Decoupling with the SRG

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National Nuclear Physics Summer School - 2007
Florida State University
July 8-22 2007

Work supported by NSF and DOE
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What is the Similarity Renormalization Group (SRG)?

Unitary transformations: [PRC 75:(2007)061001 arXiv:nucl-th/0611045]

$$H_s = U(s) H U^\dagger(s) \equiv T_{\mathrm{rel}} + V_s$$

$$\frac{dH_s}{ds} = [\eta(s), H_s] \quad \textit{where} \quad \eta(s) = \frac{dU(s)}{ds} U^\dagger(s) = -\eta^\dagger(s)$$

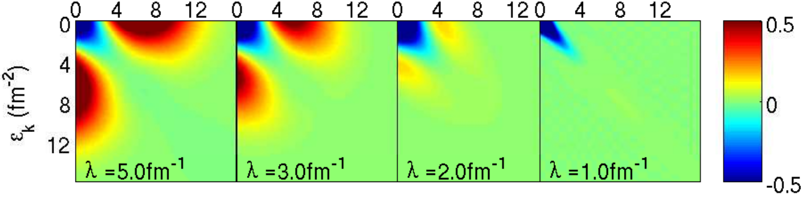
$$\eta(s) = [T_D, H_s] \quad \Longrightarrow \quad \frac{dH_s}{ds} = [[T_D, H_s], H_s]$$

Projected onto partial-wave momentum space:

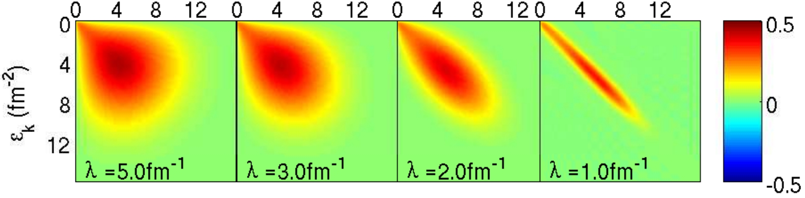
$$\frac{dV_s(k,k')}{ds} = -(\epsilon_k - \epsilon_{k'})^2 \, V_s(k,k') + \frac{2}{\pi}\int_0^\infty q^2\, dq \,(\epsilon_k + \epsilon_{k'} - 2\epsilon_q)\, V_s(k,q)\, V_s(q,k')$$

What does the SRG do?

$\lambda = 1/s^{1/4}$

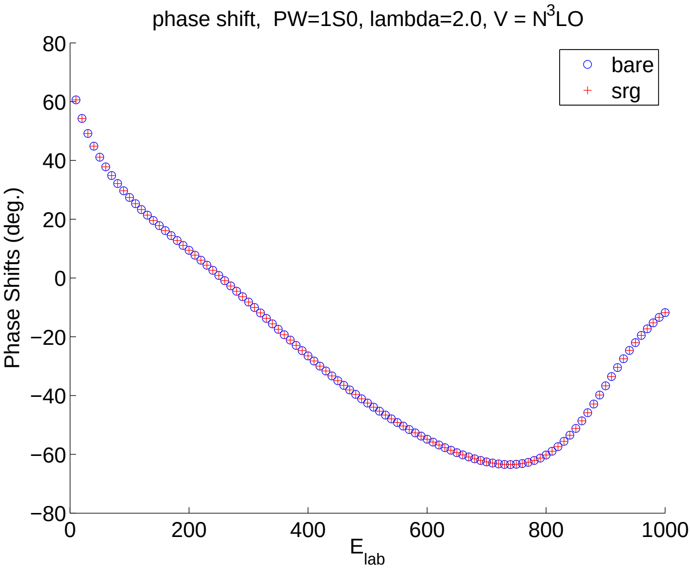


3S1, V = N3LO (kvnn = 10)



