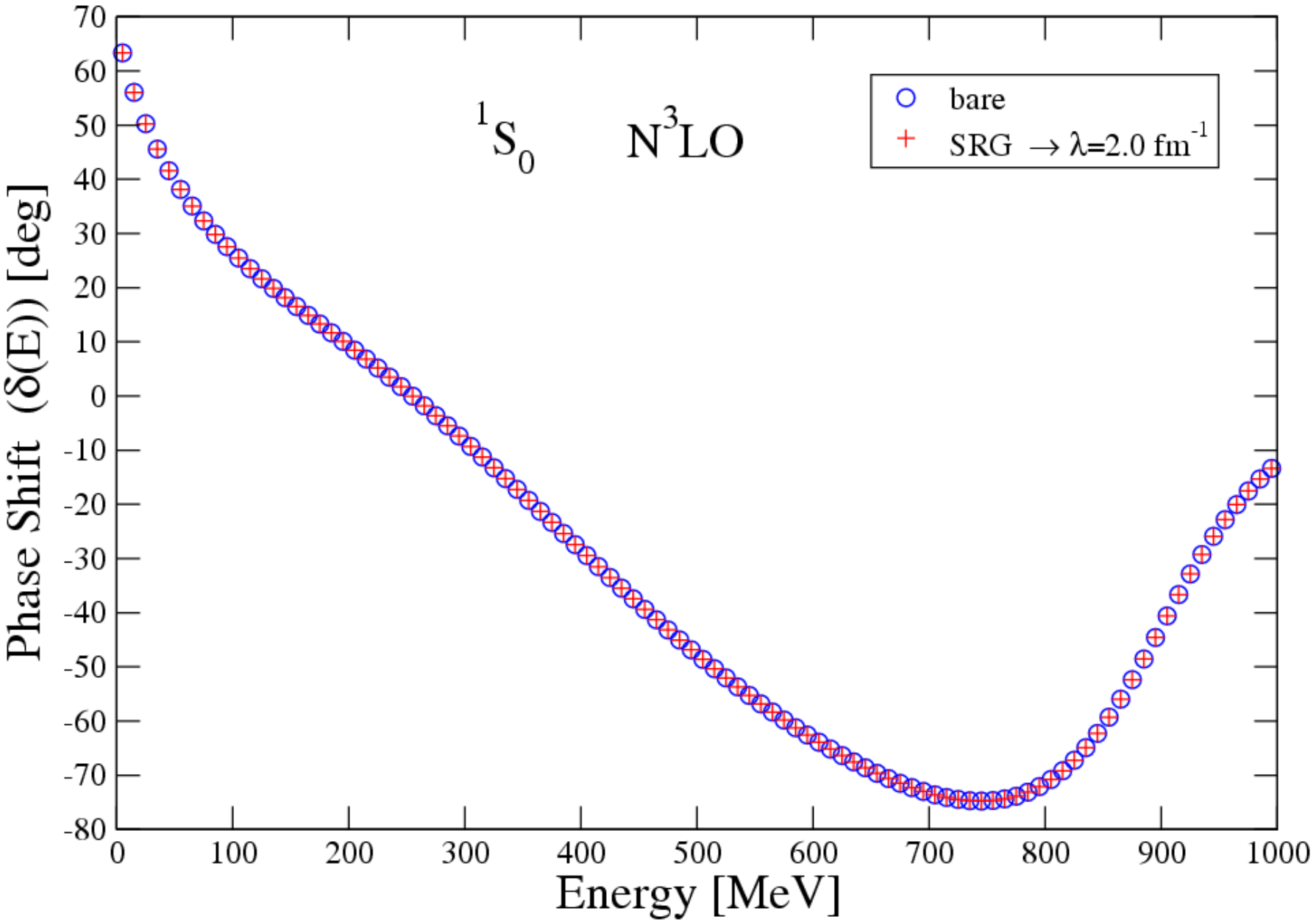
$$H_\lambda = U(\lambda) H U^\dagger(\lambda) \equiv T_{\rm rel} + V_\lambda$$

