Quantum Monte Carlo study of the Hyperon-Nucleon interaction

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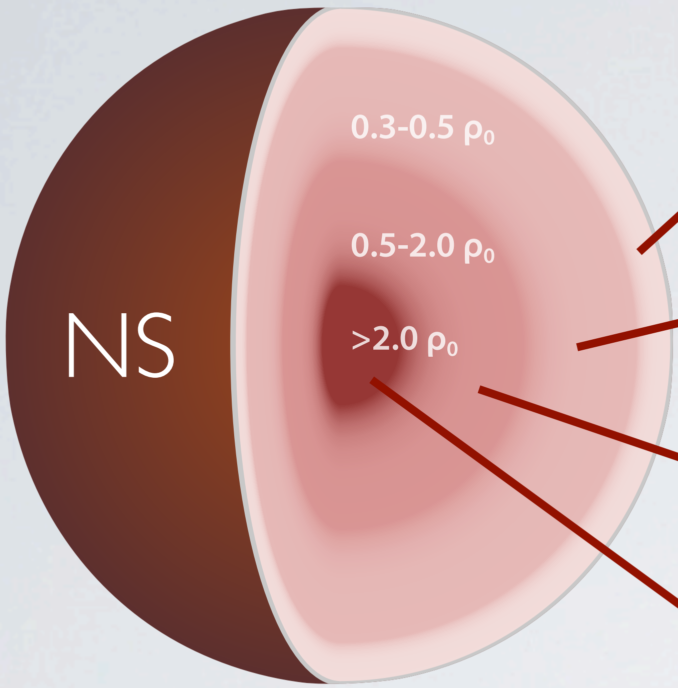
- S. Gandolfi (LANL, US-NM)
- K. E. Schmidt (ASU, US-AZ)
- G. Co' (Lecce, Italy)

INT, Seattle - October 25, 2012

Outline

- ✓ Motivations:
  - theoretical & experimental interest
  - the idea of the project
- ✓ The method: Auxiliary Field Diffusion Monte Carlo
- ✓ The interaction: Usmani ΛN & ΛNN
- ✓ Results: $B_\Lambda,\ \rho_N,\ \rho_\Lambda$
- ✓ Conclusions & Perspectives

Motivations: theoretical interest



$R \sim 10$ km

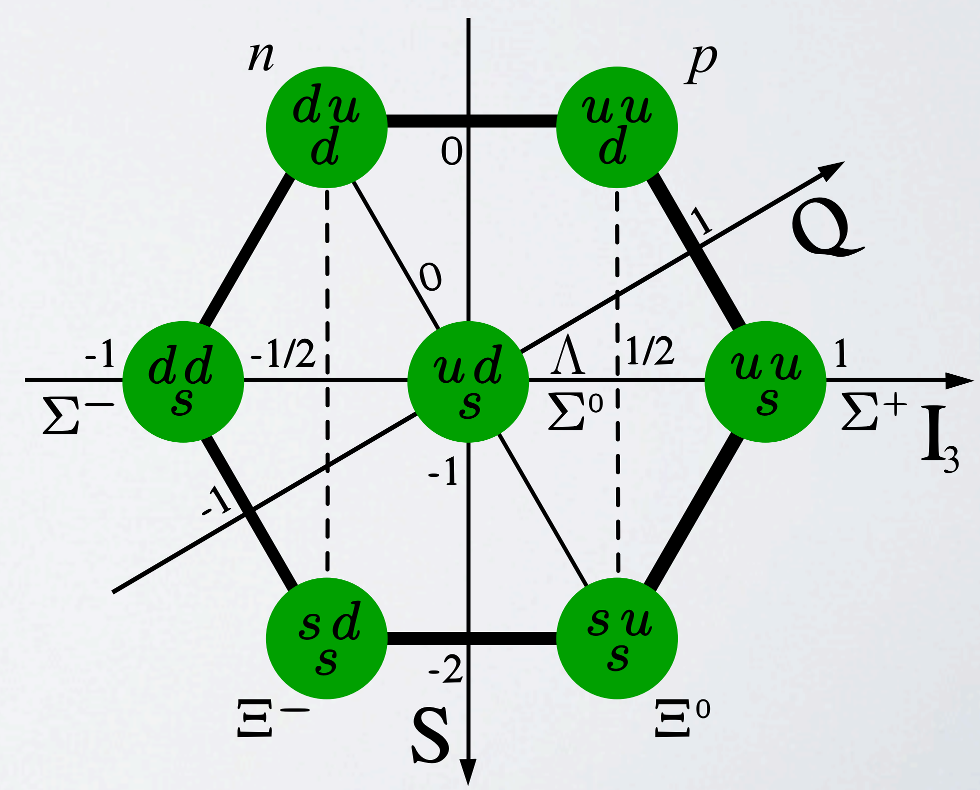
$M \sim 1.4\ M_\odot$

outer crust: $Z\ e$
$(0.3 \div 0.5$ km$)$

inner crust: $Z\ n\ e$
$(1 \div 2$ km$)$

outer core: $n\ p\ e\ \mu$
$(\sim 9$ km$)$

inner core: $n\ p\ e\ \mu\ \Lambda\ \Sigma\ \Xi\ \pi_c\ K_c\ q_p$?
$(0 \div 3$ km$)$



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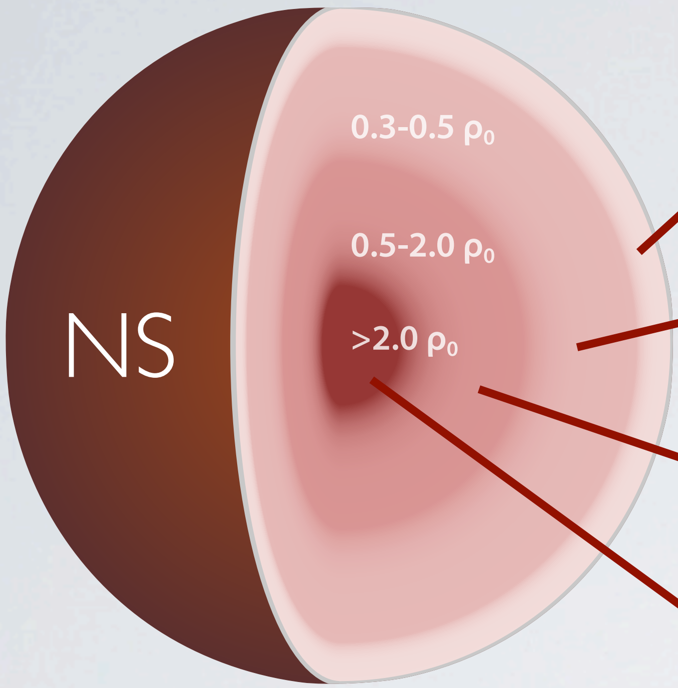

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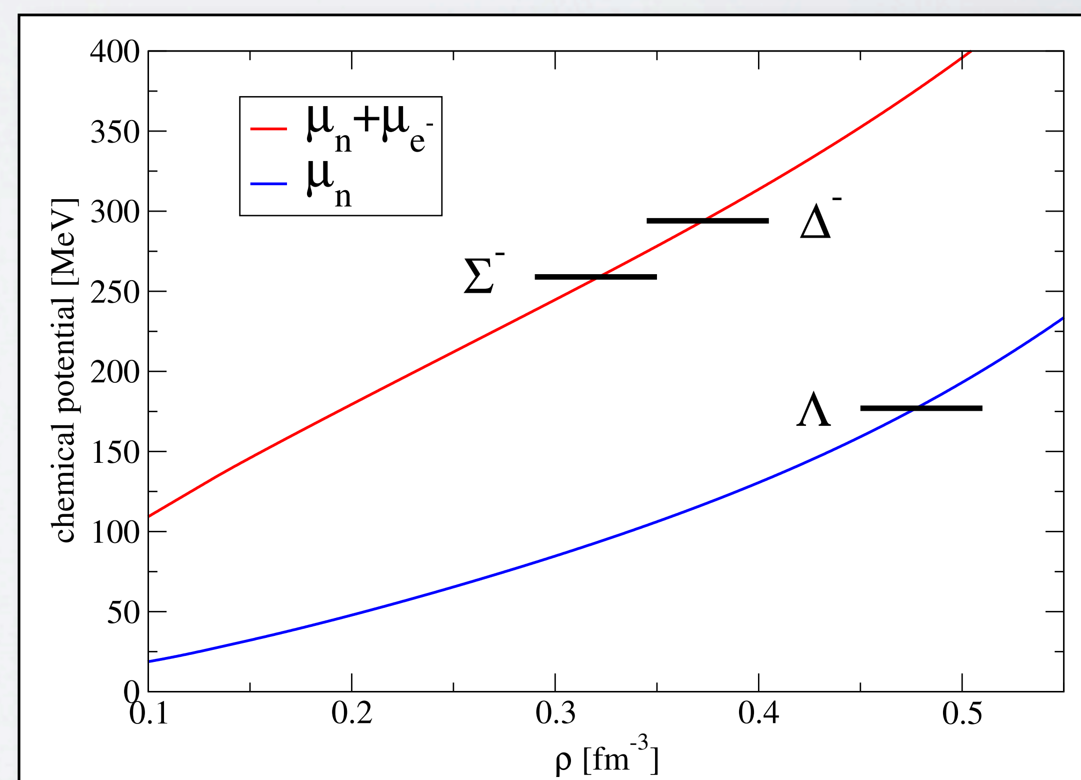
$(0 \div 3\ \mathrm{km})$

$$Q = -1: \ \ \mu_{Y^-} = \mu_n + \mu_e$$

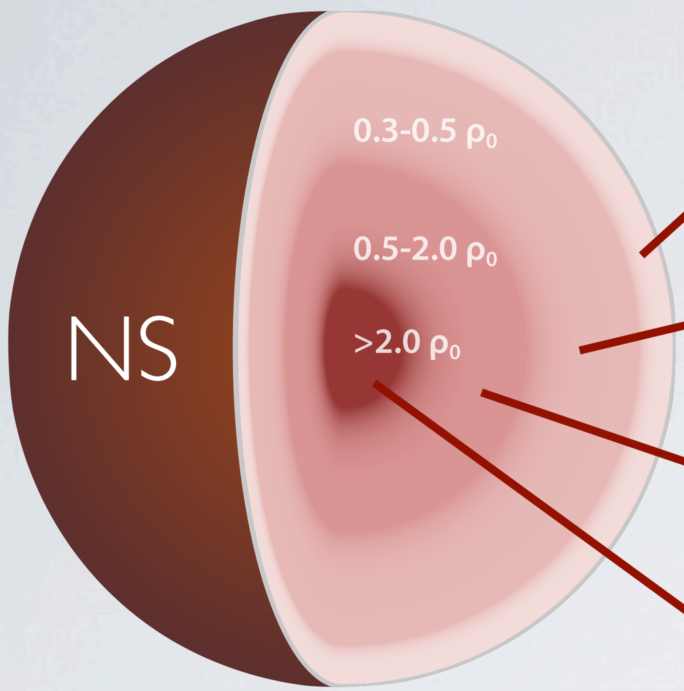
$$Q = 0: \ \ \mu_{Y^0} = \mu_n$$

$$Q = +1: \ \ \mu_{Y^+} = \mu_n - \mu_e$$



courtesy of Stefano Gandolfi

Motivations: theoretical interest



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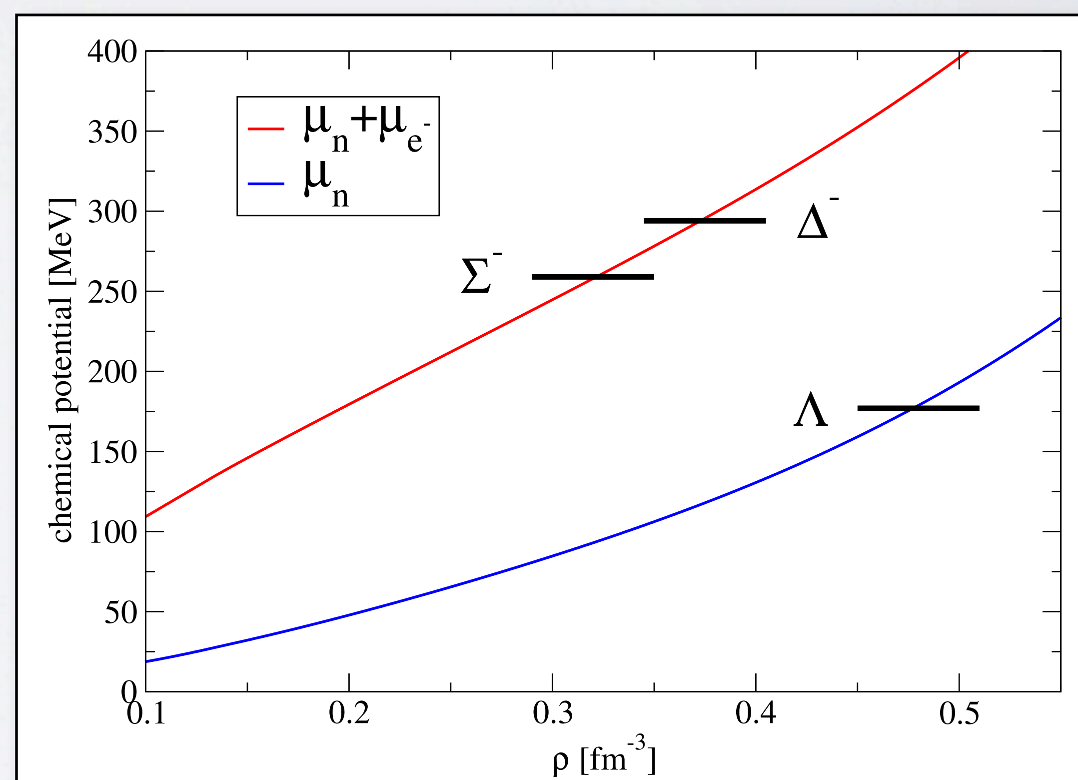
$(0 \div 3$ km$)$

composition strongly affects the properties of the neutron star

↓

EOS & M(R) relation



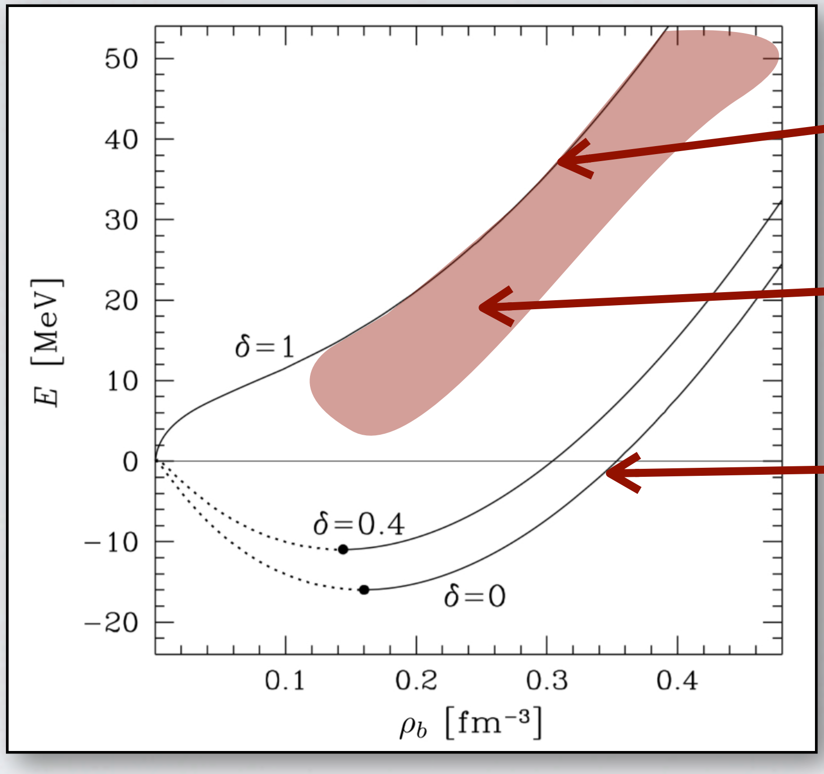
courtesy of Stefano Gandolfi

Motivations: theoretical interest

$$\begin{cases} E \equiv E(\rho_b, \delta) \\ P = \rho_b^2 \dfrac{\partial E(\rho_b, \delta)}{\partial \rho_b} \end{cases}$$