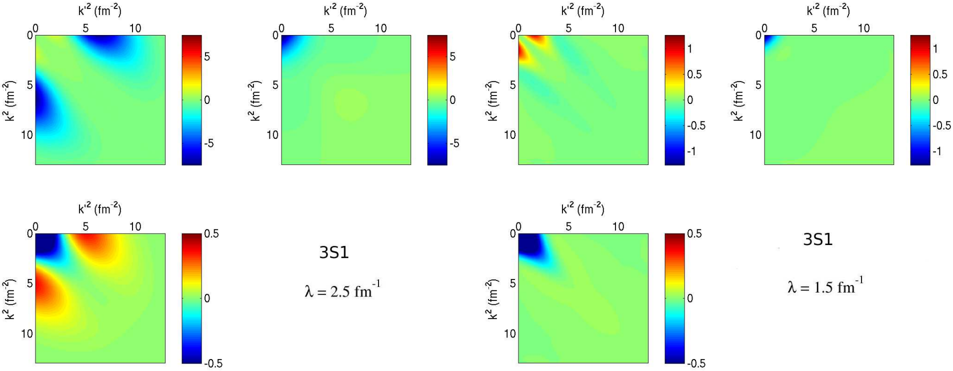
1P1, V = N3LO (kvnn = 10)

What's so special about unitary transformations?



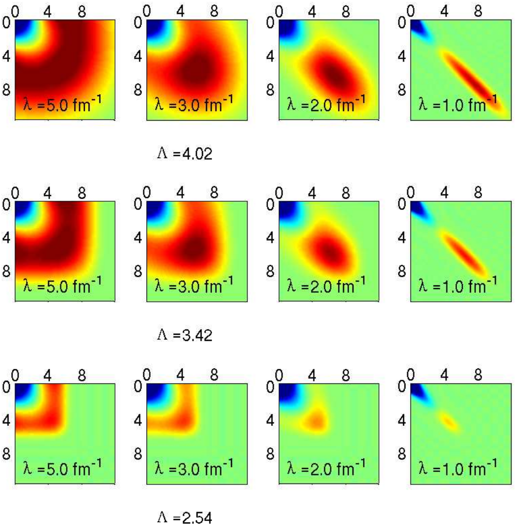
How is it doing this?

$$\frac{dV_s(k,k')}{ds} = -(\epsilon_k - \epsilon_{k'})^2 V_s(k,k') + \frac{2}{\pi}\int_0^\infty q^2 dq(\epsilon_k + \epsilon_{k'} - 2\epsilon_q) V_s(k,q) V_s(q,k')$$



$$V_s(k,k') = V_{s=0}(k,k') e^{-[(\epsilon_k - \epsilon_{k'})/\lambda^2]^2}$$

How much does the SRG decouple high/low?



- testing decoupling
- chop off the tail
- $V_{srg,\Lambda} = e^{-(\frac{k^2}{\Lambda^2})^{nexp}} V_{srg} e^{-(\frac{k'^2}{\Lambda^2})^{nexp}}$
- nexp $=$ 4,8,12,...
- physics not lost, flows to low momentum

What am I computing?

$$\text{Relative Error} = \frac{\delta_{\rm srg} - \delta_{\rm cut}}{\delta_{\rm srg}}$$

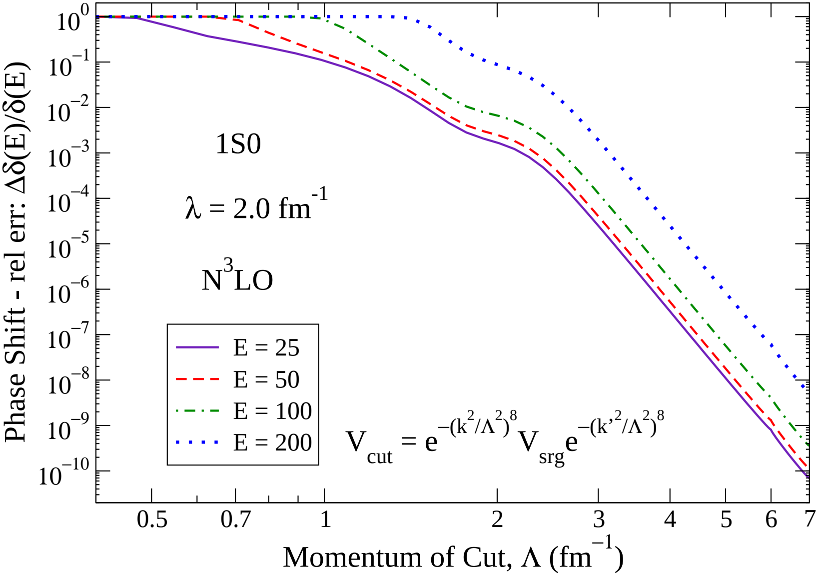
Phase Shift errors: $\Longrightarrow$ $\delta(E) = Tan^{-1}(-\frac{2\mu k}{\hbar^2} R_\ell(E))$