$^3S_1$ and $^1P_1$ Partial Waves in N^{3}LO (500 MeV) E/M



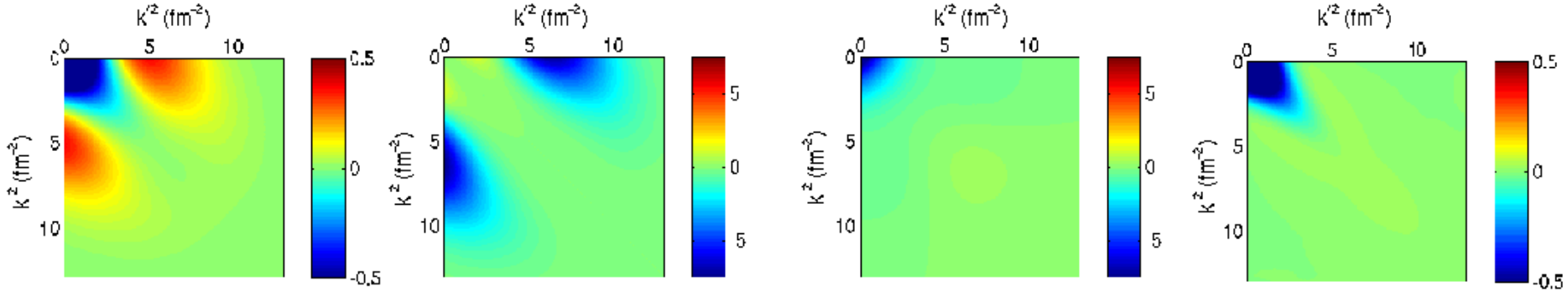
Units: $[k^2] = \mathrm{fm}^{-2}$, Important region: $0 - 4\mathrm{fm}^{-2}$

Unitary Transformations $\Longrightarrow$ Preserve Observables



The Mechanics of Decoupling

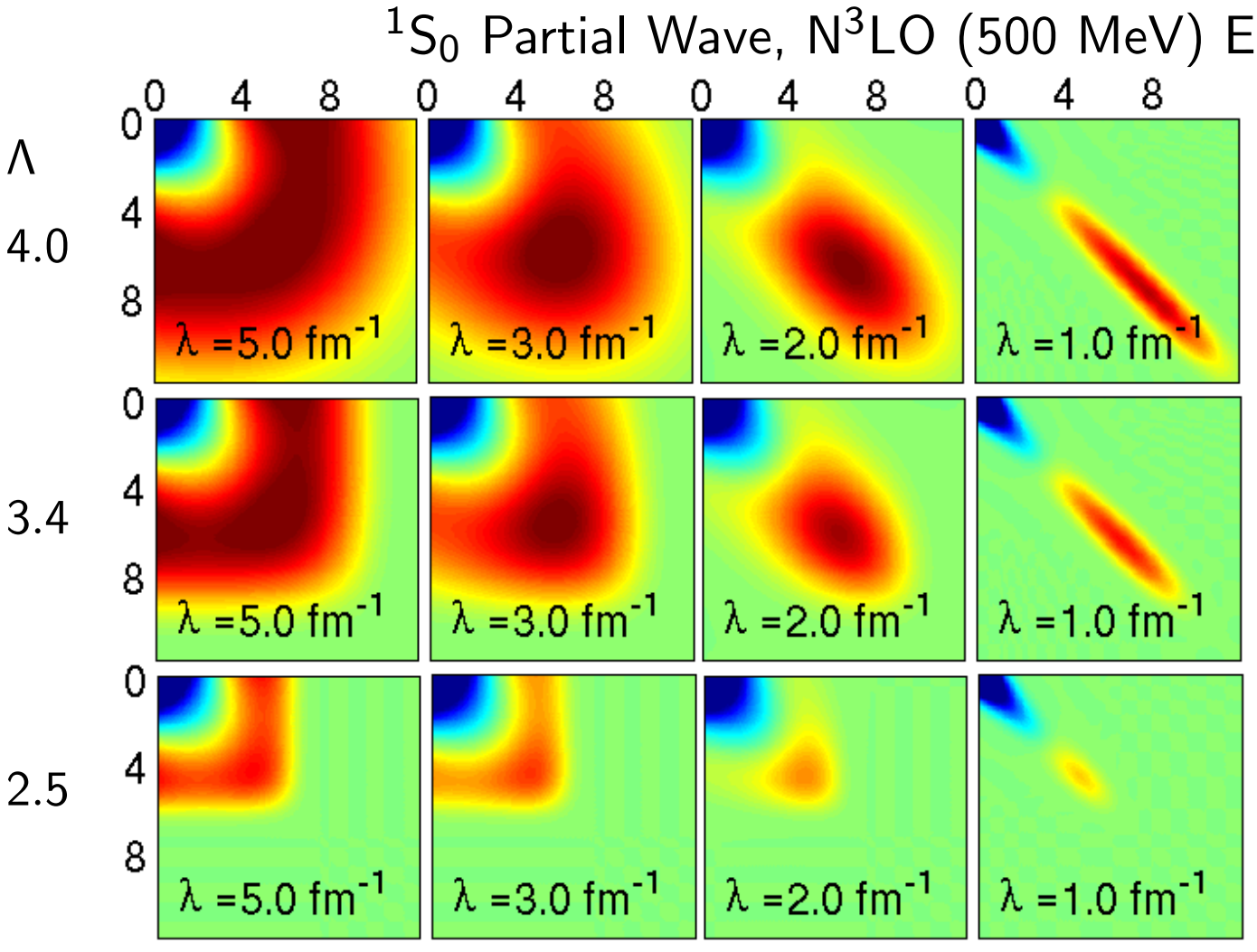
$$\frac{dV_\lambda(k,k')}{d\lambda} = -(\epsilon_k - \epsilon_{k'})^2 V_\lambda(k,k') + \sum_q (\epsilon_k + \epsilon_{k'} - 2\epsilon_q) V_\lambda(k,q) V_\lambda(q,k')$$