$$\rho_b = \rho_p + \rho_n = A/V$$

$$\delta = \frac{\rho_n - \rho_p}{\rho_b}$$



pure n matter

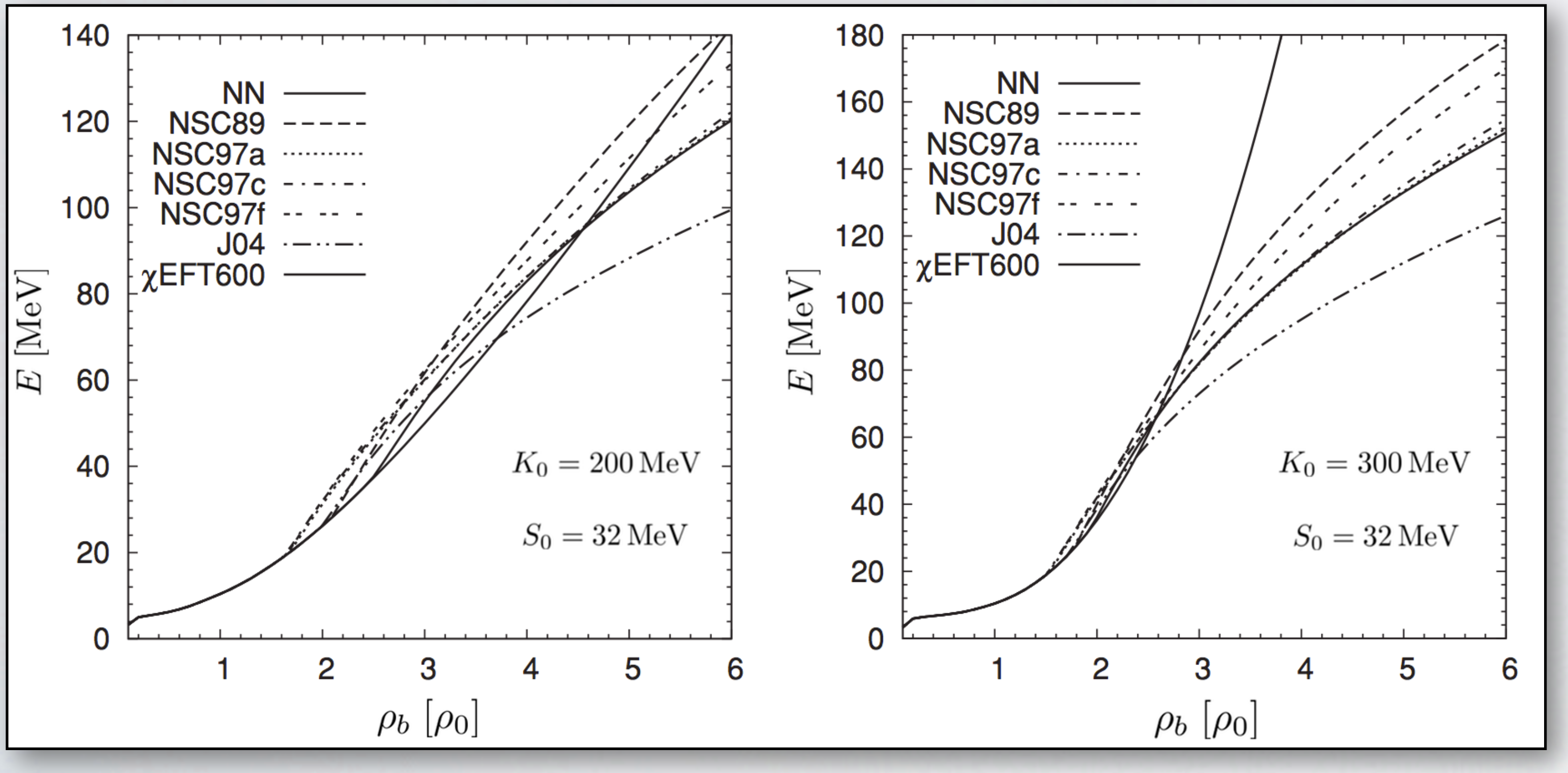
NS core

symmetric matter

$$\rho_0 = 0.16 \text{ fm}^{-3}$$

$$E_0 = -16 \text{ MeV}$$

P. Haensel, A.Y. Potekhin, D.G. Yakovlev, Neutron Stars 1, Springer 2007



hyperons: softening of the EOS

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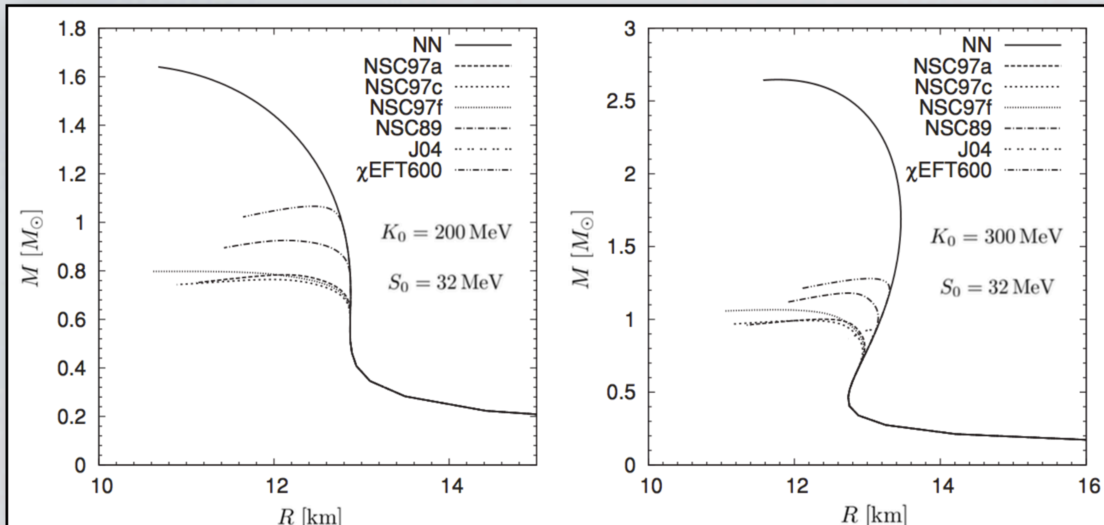
model dependent

H. Đapo, B.-J. Schaefer, and J. Wambach, Phys. Rev. C 81 (2010) 035803

Motivations: theoretical interest

TOV equations ⟶ mass-radius relation & maximum mass



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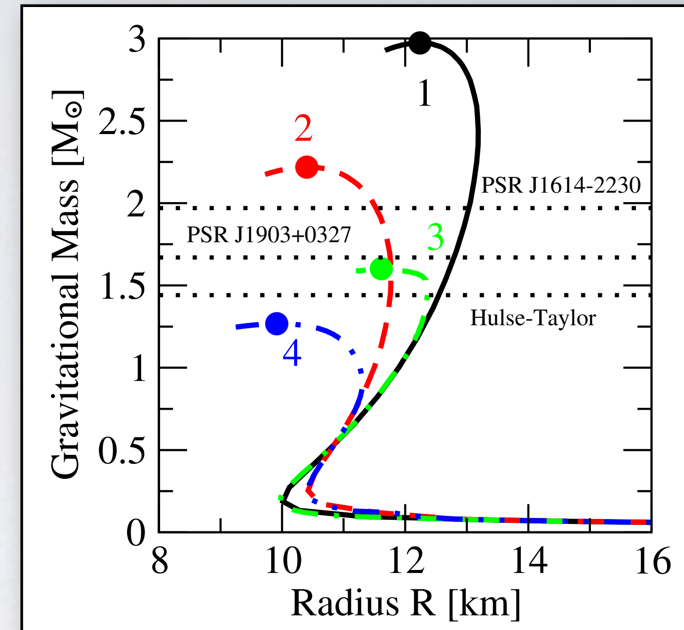
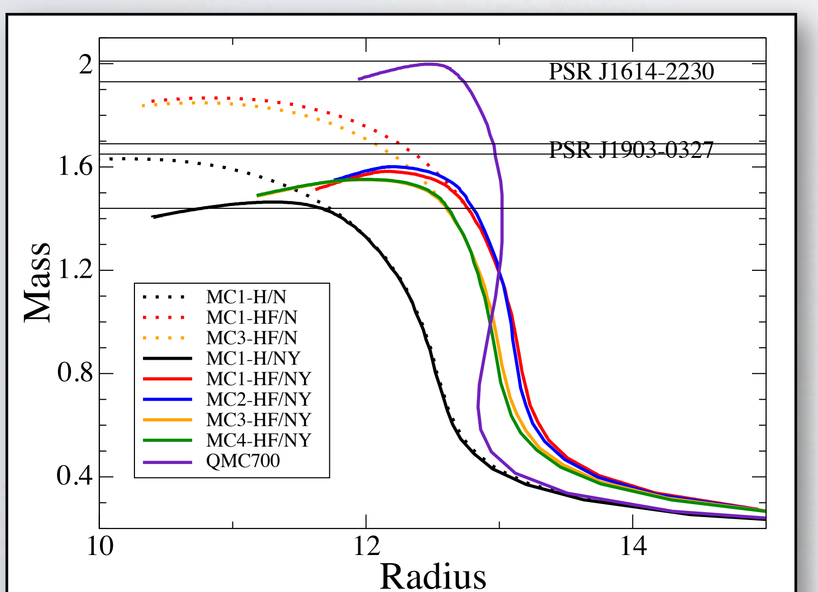
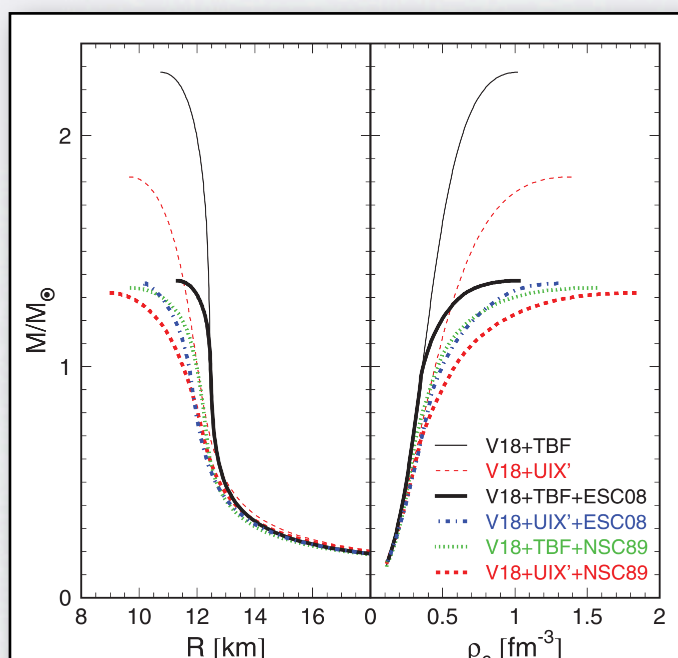
I. Vidaña, D. Logoteta, C. Providência, A. Polls, I. Bombaci, EPL 94 (2011) 11002