Deuteron observables: $\Longrightarrow$ $(T + V)|\psi\rangle = E|\psi\rangle$

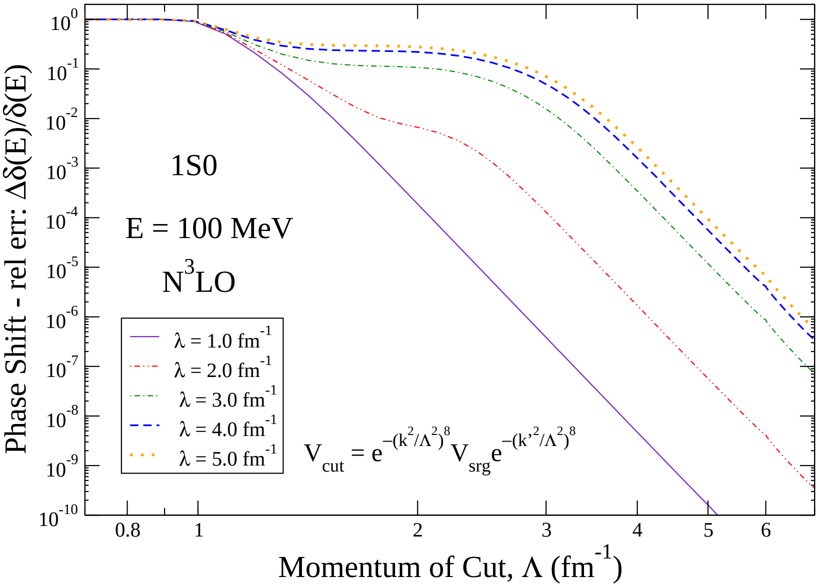
$$(\langle r^2\rangle^{1/2} = \int drr^2\psi^\dagger\psi \text{ and } Q_d = \int drr^2\psi_D^\dagger(\sqrt{8}\psi_S + \psi_D)$$