$V_{\lambda=2.5}$ + 1st term + 2nd term $\longrightarrow$ $V_{\lambda=1.5}$

- Off-diagonal elements
  $\Longrightarrow V_\lambda(k,k') \propto V_{NN}(k,k') e^{-[(\epsilon_k - \epsilon_{k'})/\lambda^2]^2}$
- Relevant physics flows to low momentum elements

Testing Decoupling Quantitatively



Tool for Study

1 - run SRG to λ

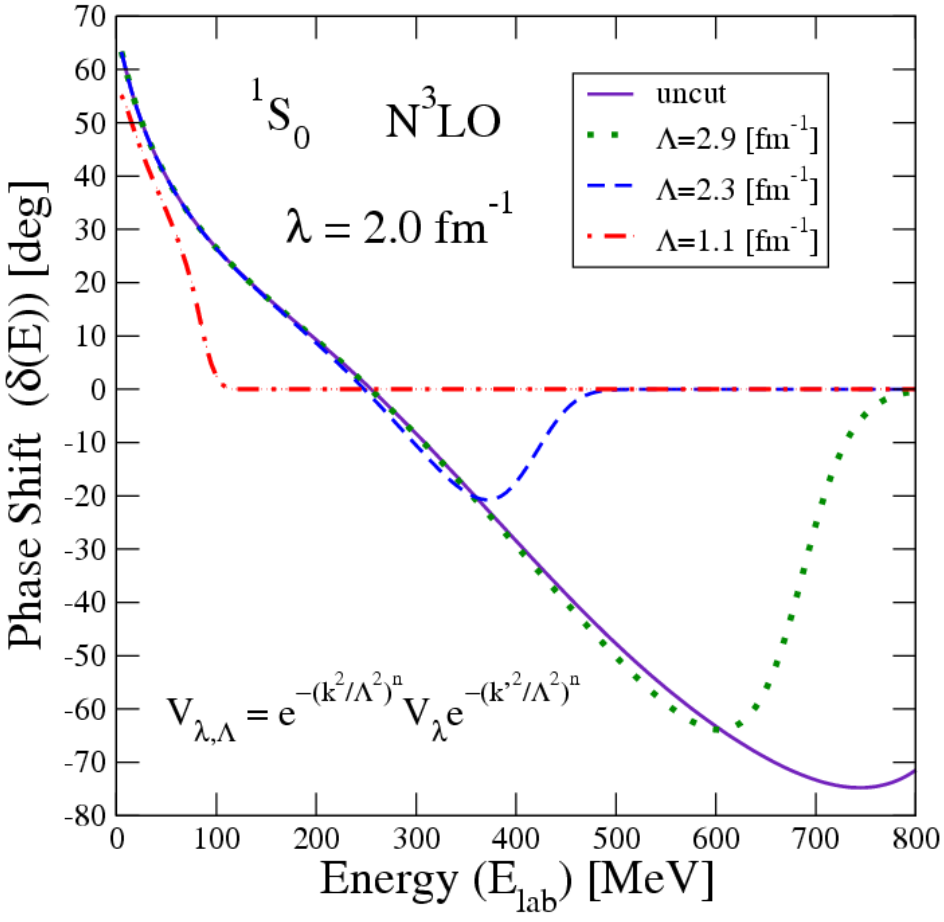