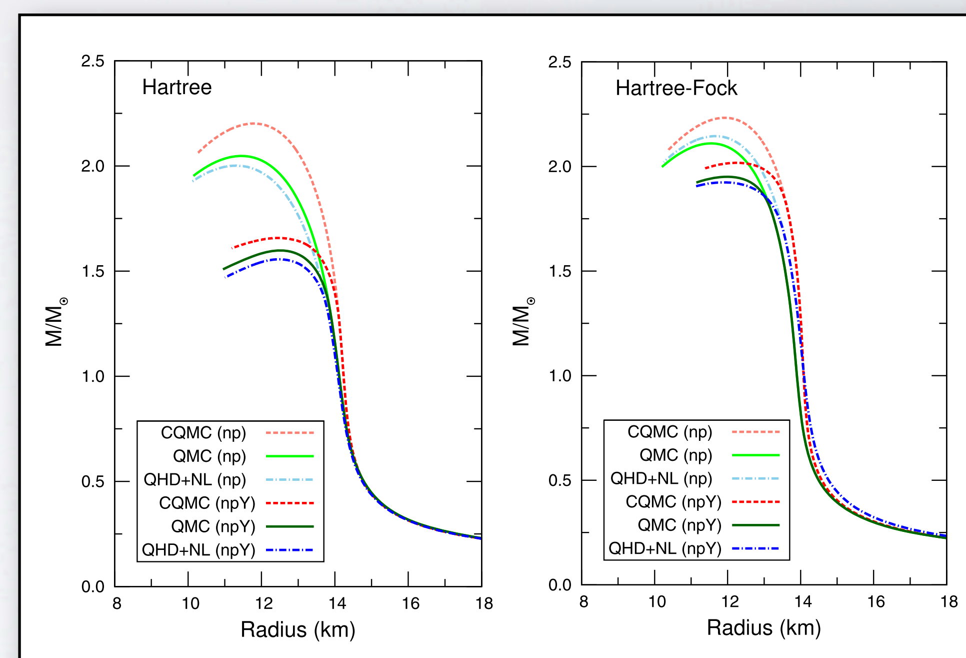
NS obs: $2\ M_\odot$



É. Massot, J. Margueron, G. Chanfray, EPL 97 (2012) 39002



H.-J. Schulze, T. Rijken, Phys. Rev. C 84 (2011) 035801



T. Miyatsu, T. Katayama, K. Saito, Phys. Lett. B 709 (2012) 242-246

Motivations: theoretical interest

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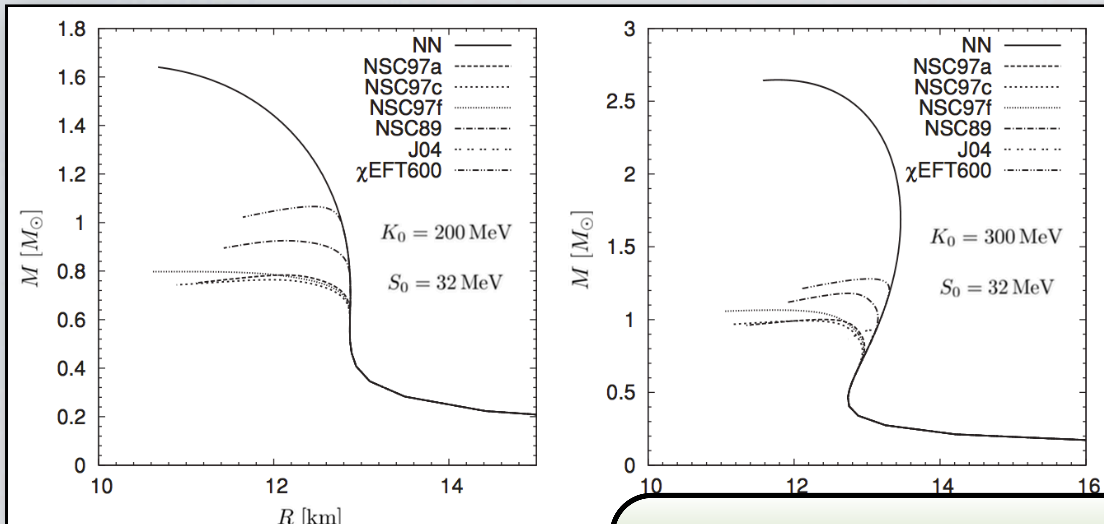
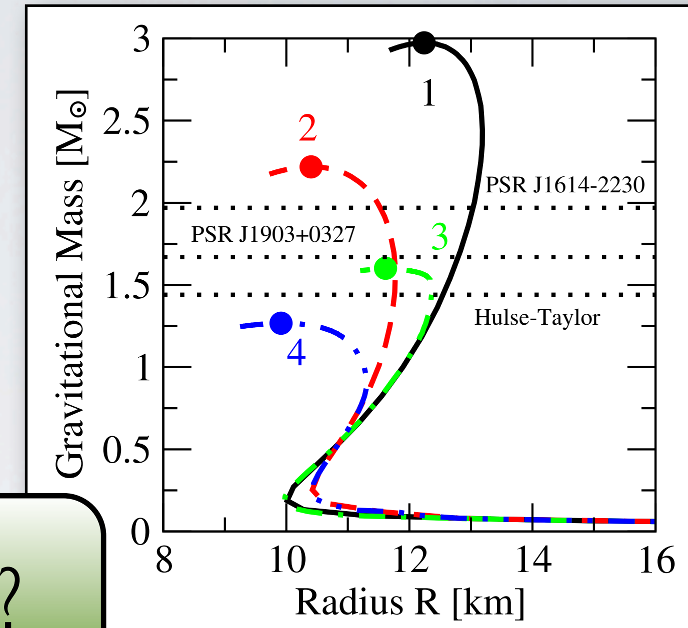
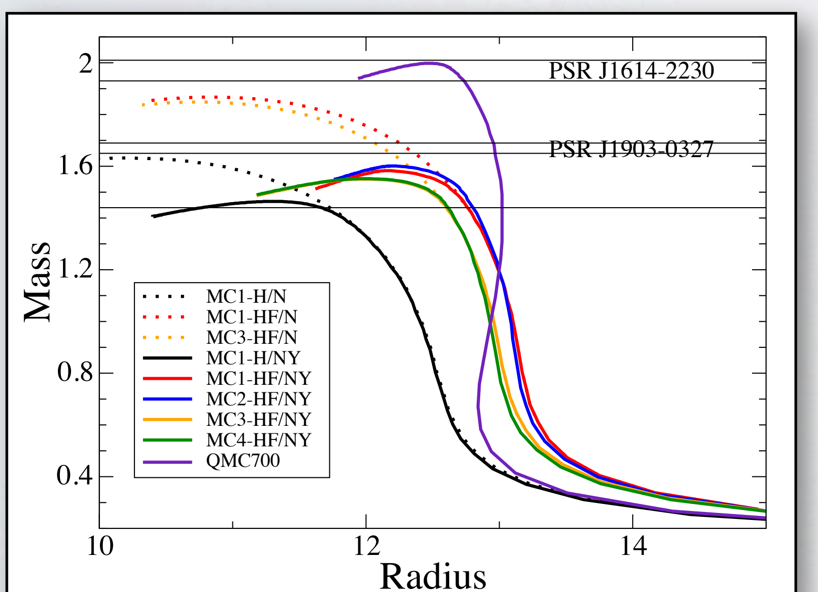


H. Đapo, B.-J. Schae
Phys. Rev. C 81 (2

I. Vidaña, D. Logoteta, C. Providência, A. Polls, I. Bombaci, EPL 94 (2011) 11002



hyperon-nucleon interaction ?



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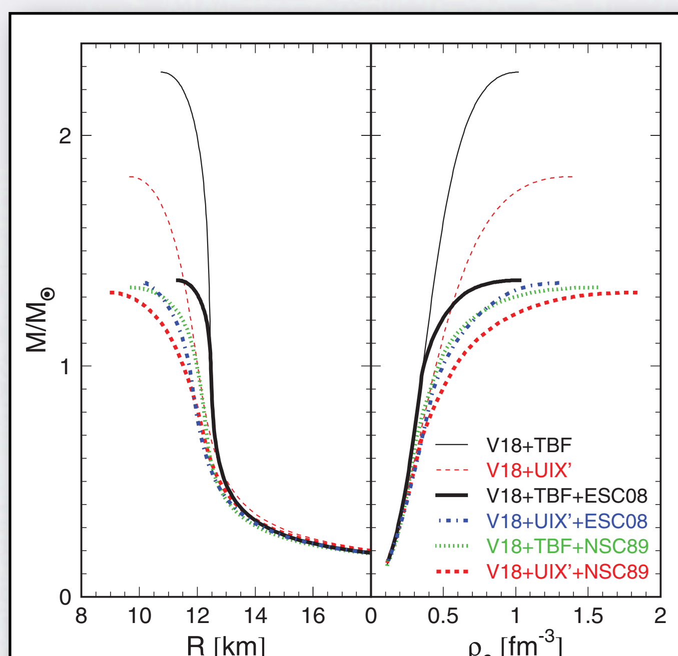

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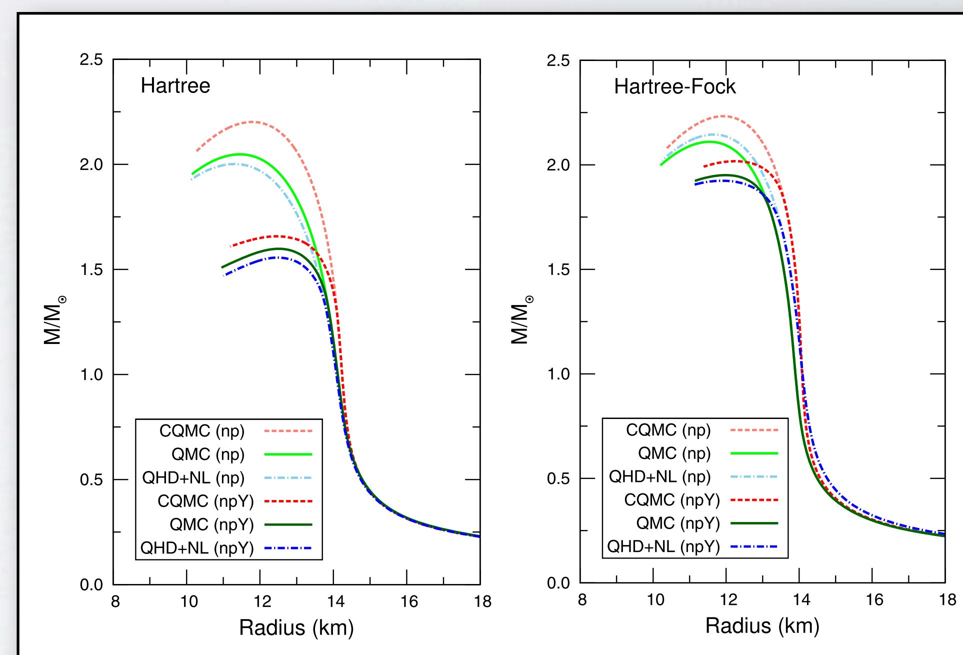
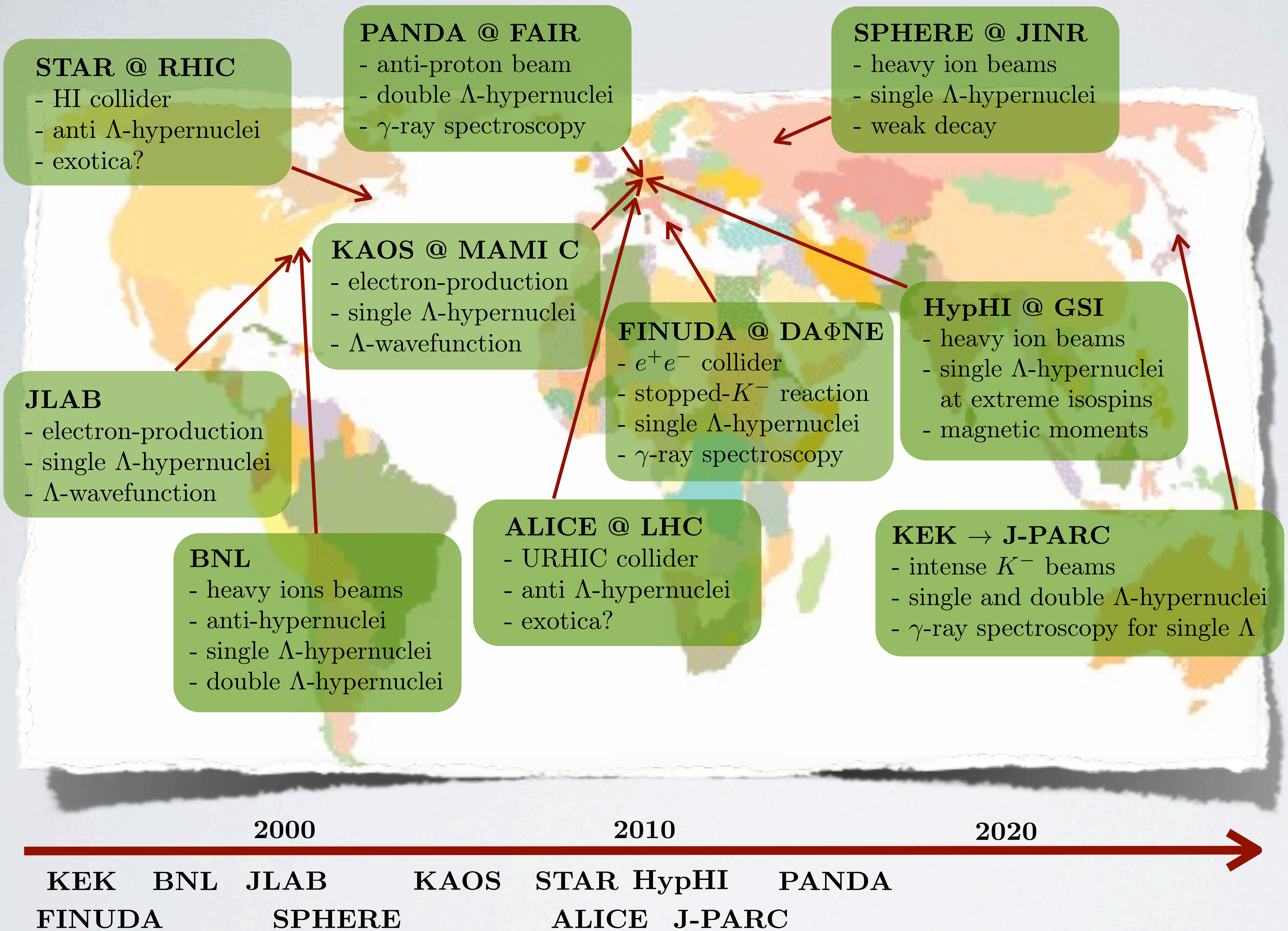
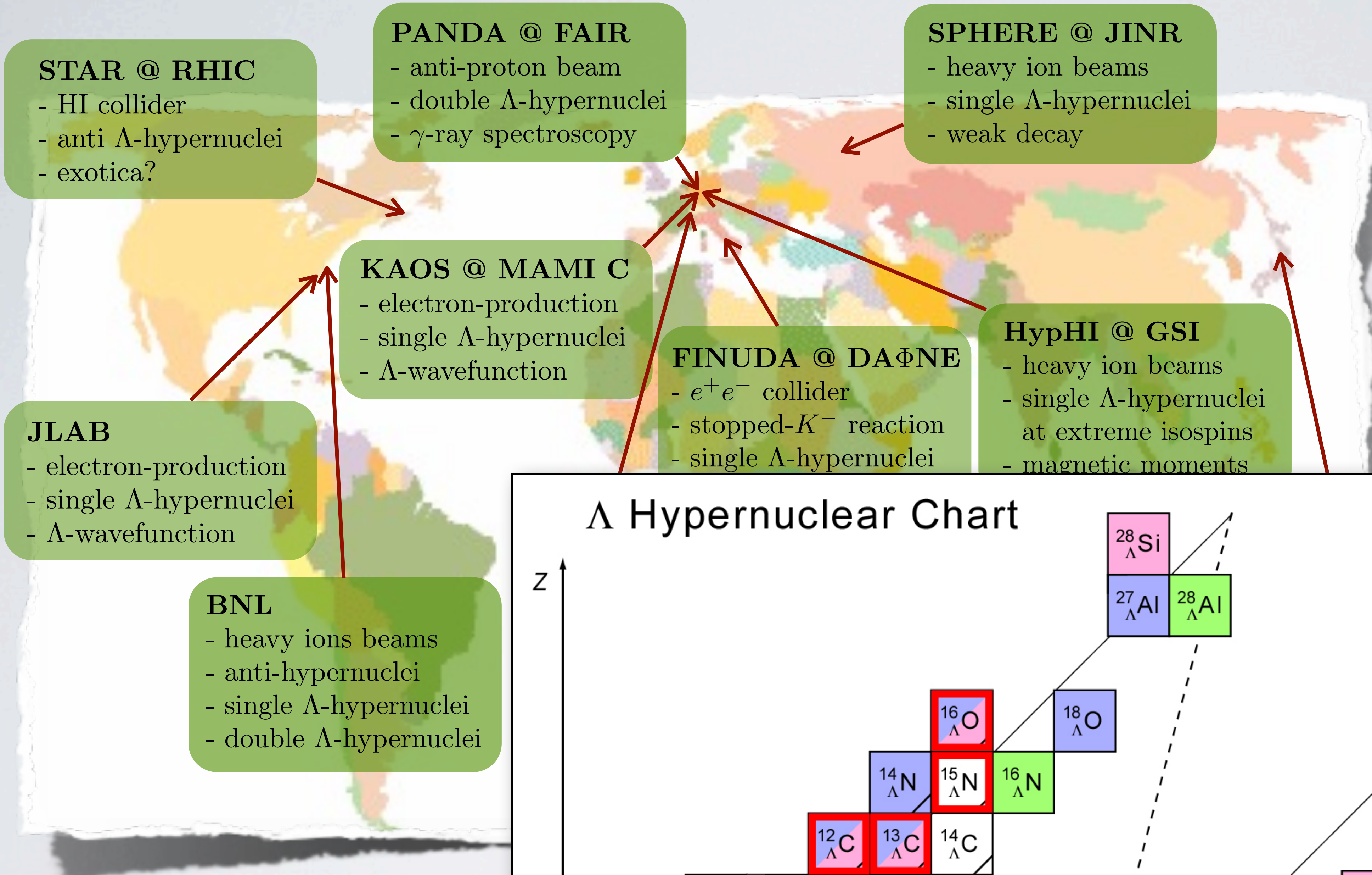