NCSM binding energies: $\Longrightarrow$ ^{3}H, ^{4}He, ^{6}Li

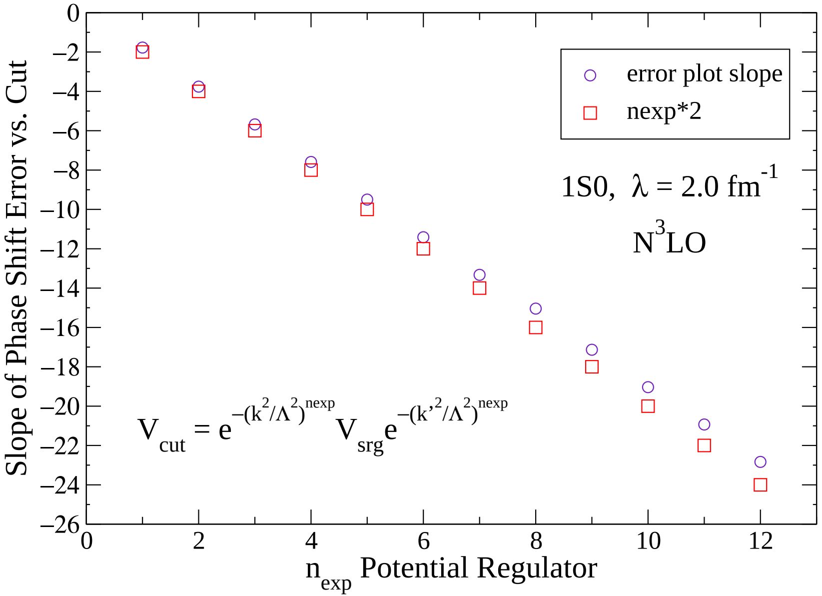
Phase Shifts - Energy



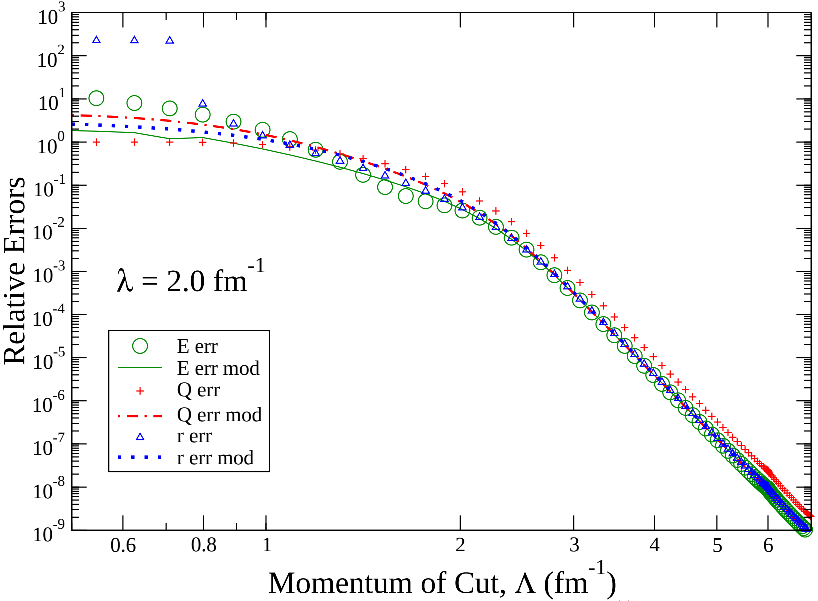
Phase Shifts - λ



What is that slope?

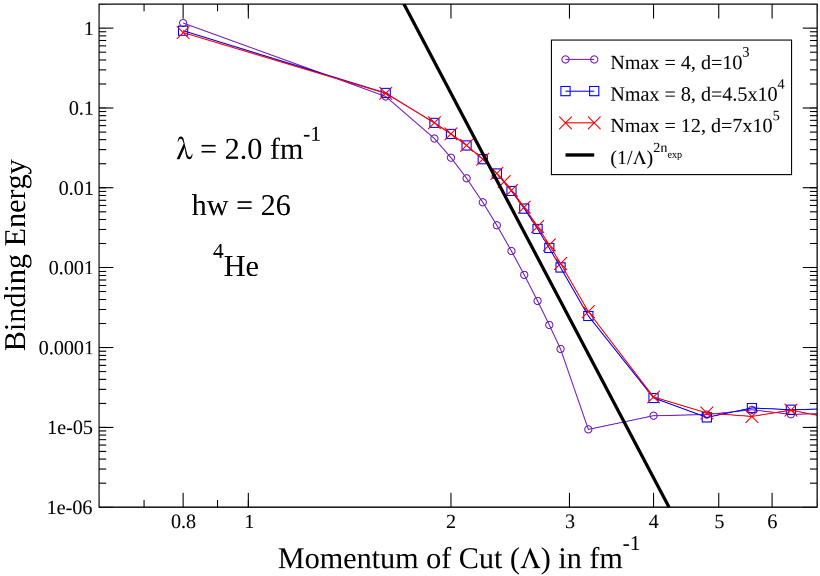


Deuteron observables?



NCSM observables?