2 - set tail to zero

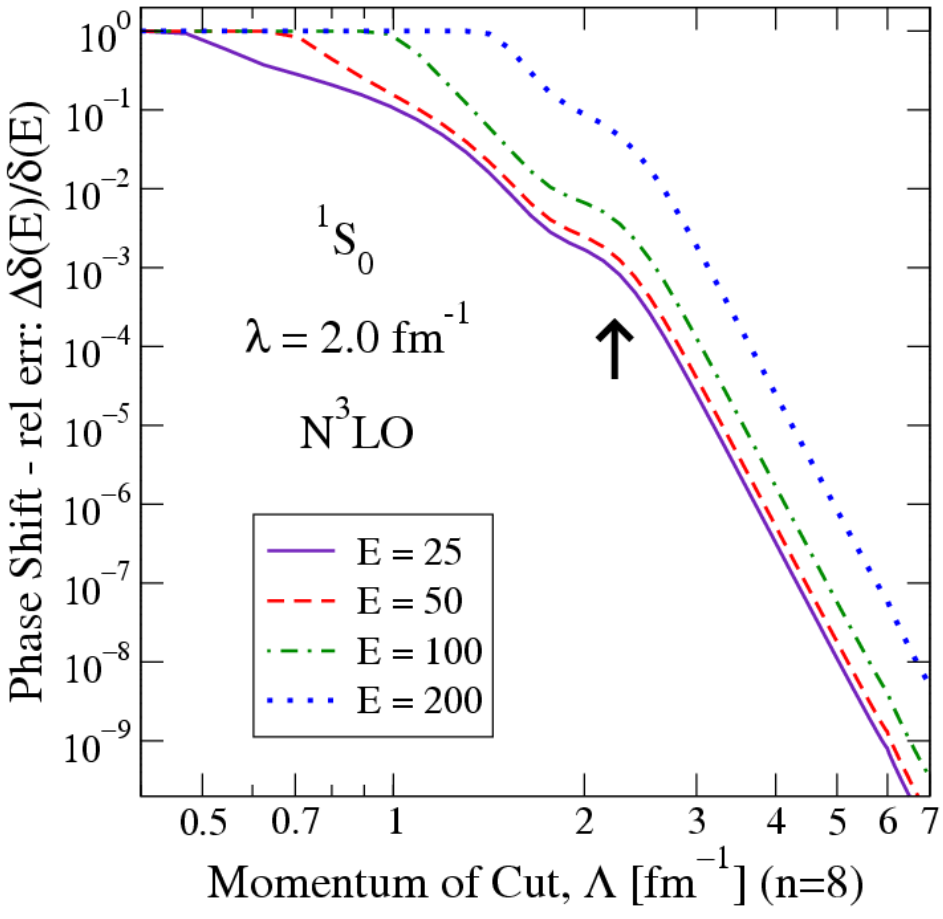
- $V_{\lambda,\Lambda} = e^{-(\frac{k^2}{\Lambda^2})^n} V_\lambda e^{-(\frac{k'^2}{\Lambda^2})^n}$
- n = 4,8,12,...

3 - relative errors

- Improves convergence of calculated observables, . . .

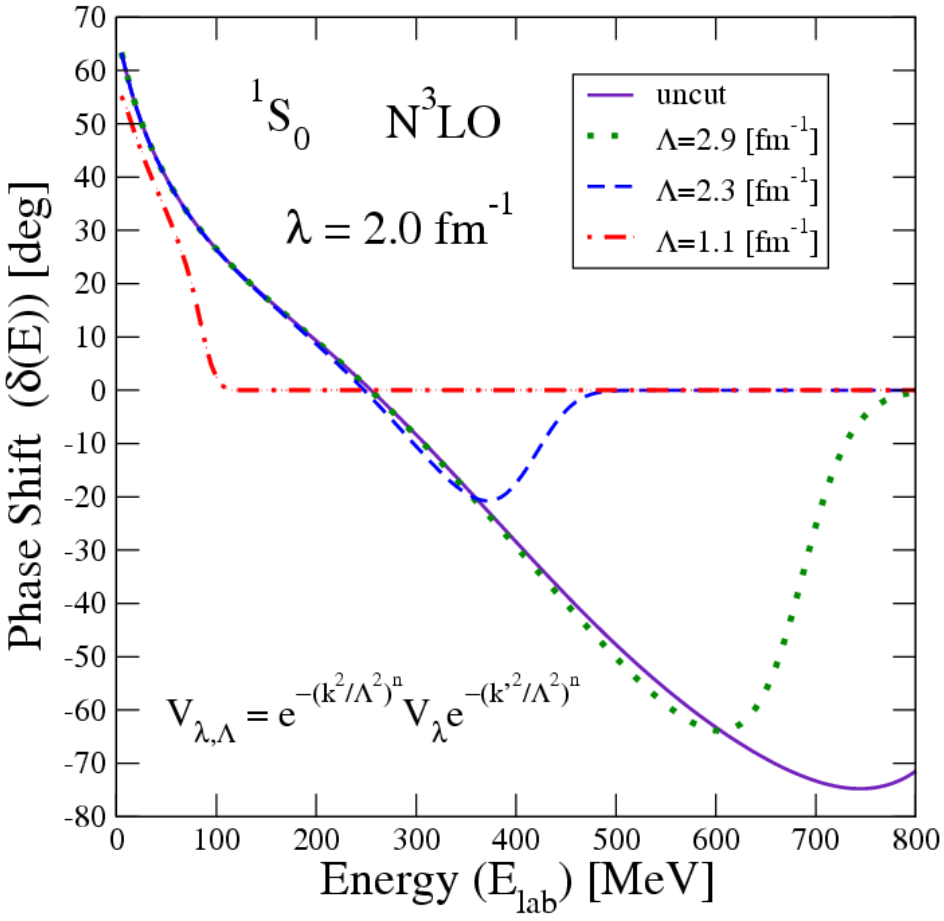
Phase Shifts:Decoupled above λ - vary Energy