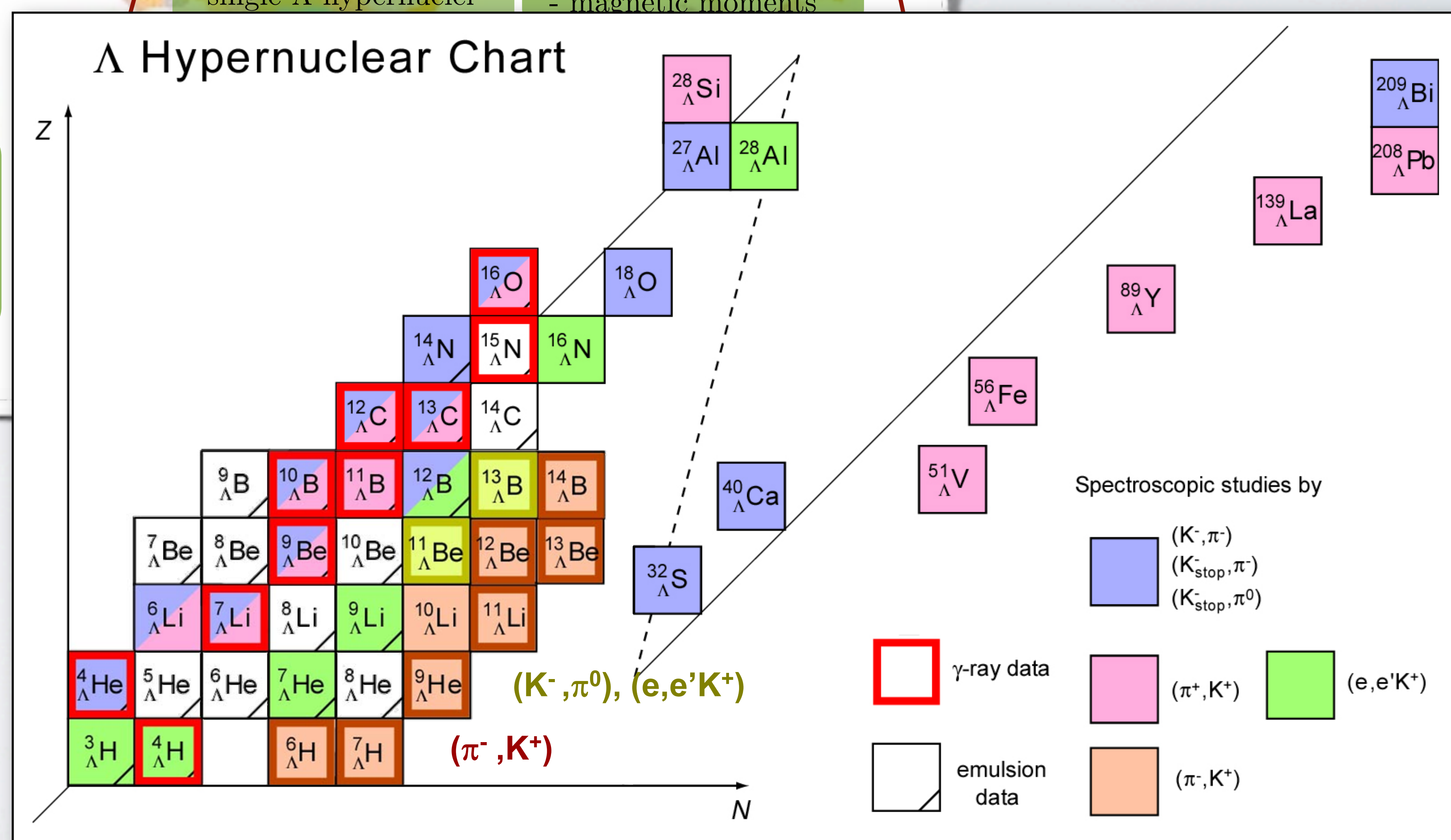
T. Miyatsu, T. Katayama, K. Saito, Phys. Lett. B 709 (2012) 242-246

Motivations: experimental interest



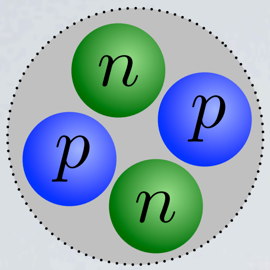
Motivations: experimental interest





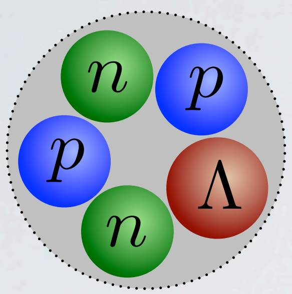
few data
↓
interactions poorly known

Motivations: the idea



nucleus $\longrightarrow$ $$BE_{nuc} = \frac{\langle \psi_{nuc} | \mathcal{H}_N | \psi_{nuc} \rangle}{\langle \psi_{nuc} | \psi_{nuc} \rangle}$$

ab-initio method



Λ-hypernucleus $\longrightarrow$ $$BE_{hyp} = \frac{\langle \psi_{hyp} | \mathcal{H}_{N+\Lambda} | \psi_{hyp} \rangle}{\langle \psi_{hyp} | \psi_{hyp} \rangle}$$

$$\mathcal{H}_N + \mathcal{H}_\Lambda$$

$$B_\Lambda = BE_{nuc} - BE_{hyp}$$

Hyp. : nuclear effects cancel at most

information about the hyperon-nucleon interaction

The method: Auxiliary Field DMC

stochastic ab-initio method with microscopic interaction

Auxiliary Field Diffusion Monte Carlo (AFDMC)

$$\tau = \frac{it}{\hbar} \quad \longrightarrow \quad -\frac{\partial}{\partial \tau}\psi(\boldsymbol{R}, \boldsymbol{S}, \tau) = \mathcal{H}\psi(\boldsymbol{R}, \boldsymbol{S}, \tau)$$

$$\begin{aligned}\psi(\boldsymbol{R}, \boldsymbol{S}, \tau) &= \mathrm{e}^{-(\mathcal{H}-E_0)\tau}\,\psi(\boldsymbol{R}, \boldsymbol{S}, 0) \\ &= \mathrm{e}^{-(E_0-E_0)\tau}\,c_0\varphi_0(\boldsymbol{R}, \boldsymbol{S}) \\ &\quad + \sum_{n>0} \mathrm{e}^{-(E_n-E_0)\tau}\,c_n\varphi_n(\boldsymbol{R}, \boldsymbol{S})\end{aligned}$$

$$\downarrow \; \tau \to \infty$$

$$c_0\varphi_0(\boldsymbol{R}, \boldsymbol{S})$$

The method: Auxiliary Field DMC

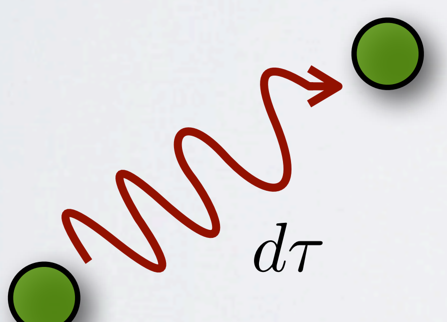
$$\psi\left(\boldsymbol{R},\boldsymbol{S},\tau+d\tau\right)=\int\langle\boldsymbol{S}\boldsymbol{R}|\,\mathrm{e}^{-(\mathcal{H}-E_0)d\tau}\,|\boldsymbol{R}'\boldsymbol{S}'\rangle\,\langle\boldsymbol{S}'\boldsymbol{R}'|\psi(\tau)\rangle\,d\boldsymbol{R}'d\boldsymbol{S}'$$

walkers

$$\mathcal{D}=\hbar^2/2m$$

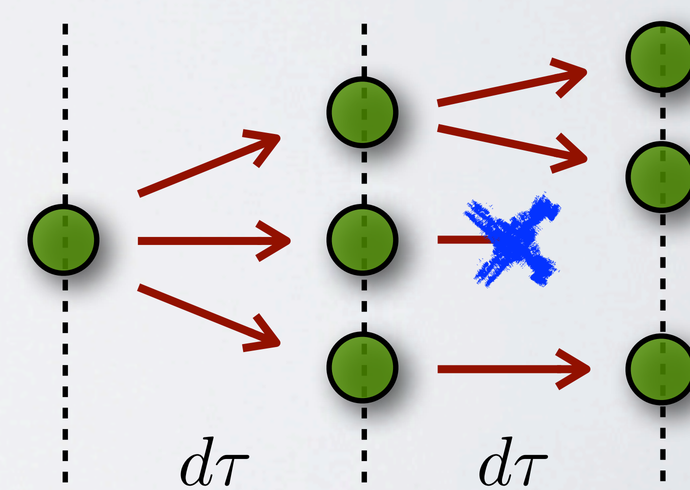
$$\left(\frac{1}{4\pi\mathcal{D}d\tau}\right)^{\frac{3N}{2}}\mathrm{e}^{-\frac{(\boldsymbol{R}-\boldsymbol{R}')^2}{4\mathcal{D}d\tau}}$$

$$\mathrm{e}^{-\left(\frac{\hat{V}(\boldsymbol{R}')+\hat{V}(\boldsymbol{R})}{2}-E_0\right)d\tau}$$



kinetic term

potential term



problem

The method: Auxiliary Field DMC

$\mathcal{P} \sim \mathrm{e}^{-\frac{1}{2}\lambda d\tau \mathcal{O}^2}$ ⇨ $\psi \sim \sum 2^A \frac{A!}{(A-Z)!Z!}$ terms

high computational cost → GFMC: $A \leq 12$

Idea: Hubbard-Stratonovich transformation

$$\mathrm{e}^{-\frac{1}{2}\lambda d\tau \mathcal{O}^2} = \frac{1}{\sqrt{2\pi}} \int dx \ \mathrm{e}^{-\frac{x^2}{2} + \sqrt{-\lambda d\tau} x \mathcal{O}}$$

dx → auxiliary field

$\int$ → rotation over spin-isospin configurations

⇨ computational cost: $\sim A!$ → $\sim A^3$

The method: Auxiliary Field DMC

AFDMC for nuclei & hypernuclei

- wave function
  - SD made of nucleon single particle orbitals (Skyrme & B1) $\times$ Λ single particle orbital
  - Jastrow correlation functions

  Note1: Λ single particle orbital

  Note2: center of mass corrections

- observables
  - nucl. & hyp. binding energy
  - Λ separation energy
  - Λ & N single particle density

- interactions ?
  - local interactions in coordinate space

The interaction

- nuclear potentials
  - Argonne V4',V6',V8'(6)
  - Minnesota

$$V_{NN}(\mathrm{AV6}) : \mathcal{O}_{ij}^{p=1,6} = \underbrace{\{1, \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j, S_{ij}\} \otimes \{1, \boldsymbol{\tau}_i \cdot \boldsymbol{\tau}_j\}}_{V_{NN}^{sd} + V_{NN}^{si}}$$

$$V_{NN}^{sd} = \frac{1}{2} \sum_{ij} \sum_{\gamma} \tau_i^{\gamma} \left(\mathcal{A}_{ij}^{[\tau]} \right) \tau_j^{\gamma} \qquad A \times A$$

$$+ \frac{1}{2} \sum_{ij} \sum_{\alpha\beta} \sigma_i^{\alpha} \left(\mathcal{A}_{i\alpha,j\beta}^{[\sigma]} \right) \sigma_j^{\beta} \qquad 3A \times 3A$$

$$+ \frac{1}{2} \sum_{ij} \sum_{\alpha\beta\gamma} \tau_i^{\gamma} \sigma_i^{\alpha} \left(\mathcal{A}_{i\alpha,j\beta}^{[\sigma\tau]} \right) \tau_j^{\gamma} \sigma_j^{\beta} \qquad 3A \times 3A$$

The interaction

- nuclear potentials
  - Argonne V4',V6',V8'(6)
  - Minnesota
- hypernuclear potential
  - Usmani interaction

✓ diagrammatic contributions due to pion exchange

✓ 2-body ΛN and 3-body ΛNN terms

A. Bodmer, Q. N. Usmani, J. Carlson, Phys. Rev. C 29 (1984) 684-687

A. Bodmer, Q. N. Usmani, Nucl. Phys. A 477 (1988) 621-651

A. A. Usmani, S. C. Pieper, Q. N. Usmani, Phys. Rev. C 51 (1995) 2347

A. A. Usmani, Phys. Rev. C 52 (1995) 1773-1777

A. A. Usmani, S. Murtaza, Phys. Rev. C 68 (2003) 024001

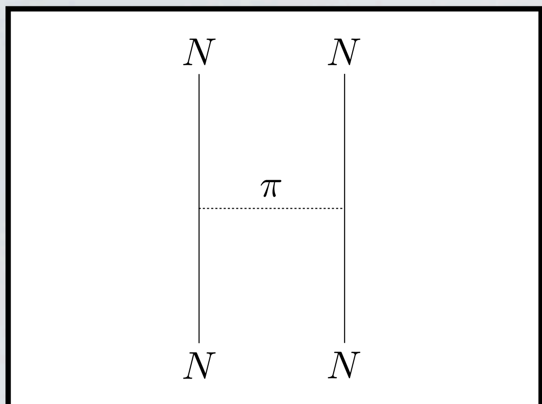
A. A. Usmani, Phys. Rev. C 73 (2006) 011302

A. A. Usmani, F. C. Khanna, J. Phys. G: Nucl. Part. Phys. 35 (2008) 025105

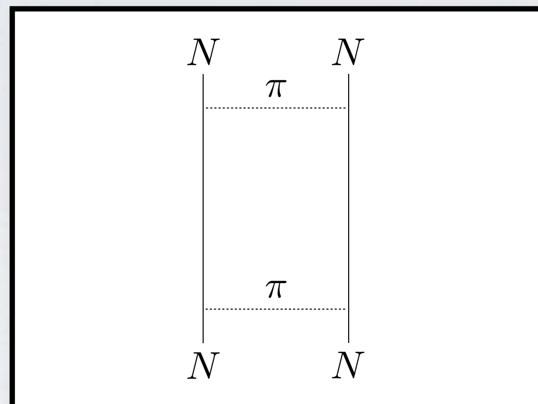
The interaction

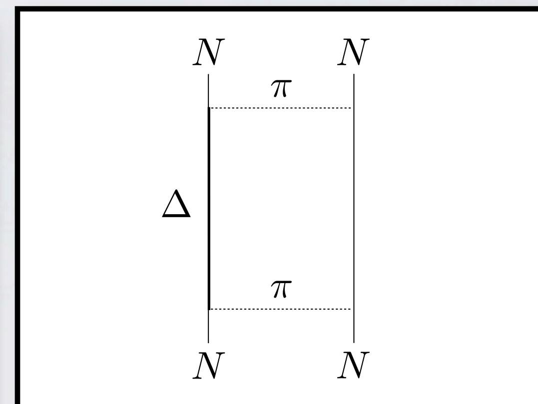
2-body

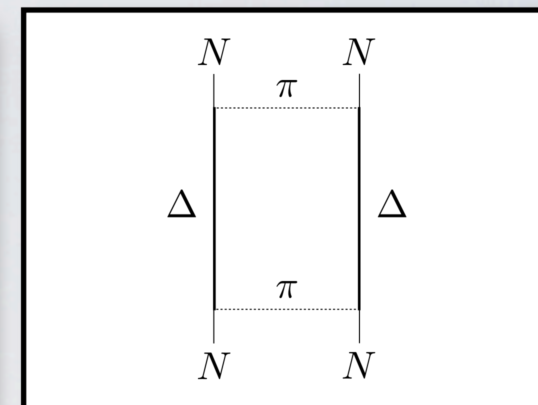
1π



2π







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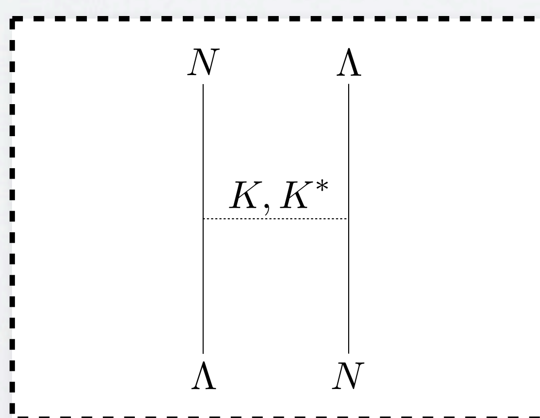
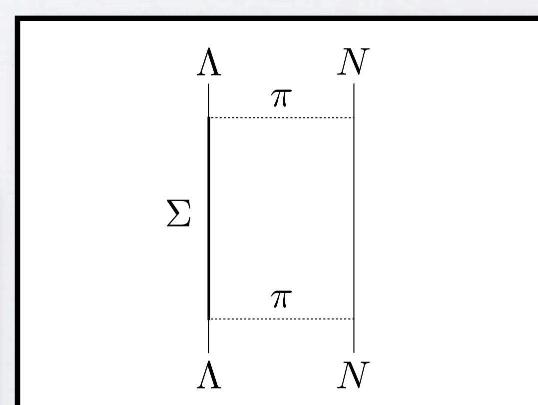
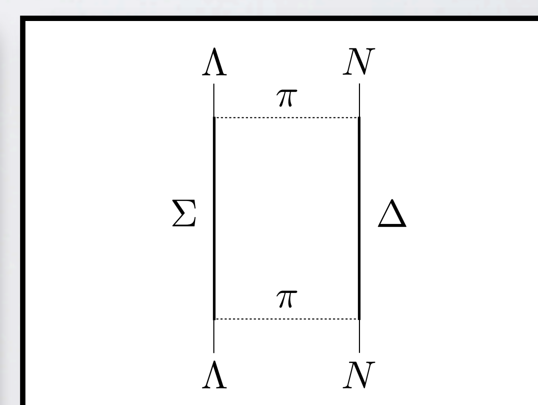