Confirmation of the same behavior



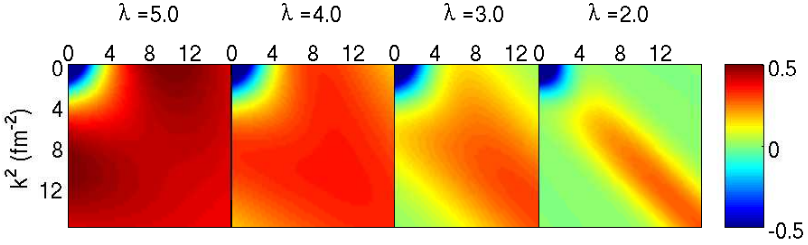
Conclusions and Goals

Recap

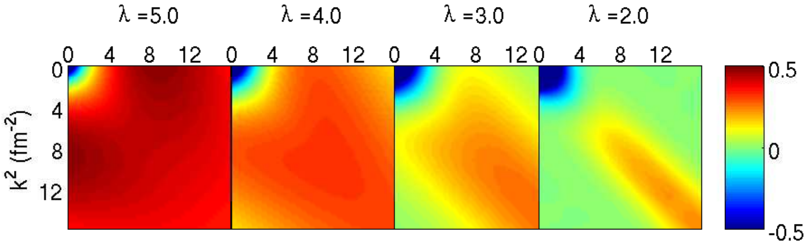
- SRG diagonalizes potential
- High decouples from low
- Very clean and universal in NN forces

Future

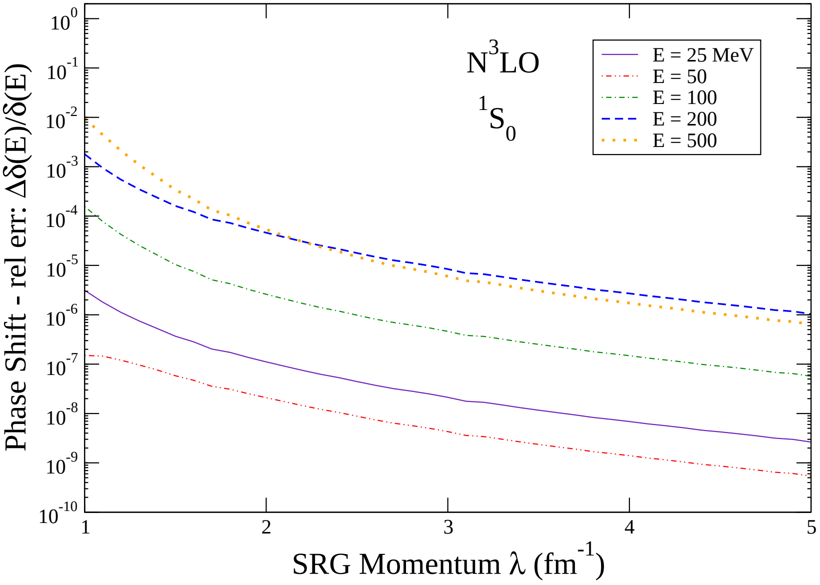
- NNN forces need to be included
- Cutting helps speed up SRG evolution (especially in 3N)
- interesting to understand the transient region



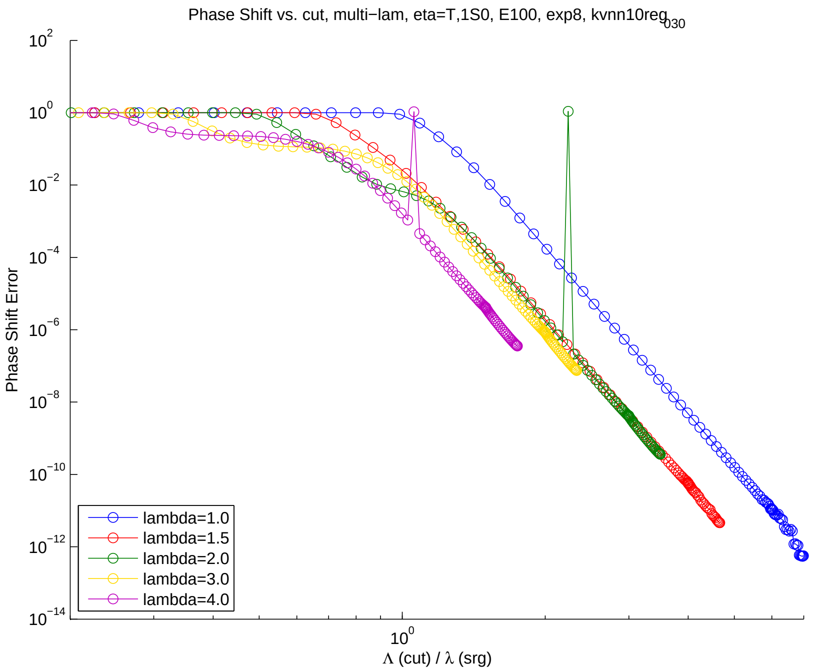
1S0, V = argonne v18 (kvnn = 06)