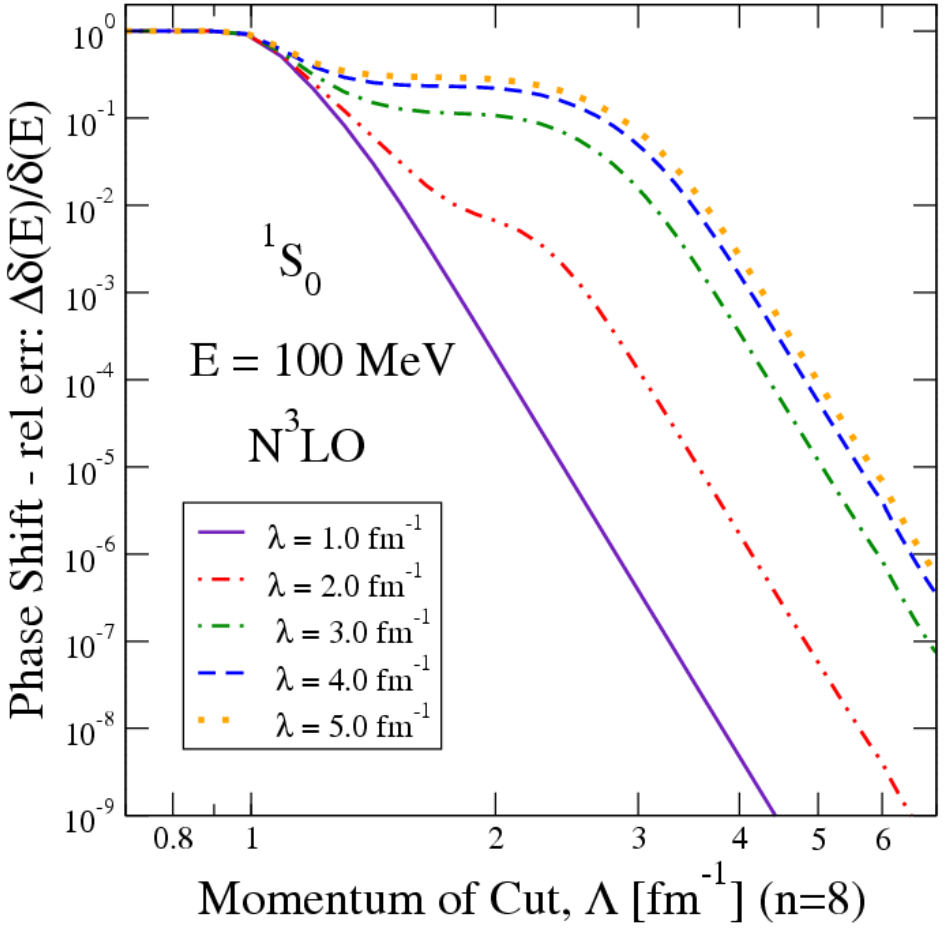




- Relevant physics flows to low momentum $\rightarrow$ Decoupling!