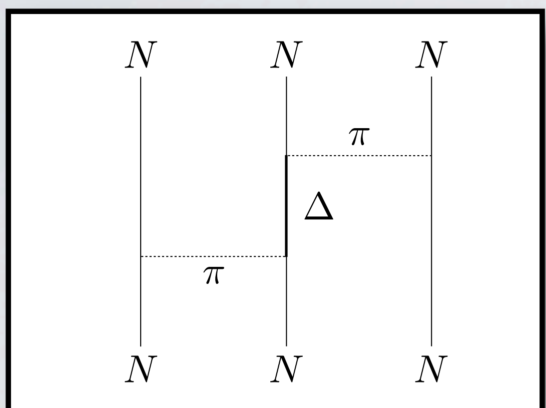


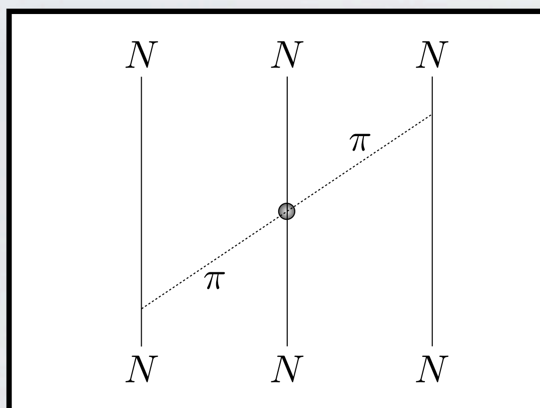


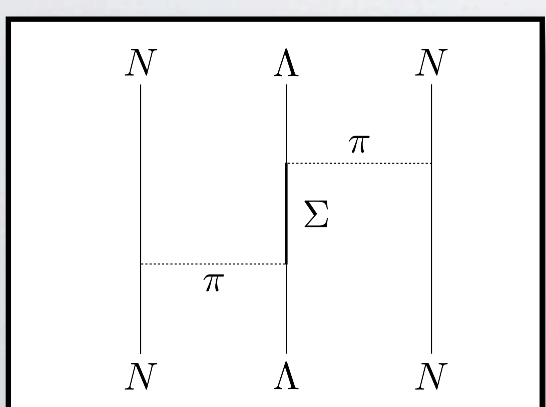
The interaction

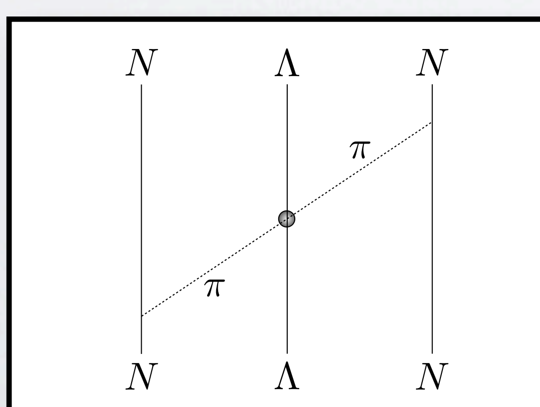
3-body

2π

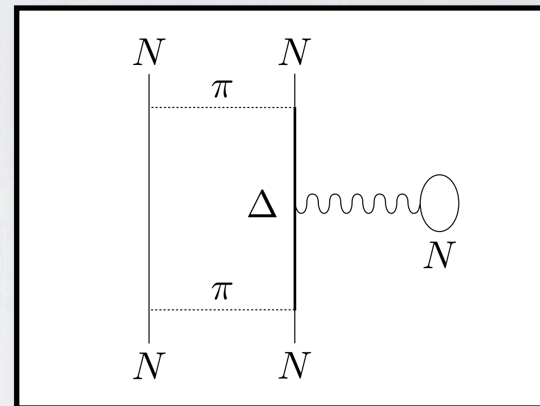


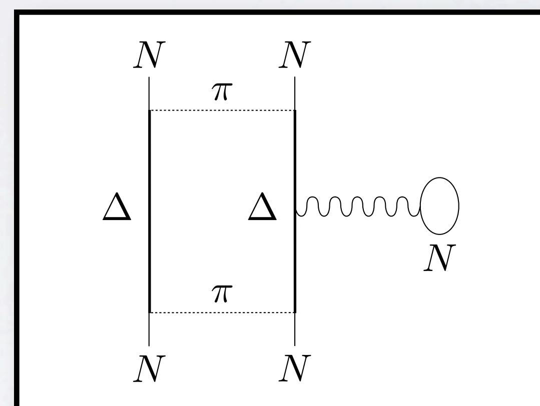


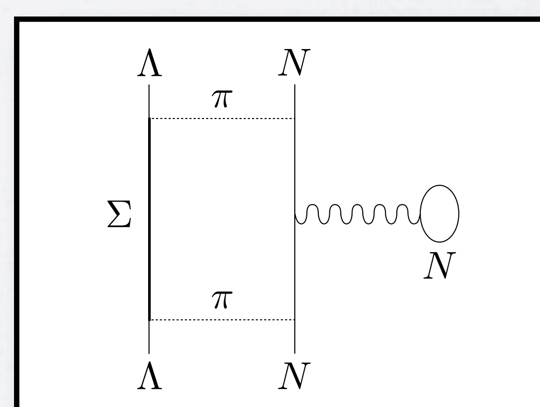




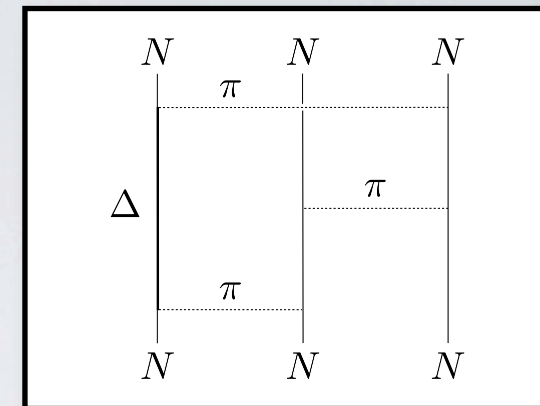
dispersive

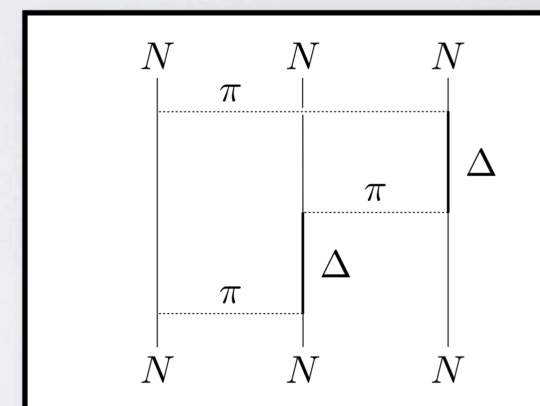






3π





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The interaction

ΛN

$$v_{\Lambda i}(r) = v_0(r) + v_0(r)\varepsilon(\mathcal{P}_x - 1) + \frac{1}{4} v_\sigma T_\pi^2(m_\pi r) \boldsymbol{\sigma}_\Lambda \cdot \boldsymbol{\sigma}_i$$

$$\begin{cases} v_0(r) & = & v_c(r) - v_{2\pi}(r) \\ v_c(r) & = & W_c \left[1 + \mathrm{e}^{\frac{r-\bar{r}}{a}}\right]^{-1} \\ v_{2\pi}(r) & = & \bar{v}\, T_\pi^2(m_\pi r) \end{cases}$$

$$\begin{cases} v_\sigma & = & v_s - v_t \\ \bar{v} & = & \frac{1}{4}(v_s + 3v_t) \end{cases}$$

parameters fitted on Λp scattering data

The interaction

ΛN $$v_{\Lambda i}(r) = v_0(r) + v_0(r)\varepsilon(\mathcal{P}_x - 1) + \frac{1}{4} v_\sigma T_\pi^2(m_\pi r)\boldsymbol{\sigma}_\Lambda \cdot \boldsymbol{\sigma}_i$$

ΛNN $$v_{\Lambda ij} = v_{\Lambda ij}^{2\pi} + v_{\Lambda ij}^{D} = v_{\Lambda ij}^{PW} + v_{\Lambda ij}^{SW} + v_{\Lambda ij}^{D}$$

$$\begin{cases} v_{\Lambda ij}^{PW} = -\frac{1}{6} C^P \{X_{i\Lambda}, X_{\Lambda j}\} \boldsymbol{\tau}_i \cdot \boldsymbol{\tau}_j \\ v_{\Lambda ij}^{SW} = C^S Z_\pi(m_\pi r_{\Lambda i}) Z_\pi(m_\pi r_{\Lambda j}) (\boldsymbol{\sigma}_i \cdot \hat{\boldsymbol{r}}_{i\Lambda}\, \boldsymbol{\sigma}_j \cdot \hat{\boldsymbol{r}}_{j\Lambda}) \boldsymbol{\tau}_i \cdot \boldsymbol{\tau}_j \\ v_{\Lambda ij}^{D} = W^D T_\pi^2(m_\pi r_{\Lambda i}) T_\pi^2(m_\pi r_{\Lambda j}) \left[1 + \frac{1}{6}\boldsymbol{\sigma}_\Lambda \cdot (\boldsymbol{\sigma}_i + \boldsymbol{\sigma}_j)\right] \end{cases}$$

→ parameters not yet fixed !!

⇨ fitting of the parameters to reproduce experimental separation energies

The method: Auxiliary Field DMC

$V_{\Lambda N} + V_{\Lambda NN}$

$$V_{\Lambda N} = \sum_i v_0(r_{\Lambda i})(1 - \epsilon + \epsilon P_x) + \sum_i \sum_\alpha \sigma_\Lambda^\alpha \left(\mathcal{B}_i \right) \sigma_i^\alpha \qquad 1 \times A$$

$$V_{\Lambda NN}^D = \frac{1}{2} \sum_{i \neq j} W^D T_{\Lambda i}^2 T_{\Lambda j}^2 + \frac{1}{2} \sum_{i \neq j} \sum_\alpha \sigma_\Lambda^\alpha \left(\mathcal{C}_{ij} \right) \sigma_i^\alpha \qquad A \times A$$

$$V_{\Lambda NN}^{2\pi} = \frac{1}{2} \sum_{i \neq j} \sum_{\alpha\beta\gamma} \tau_i^\gamma \sigma_i^\alpha \left(\mathcal{D}_{i\alpha, j\beta} \right) \tau_j^\gamma \sigma_j^\beta \qquad 3A \times 3A$$

⇨ good for Hubbard-Stratonovich

The interaction work in progress

possible charge symmetry breaking term:

$$v_{\Lambda i}^{\rm CSB} = \tau_i^3 \, v_0^{\rm CSB} \, T_\pi^2(m_\pi r_{\Lambda i})$$

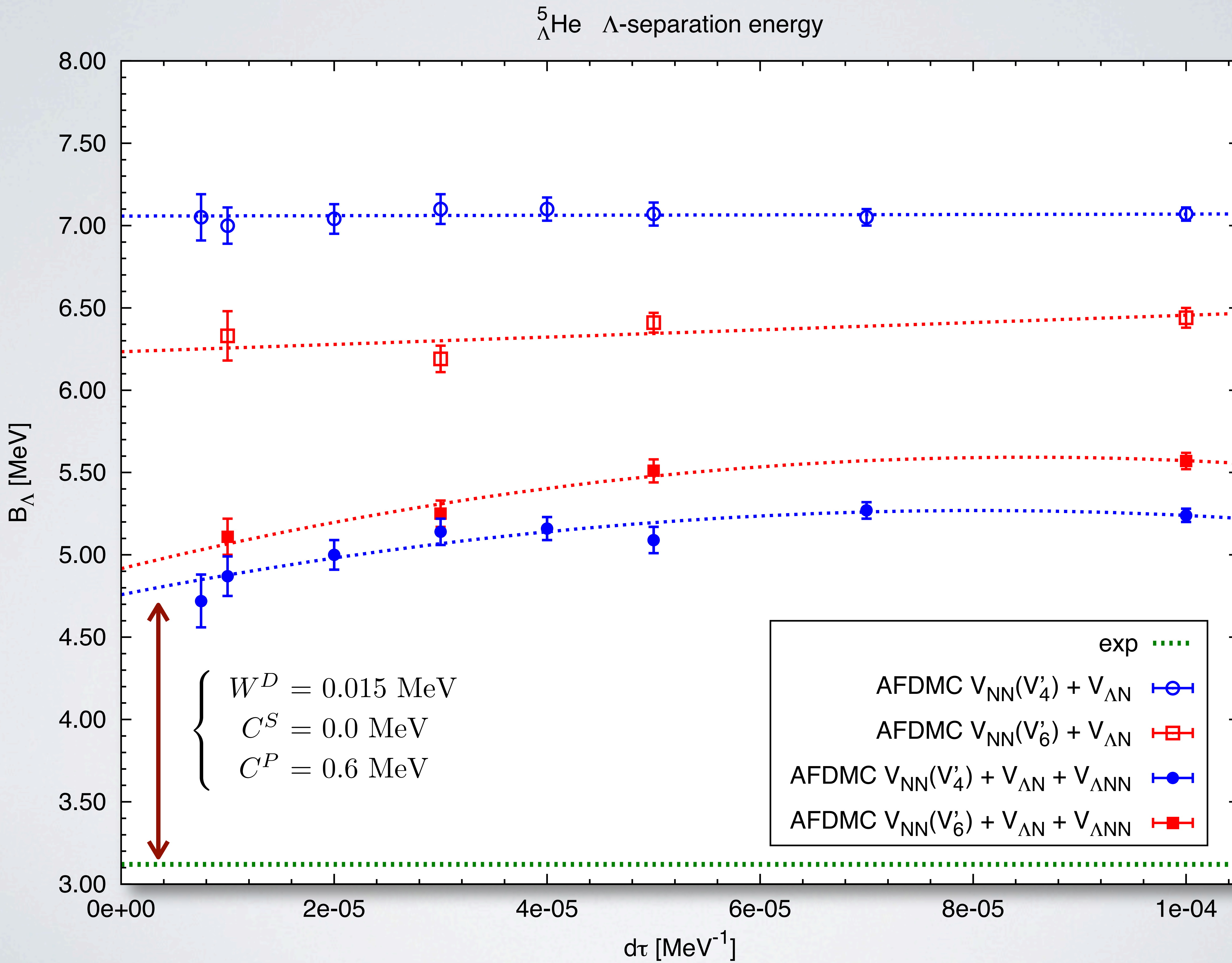
$$v_0^{\rm CSB} = -0.050(5)\ \rm MeV$$ → from $A = 4$ hypernuclei