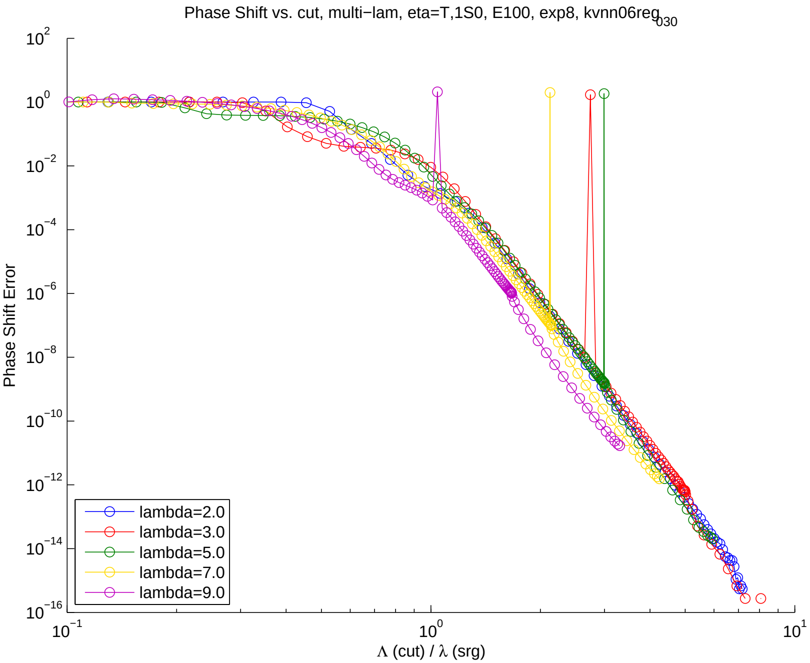
3S1, V = argonne v18 (kvnn = 06)



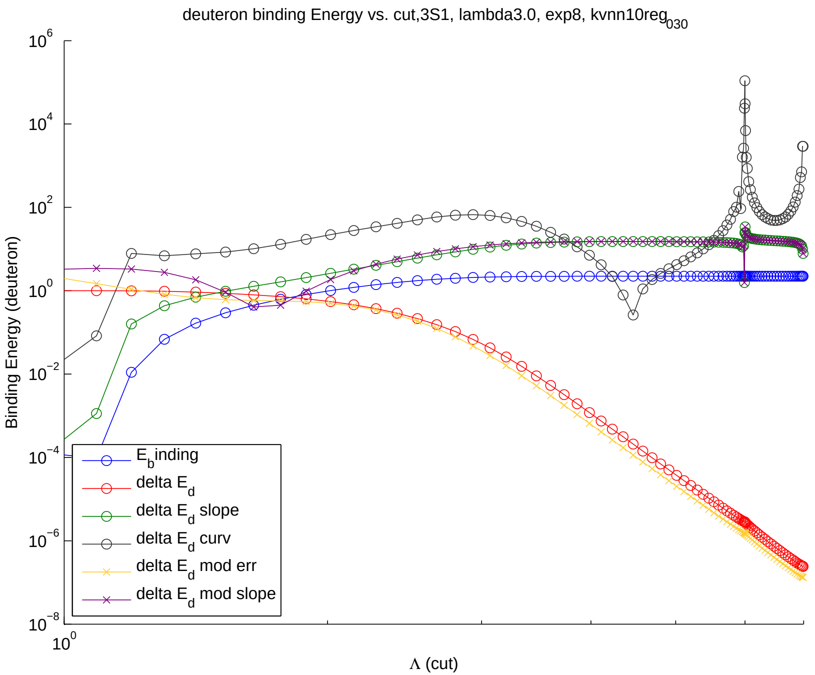
N^3LO
^1S_0
E = 25 MeV
E = 50
E = 100
E = 200
E = 500
Phase Shift - rel err: Δδ(E)/δ(E)
SRG Momentum λ (fm^-1)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
1
2
3
4
5