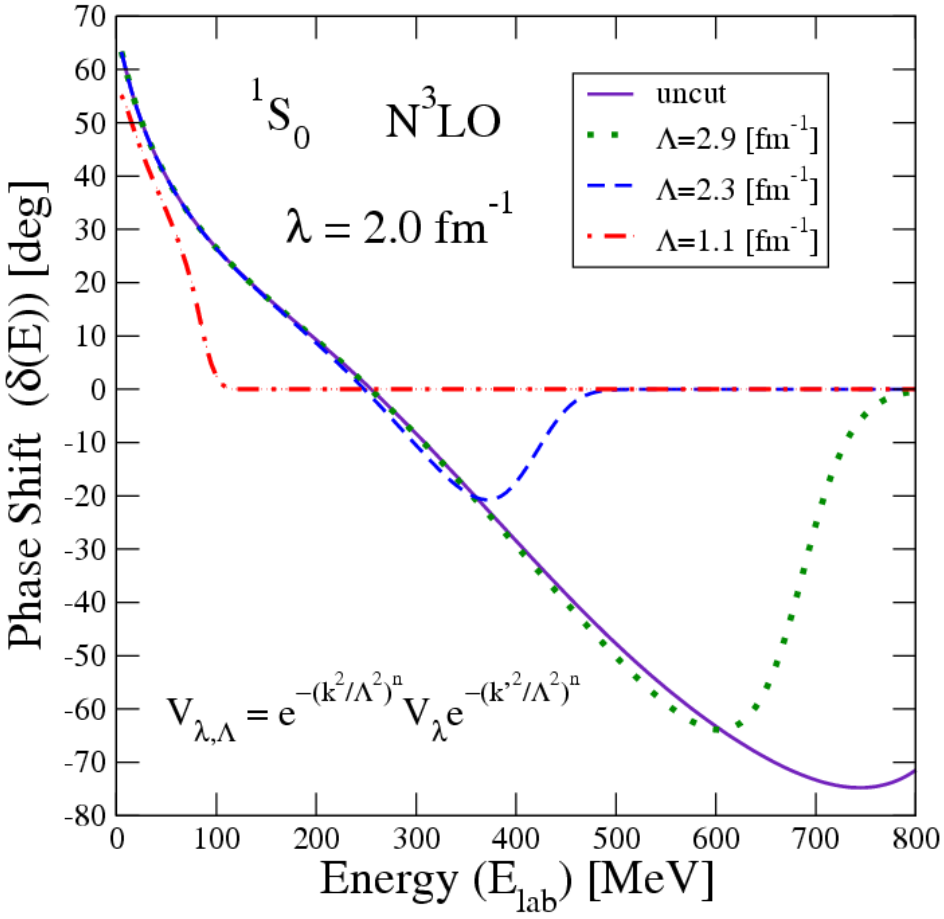
Phase Shifts:Decoupled above λ - vary λ

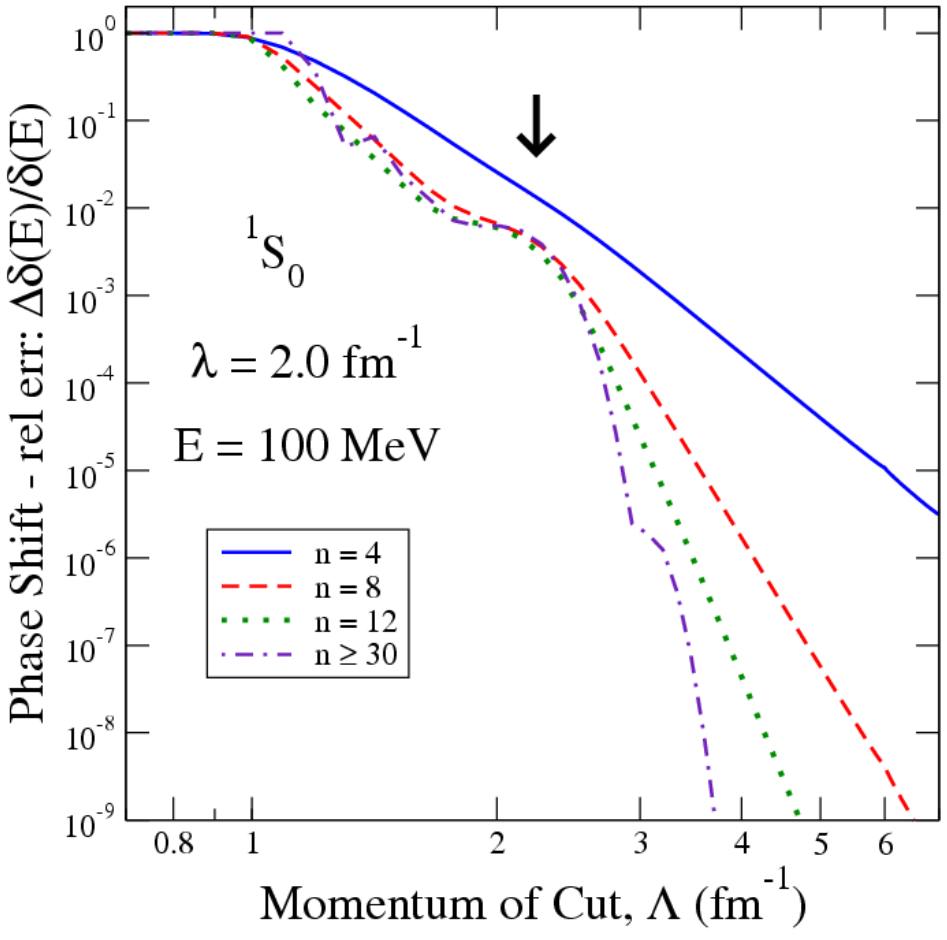




- Relevant physics flows to low momentum $\rightarrow$ Decoupling!