Q. N. Usmani, A. R. Bodmer, Phys. Rev. C 60 (1998) 055215

- Λp : more attractive → important for light isobar hypernuclei
- Λn : less attractive → significant effect for heavy hypernuclei, with large n excess

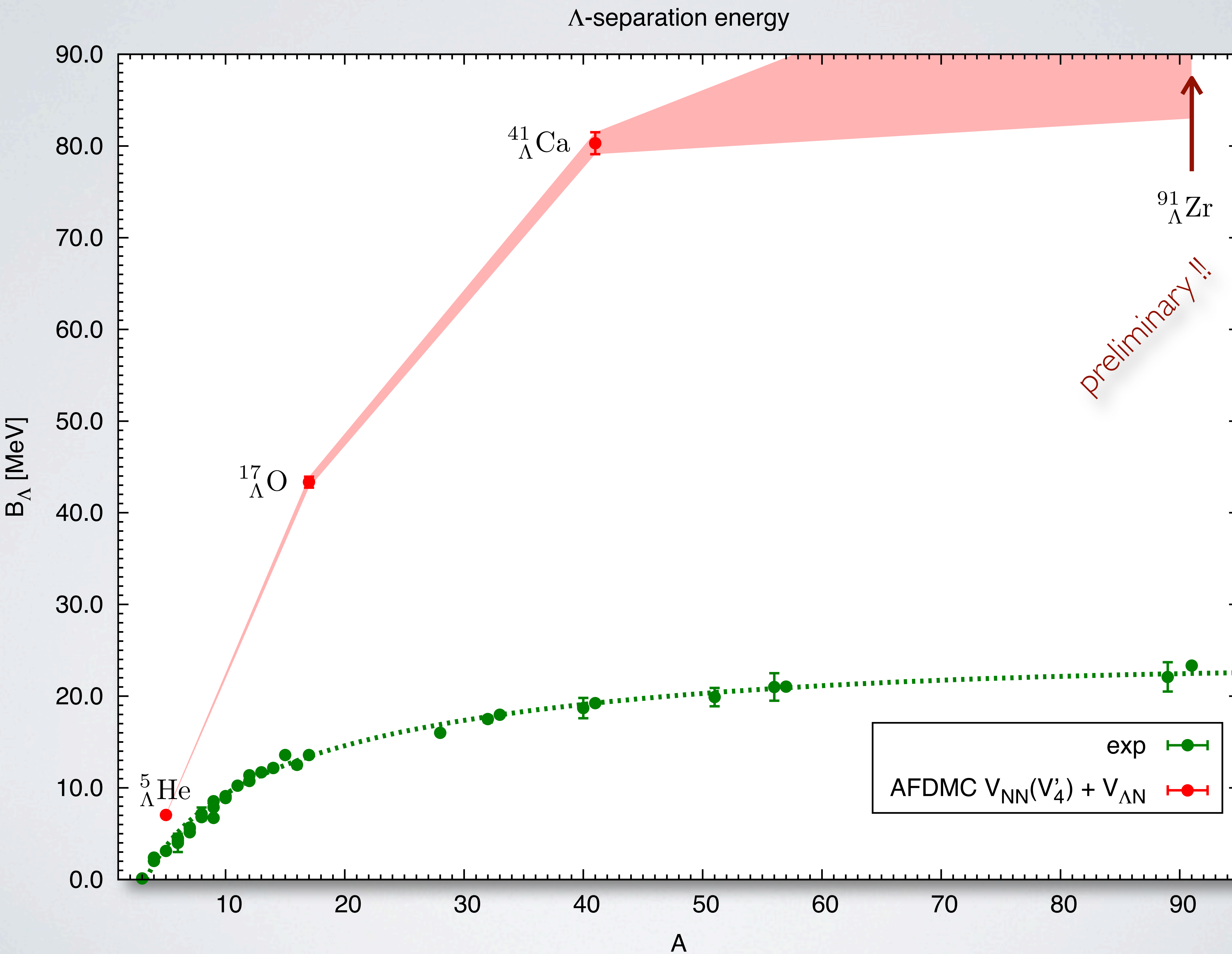
no quadratic operator ⇒ simple implementation in the AFDMC code

Results



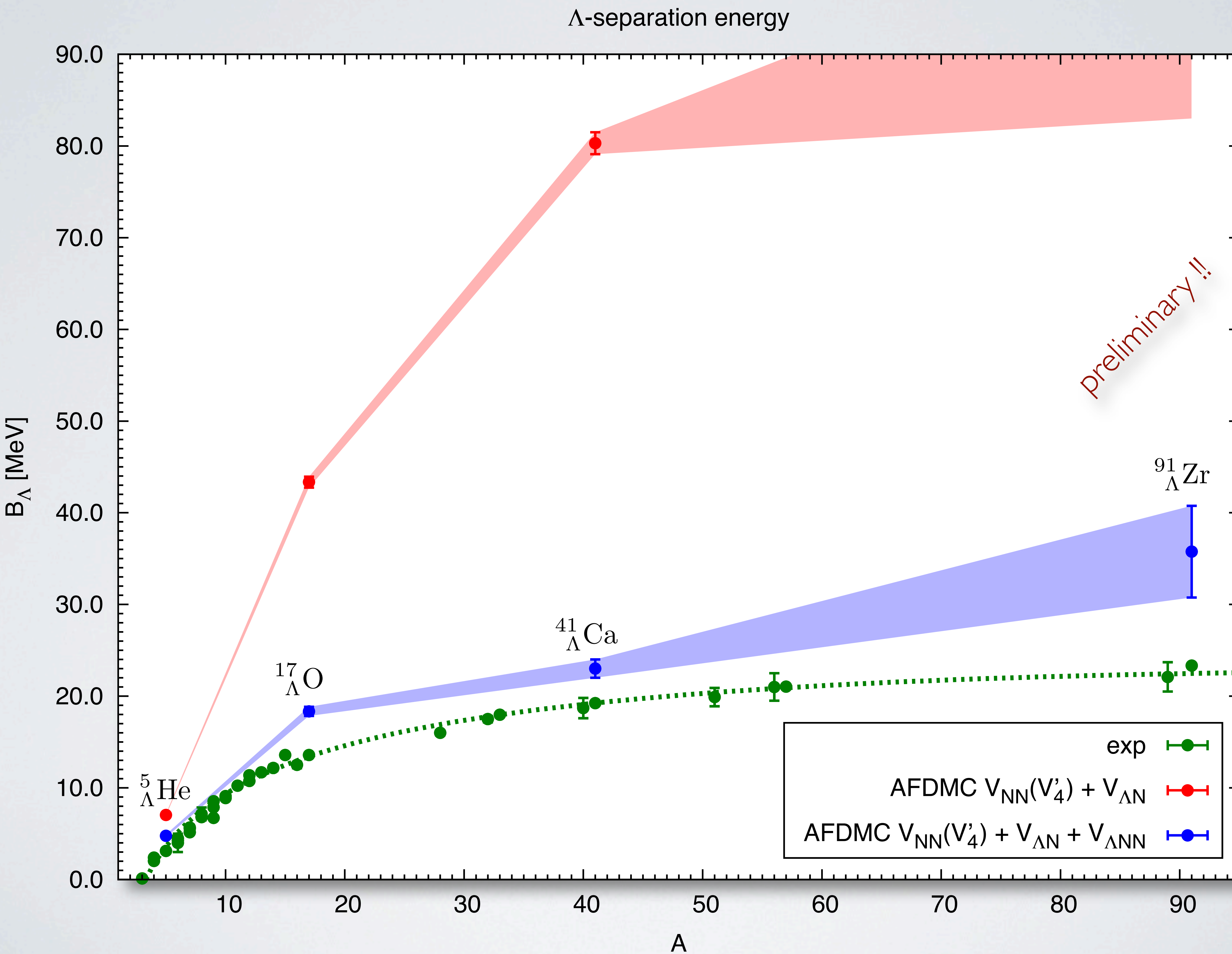
$^{5}_{\Lambda}$He Λ-separation energy
B_Λ [MeV]
dτ [MeV^{-1}]
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
0e+00
2e-05
4e-05
6e-05
8e-05
1e-04
$W^D = 0.015$ MeV
$C^S = 0.0$ MeV
$C^P = 0.6$ MeV
exp
AFDMC $V_{NN}(V'_4) + V_{\Lambda N}$
AFDMC $V_{NN}(V'_6) + V_{\Lambda N}$
AFDMC $V_{NN}(V'_4) + V_{\Lambda N} + V_{\Lambda NN}$
AFDMC $V_{NN}(V'_6) + V_{\Lambda N} + V_{\Lambda NN}$

Results



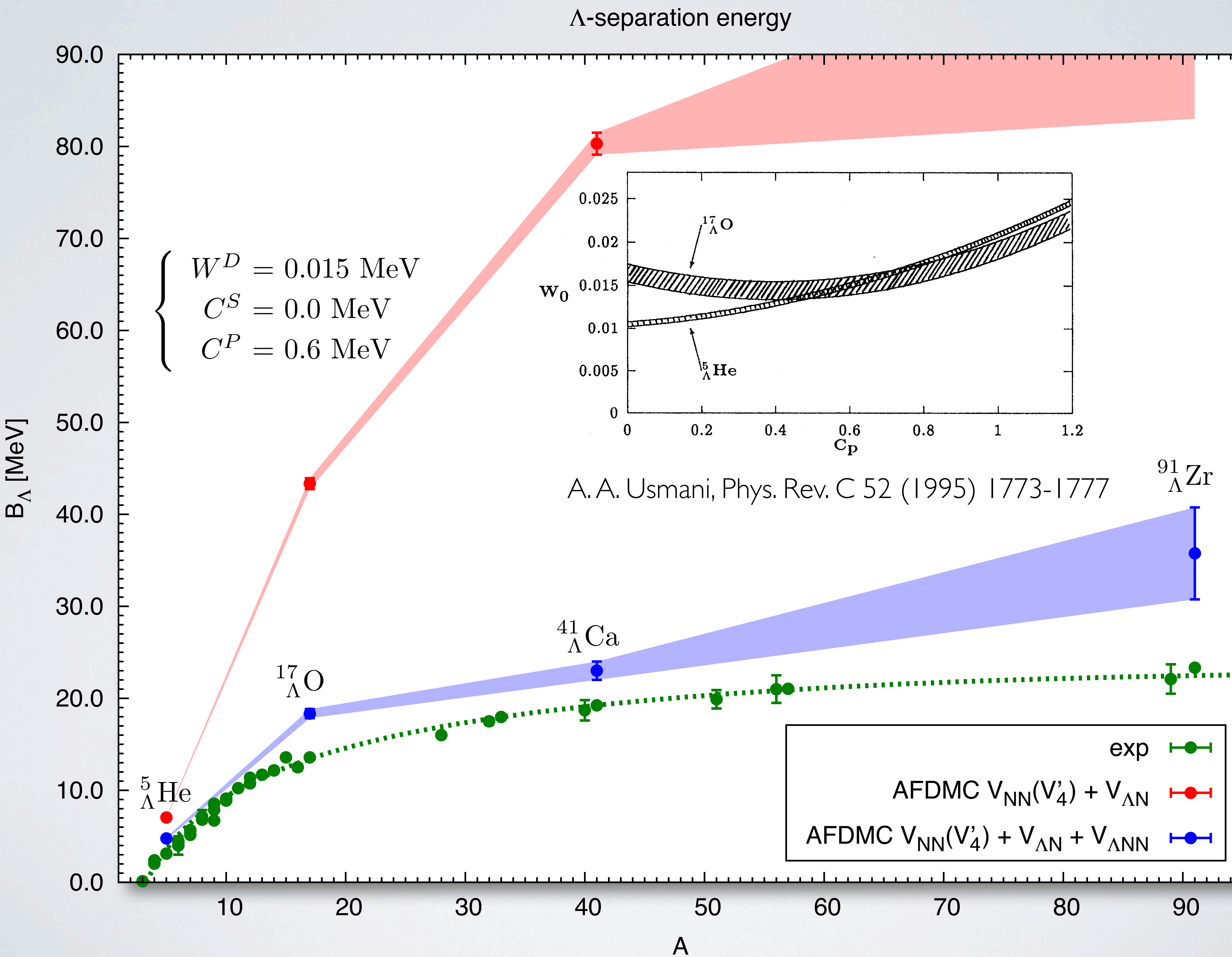
Λ-separation energy
B_Λ [MeV]
A
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10
20
30
40
50
60
70
80
90
${}^{41}_{\Lambda}$Ca
${}^{17}_{\Lambda}$O
${}^{5}_{\Lambda}$He
${}^{91}_{\Lambda}$Zr
preliminary !!
exp
AFDMC $V_{NN}(V'_4) + V_{\Lambda N}$