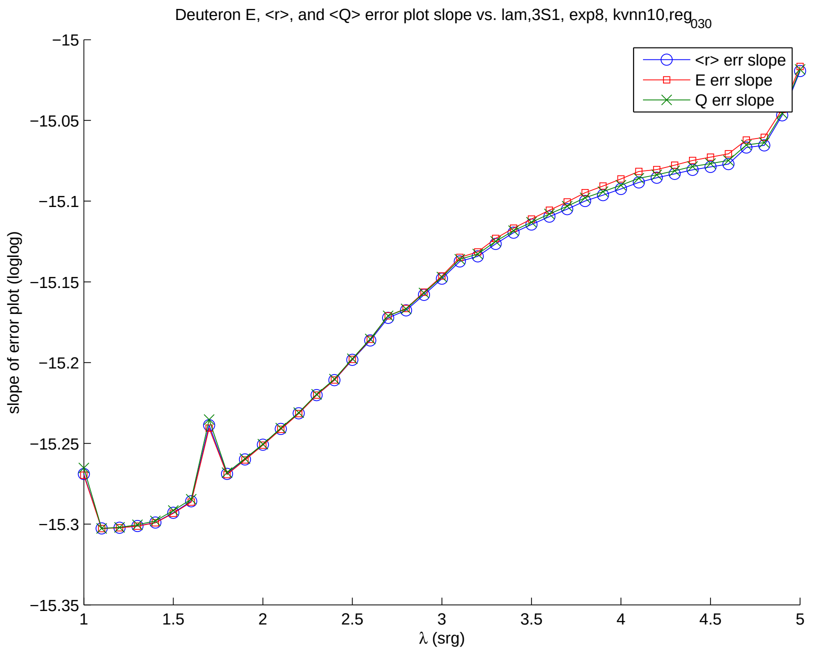
Phase Shift vs. cut, multi−lam, eta=T,1S0, E100, exp8, kvnn10reg030
Phase Shift Error
Λ (cut) / λ (srg)
10^2
10^0
10^−2
10^−4
10^−6
10^−8
10^−10
10^−12
10^−14
lambda=1.0
lambda=1.5
lambda=2.0
lambda=3.0
lambda=4.0



Phase Shift vs. cut, multi−lam, eta=T,1S0, E100, exp8, kvnn06reg030
Phase Shift Error
Λ (cut) / λ (srg)
10^2
10^0
10^−2
10^−4
10^−6
10^−8
10^−10
10^−12
10^−14
10^−16
10^−1
10^0
10^1
lambda=2.0
lambda=3.0
lambda=5.0
lambda=7.0
lambda=9.0



deuteron binding Energy vs. cut,3S1, lambda3.0, exp8, kvnn10reg030
Binding Energy (deuteron)
Λ (cut)
10^6
10^4
10^2
10^0
10^-2
10^-4
10^-6
10^-8
10^0
E_binding
delta E_d
delta E_d slope
delta E_d curv
delta E_d mod err
delta E_d mod slope


Deuteron E, <r>, and <Q> error plot slope vs. lam,3S1, exp8, kvnn10,reg030
slope of error plot (loglog)
λ (srg)
<r> err slope
E err slope
Q err slope
−15
−15.05
−15.1
−15.15
−15.2
−15.25
−15.3
−15.35
1
1.5
2
2.5
3
3.5
4
4.5
5