Phase Shifts:Decoupled above λ - vary n



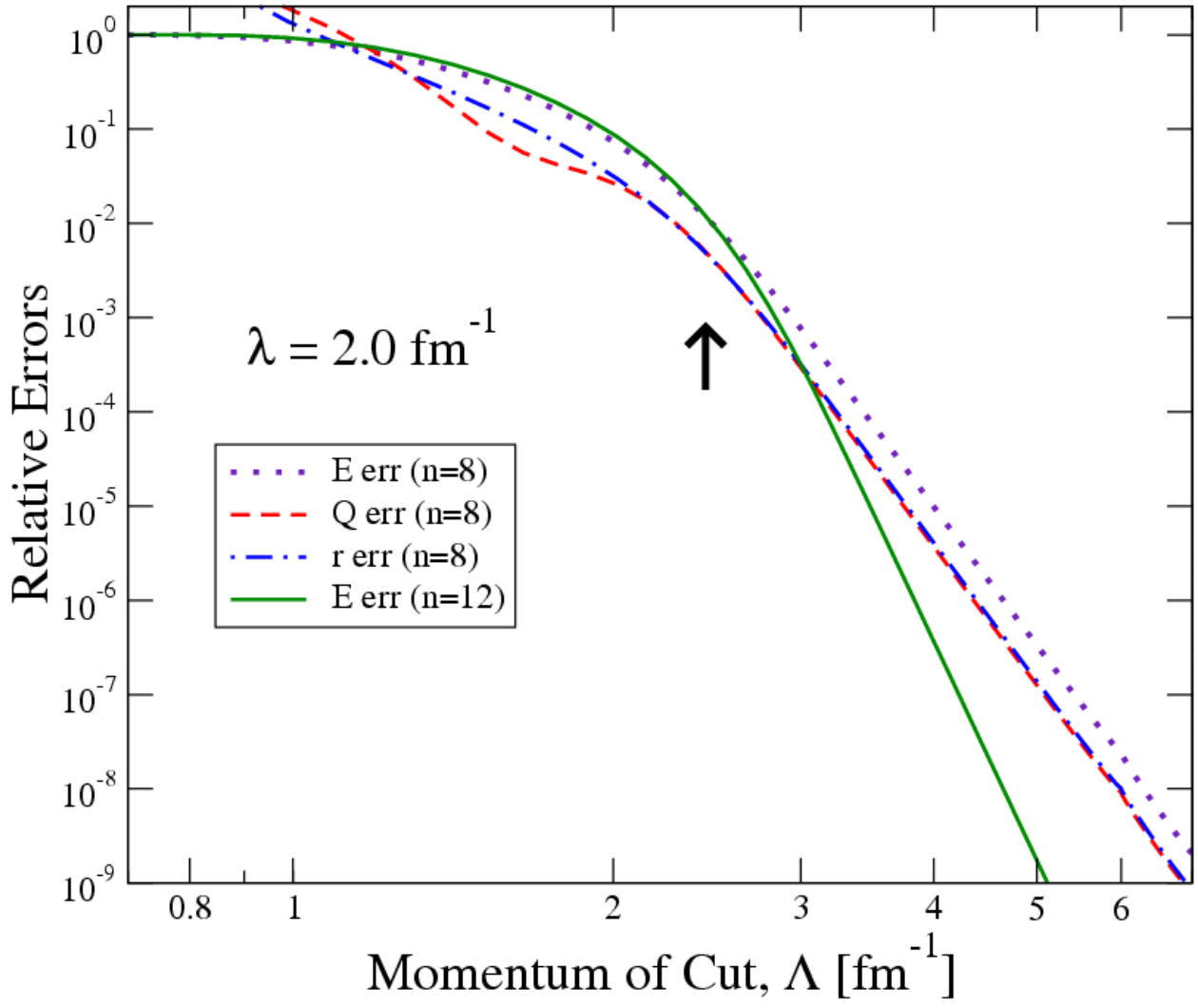


- Relevant physics flows to low momentum $\rightarrow$ Decoupling!