Results



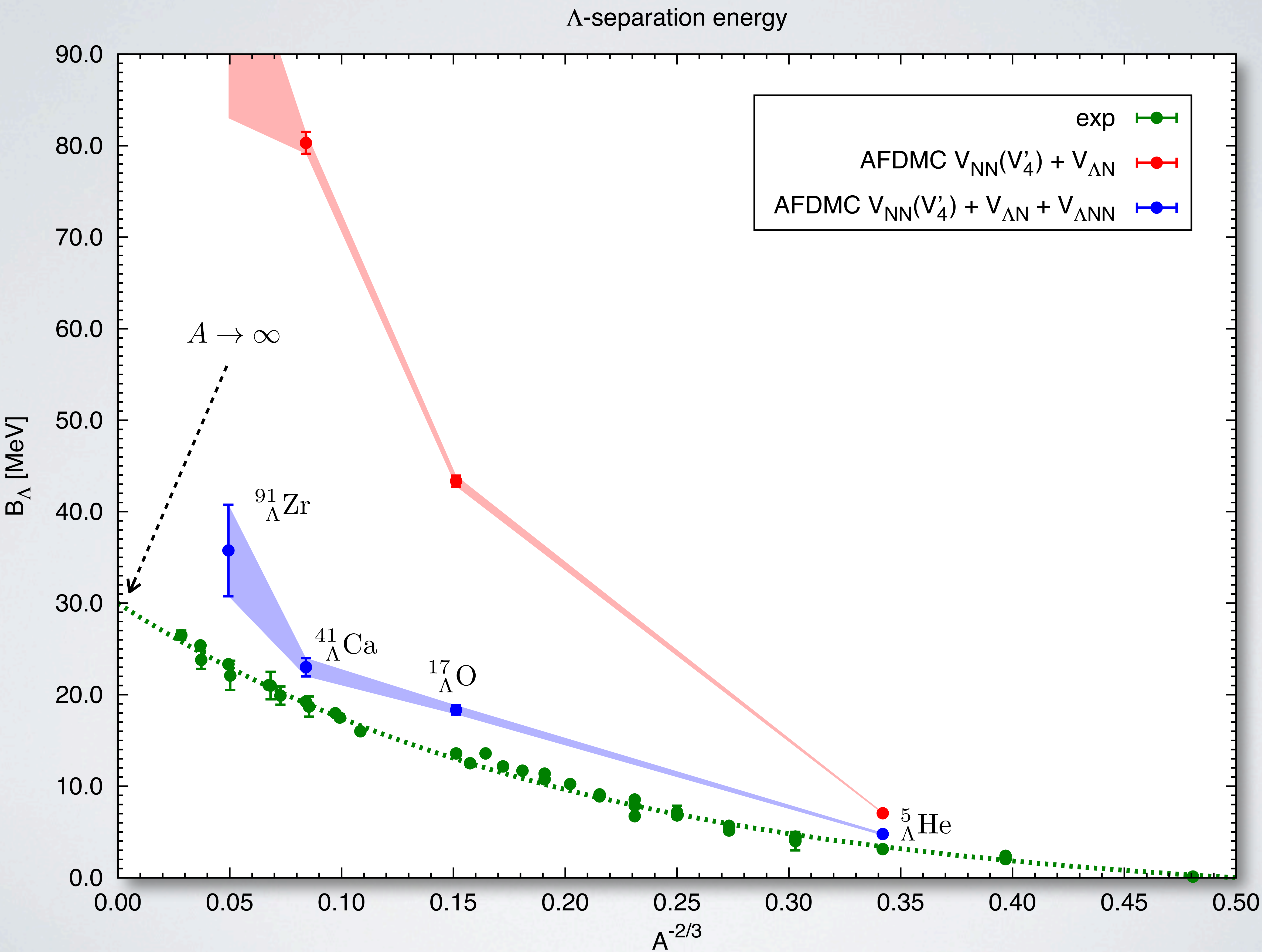
Λ-separation energy
B_Λ [MeV]
A
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10
20
30
40
50
60
70
80
90
$^{5}_{\Lambda}$He
$^{17}_{\Lambda}$O
$^{41}_{\Lambda}$Ca
$^{91}_{\Lambda}$Zr
preliminary !!
exp
AFDMC $V_{NN}(V'_4) + V_{\Lambda N}$
AFDMC $V_{NN}(V'_4) + V_{\Lambda N} + V_{\Lambda NN}$

Results



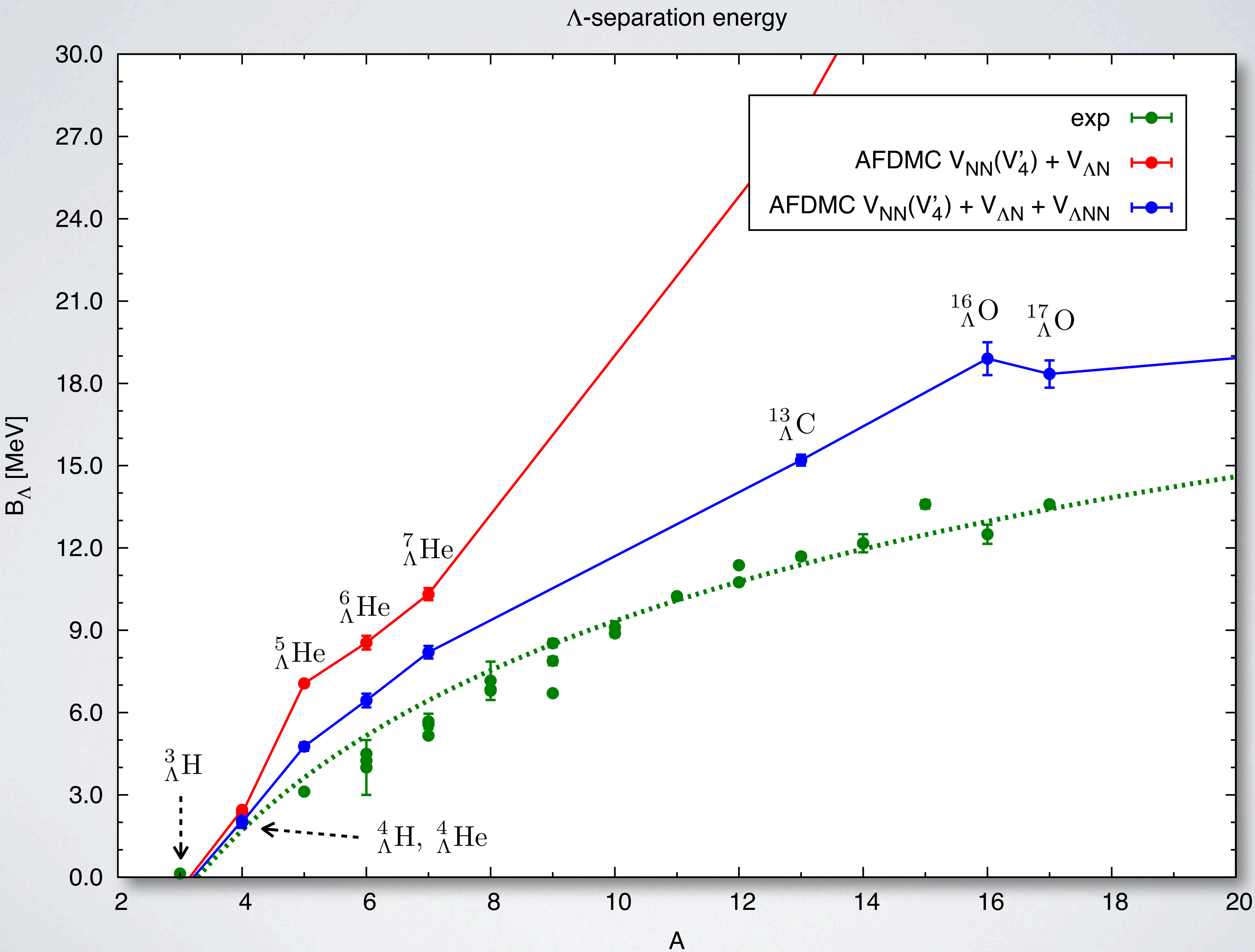
Λ-separation energy
B_Λ [MeV]
A
$W^D = 0.015$ MeV
$C^S = 0.0$ MeV
$C^P = 0.6$ MeV
A. A. Usmani, Phys. Rev. C 52 (1995) 1773-1777
$^{5}_{\Lambda}$He
$^{17}_{\Lambda}$O
$^{41}_{\Lambda}$Ca
$^{91}_{\Lambda}$Zr
exp
AFDMC $V_{NN}(V_4') + V_{\Lambda N}$
AFDMC $V_{NN}(V_4') + V_{\Lambda N} + V_{\Lambda NN}$
W_0
C_P

Results



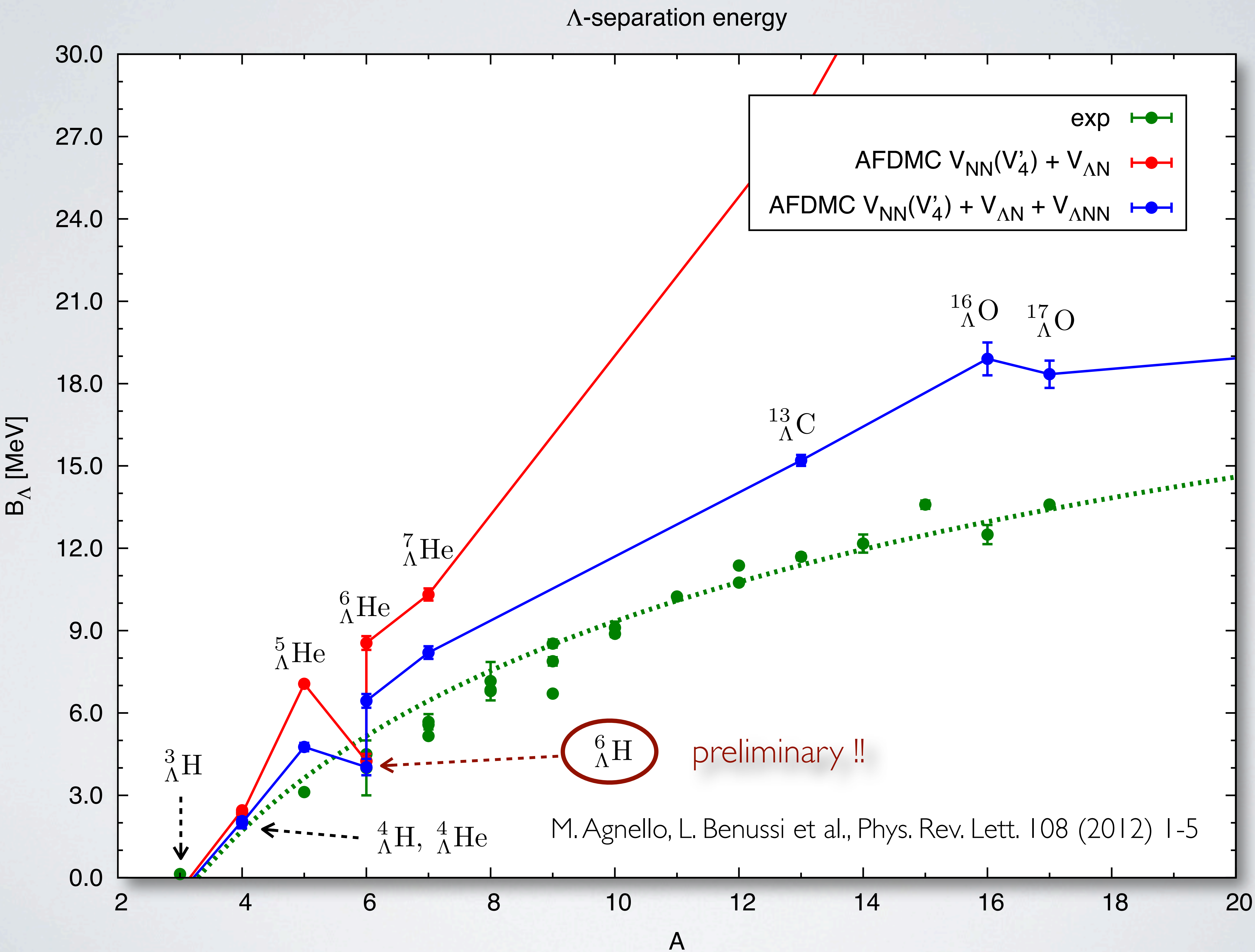
Λ-separation energy
exp
AFDMC $V_{NN}(V'_4) + V_{\Lambda N}$
AFDMC $V_{NN}(V'_4) + V_{\Lambda N} + V_{\Lambda NN}$
$A \to \infty$
$^{91}_{\Lambda}$Zr
$^{41}_{\Lambda}$Ca
$^{17}_{\Lambda}$O
$^{5}_{\Lambda}$He
B_Λ [MeV]
$A^{-2/3}$
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50

Results

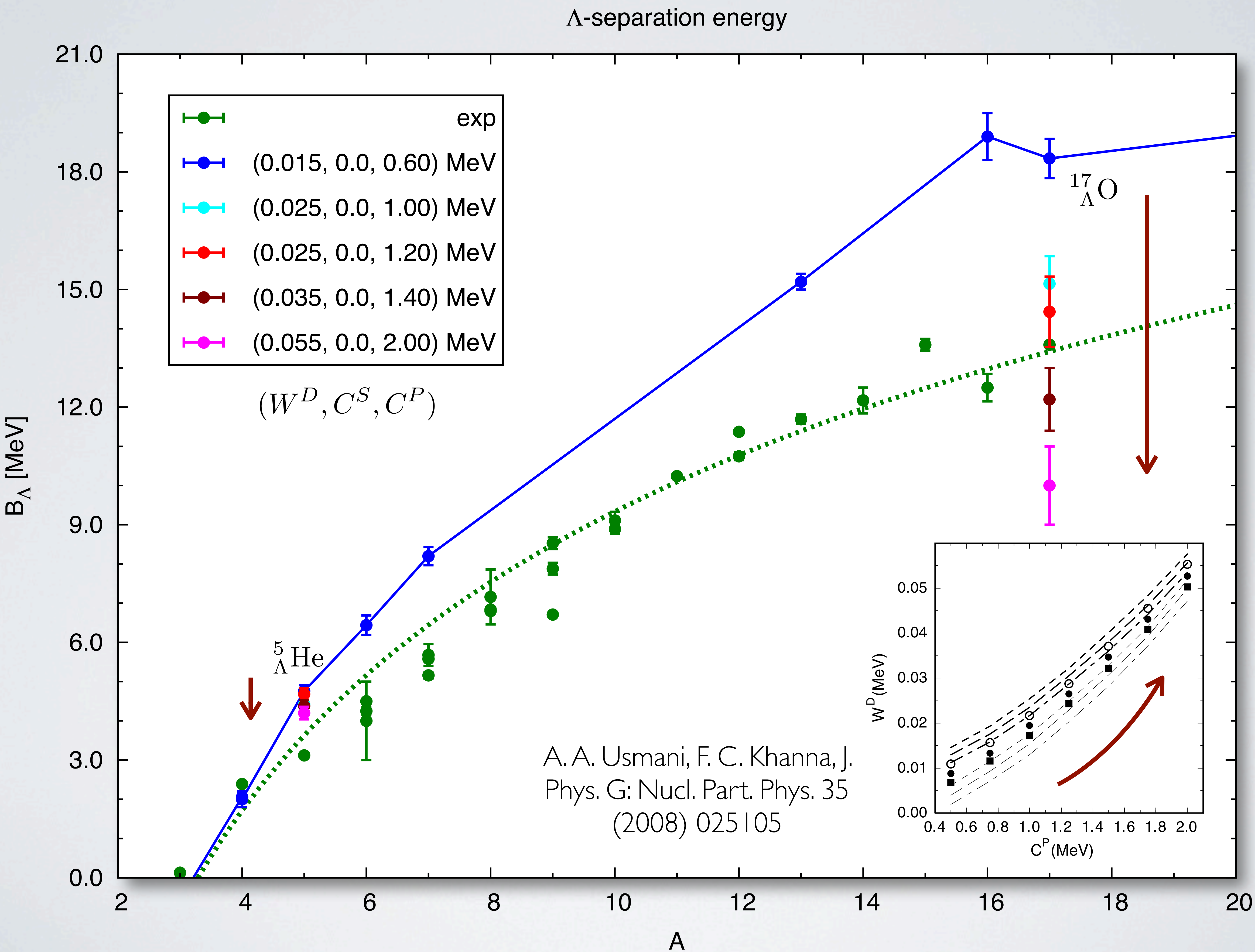


Λ-separation energy
B_Λ [MeV]
A
exp
AFDMC $V_{NN}(V'_4) + V_{\Lambda N}$
AFDMC $V_{NN}(V'_4) + V_{\Lambda N} + V_{\Lambda NN}$
$^{3}_{\Lambda}$H
$^{4}_{\Lambda}$H, $^{4}_{\Lambda}$He
$^{5}_{\Lambda}$He
$^{6}_{\Lambda}$He
$^{7}_{\Lambda}$He
$^{13}_{\Lambda}$C
$^{16}_{\Lambda}$O
$^{17}_{\Lambda}$O
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
2
4
6
8
10
12
14
16
18
20