Deuteron Observables

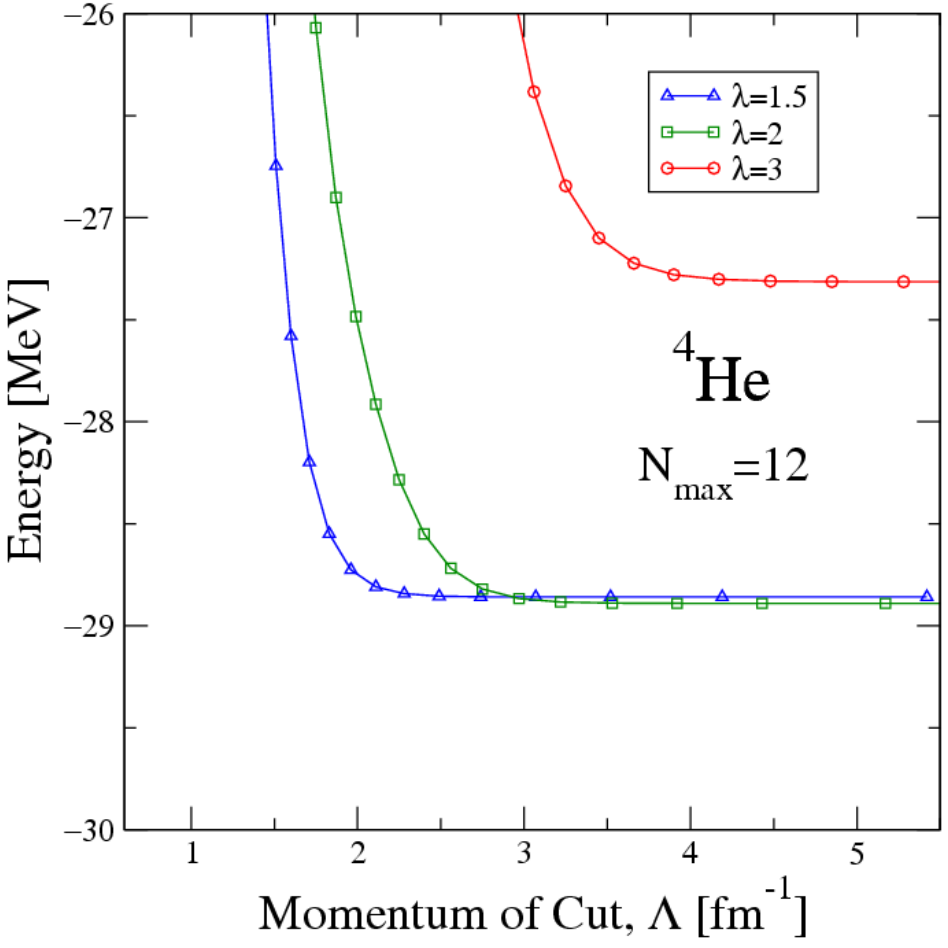
Deuteron Observables

- Binding Energy
- Quadrupole Moment
- RMS radius

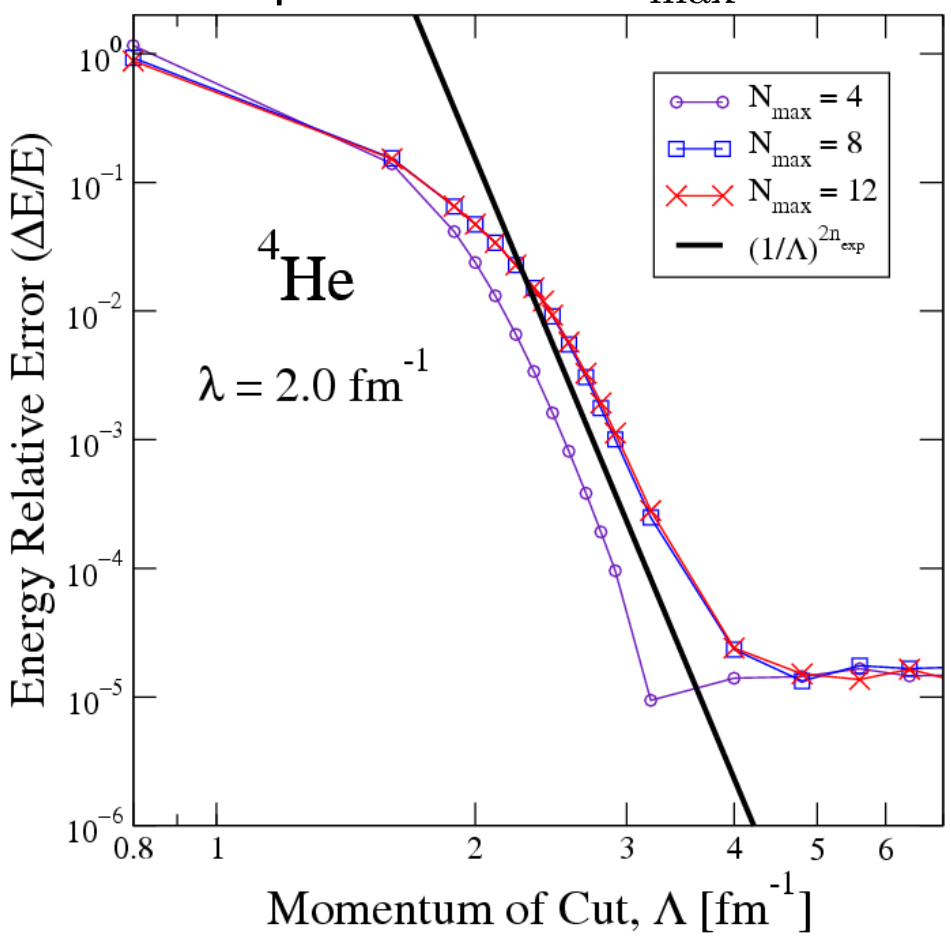


^{4}He Energy using No Core Shell Model

dependence on λ



dependence on N_{max}



- SRG improves convergence with basis size in NCSM
- NN-only $\Longrightarrow$ different ^{4}He Binding Energies

Conclusions

Recap

- SRG partially diagonalizes potential
- Studied how high-energy decouples from low-energy
- Very clean and universal for NN forces
- Perturbation theory shows power-law behavior
- Regulator is Tool for Study - not kept in calculations!

Outlook

- 3N forces will be included
- Cutting may speed SRG evolution (especially in 3N)
- Interesting to understand the coupled region ($\Lambda < \lambda$)
  - Second order Bloch-Horowitz Analysis