Results

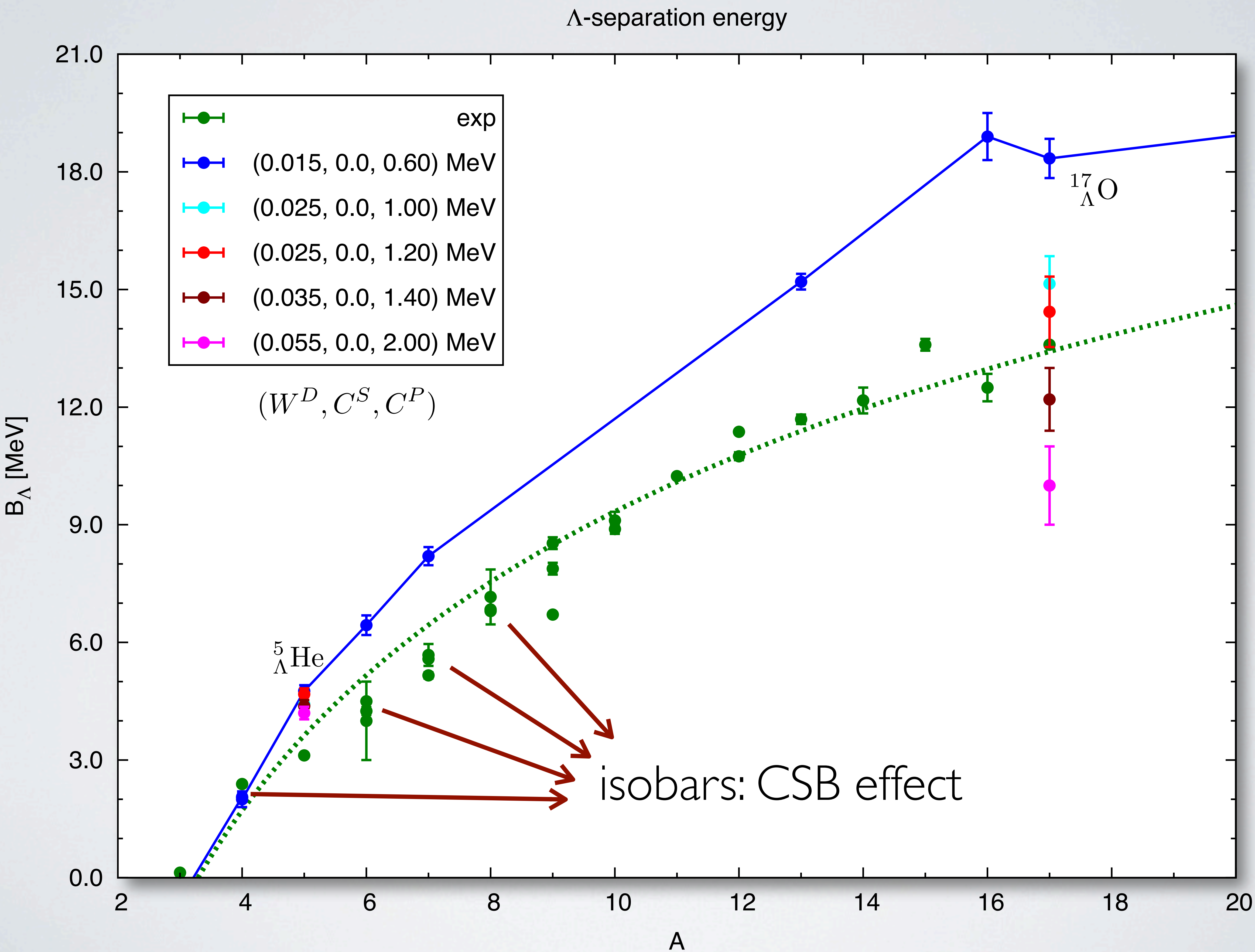

Λ-separation energy
exp
AFDMC V_NN(V'_4) + V_ΛN
AFDMC V_NN(V'_4) + V_ΛN + V_ΛNN
B_Λ [MeV]
A
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
2
4
6
8
10
12
14
16
18
20
16 Λ O
17 Λ O
13 Λ C
7 Λ He
6 Λ He
5 Λ He
3 Λ H
6 Λ H
preliminary !!
4 Λ H, 4 Λ He
M. Agnello, L. Benussi et al., Phys. Rev. Lett. 108 (2012) 1-5

Results



Λ-separation energy
exp
(0.015, 0.0, 0.60) MeV
(0.025, 0.0, 1.00) MeV
(0.025, 0.0, 1.20) MeV
(0.035, 0.0, 1.40) MeV
(0.055, 0.0, 2.00) MeV
(W^D, C^S, C^P)
$^{17}_{\Lambda}$O
$^{5}_{\Lambda}$He
B_Λ [MeV]
A
A. A. Usmani, F. C. Khanna, J. Phys. G: Nucl. Part. Phys. 35 (2008) 025105
W^D (MeV)
C^P (MeV)

Results



Λ-separation energy
exp
(0.015, 0.0, 0.60) MeV
(0.025, 0.0, 1.00) MeV
(0.025, 0.0, 1.20) MeV
(0.035, 0.0, 1.40) MeV
(0.055, 0.0, 2.00) MeV
(W^D, C^S, C^P)
$^{17}_{\Lambda}$O
$^{5}_{\Lambda}$He
isobars: CSB effect
B_Λ [MeV]
A
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
2
4
6
8
10
12
14
16
18
20

Results

charge symmetry breaking effect → $A = 4 \ldots 17$

preliminary !!

	${}^{4}_{\Lambda}\mathrm{H}$	${}^{4}_{\Lambda}\mathrm{He}$	${}^{5}_{\Lambda}\mathrm{He}$	${}^{6}_{\Lambda}\mathrm{H}$	${}^{6}_{\Lambda}\mathrm{He}$	${}^{17}_{\Lambda}\mathrm{O}$
B_{Λ}^{noCSB}	2.06(8)	2.0(1)	5.24(4)	4.0(2)	6.5(2)	18.3(5)
B_{Λ}^{CSB}	1.95(8)	2.1(1)	5.21(7)	3.7(2)	6.4(2)	–
B_{Λ}^{exp}	2.04(4)	2.39(3)	3.12(2)	4(1)	4.2(1)	13.6(∗)
ΔB_{Λ}	0.15(13)			2.7(3)		
ΔB_{Λ}^{exp}	0.35(5)			?		

Results

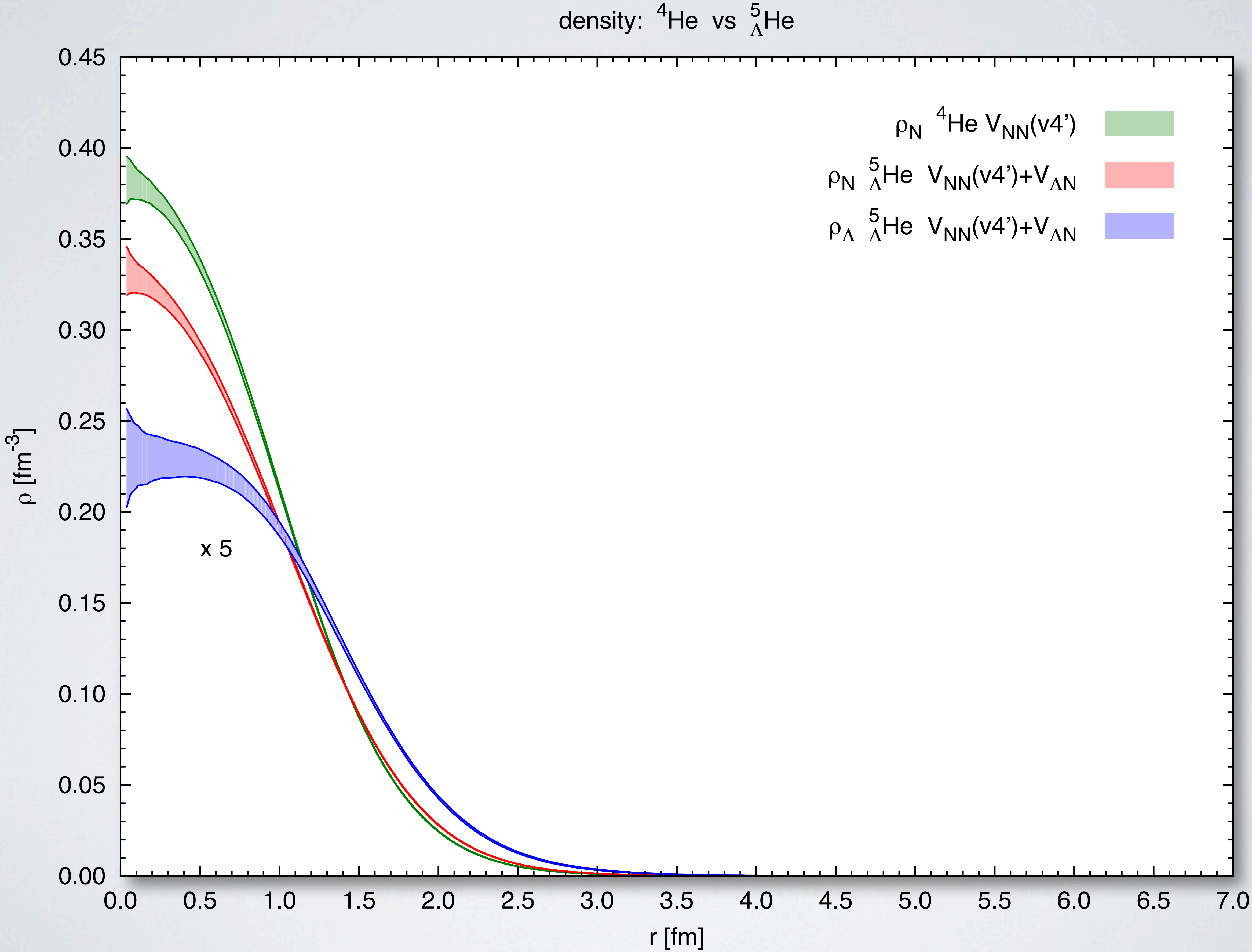
charge symmetry breaking effect ⟶ $A = 4 \ldots 17$

preliminary !!	${}^{4}_{\Lambda}\mathrm{H}$	${}^{4}_{\Lambda}\mathrm{He}$	${}^{5}_{\Lambda}\mathrm{He}$	${}^{6}_{\Lambda}\mathrm{H}$	${}^{6}_{\Lambda}\mathrm{He}$	${}^{17}_{\Lambda}\mathrm{O}$
B_{Λ}^{noCSB}	2.06(8)	2.0(1)	5.24(4)	4.0(2)	6.5(2)	18.3(5)
B_{Λ}^{CSB*}	1.88(9)	2.30(15)	5.21(7)	3.7(2)	6.4(2)	–
B_{Λ}^{exp}	2.04(4)	2.39(3)	3.12(2)	4(1)	4.2(1)	13.6(∗)
$\Delta B_{\Lambda}{}^{*}$	0.43(17)			2.7(3)		
ΔB_{Λ}^{exp}	0.35(5)			?		

consistent for the Λp & Λn channels

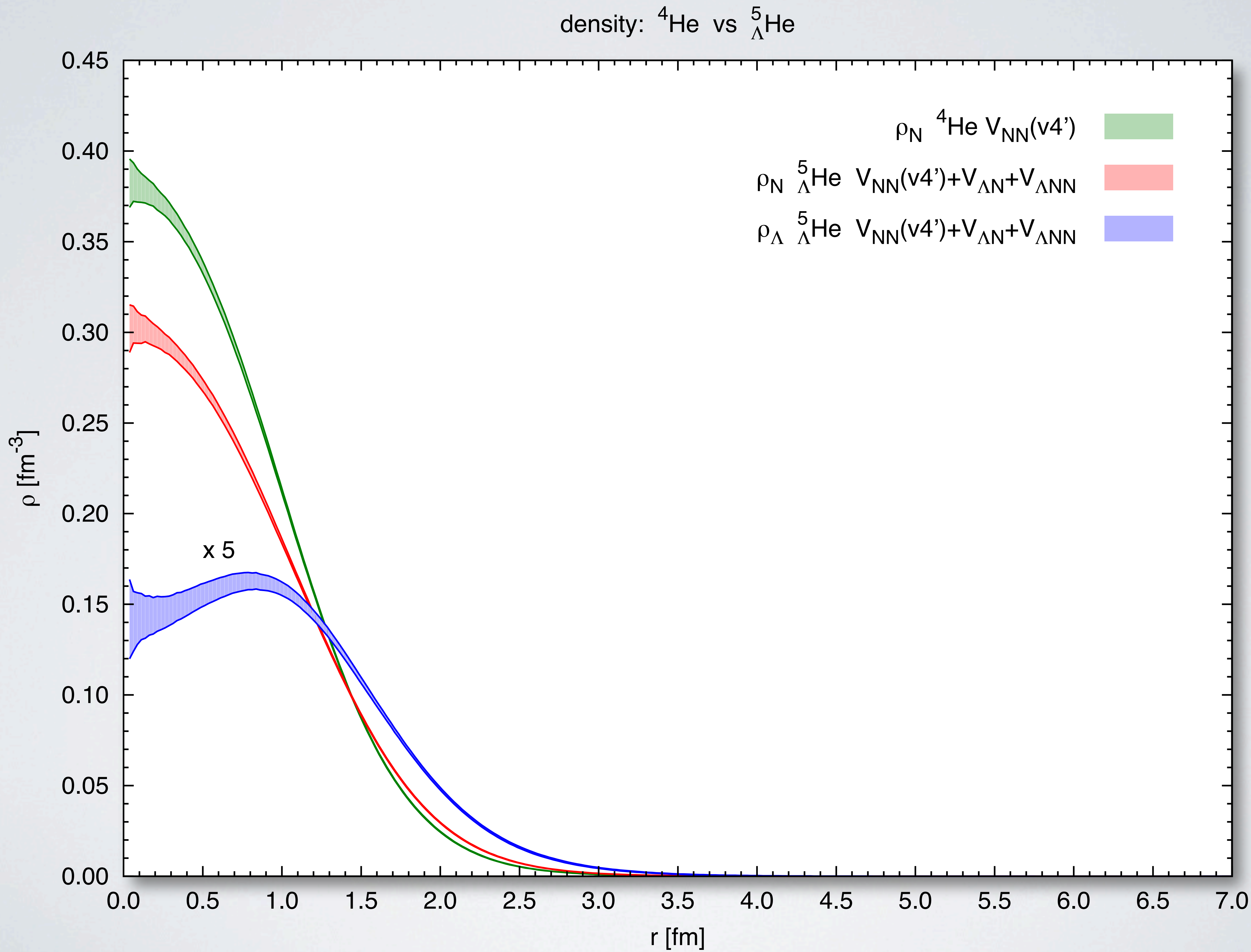
deeper investigation needed !!

Results



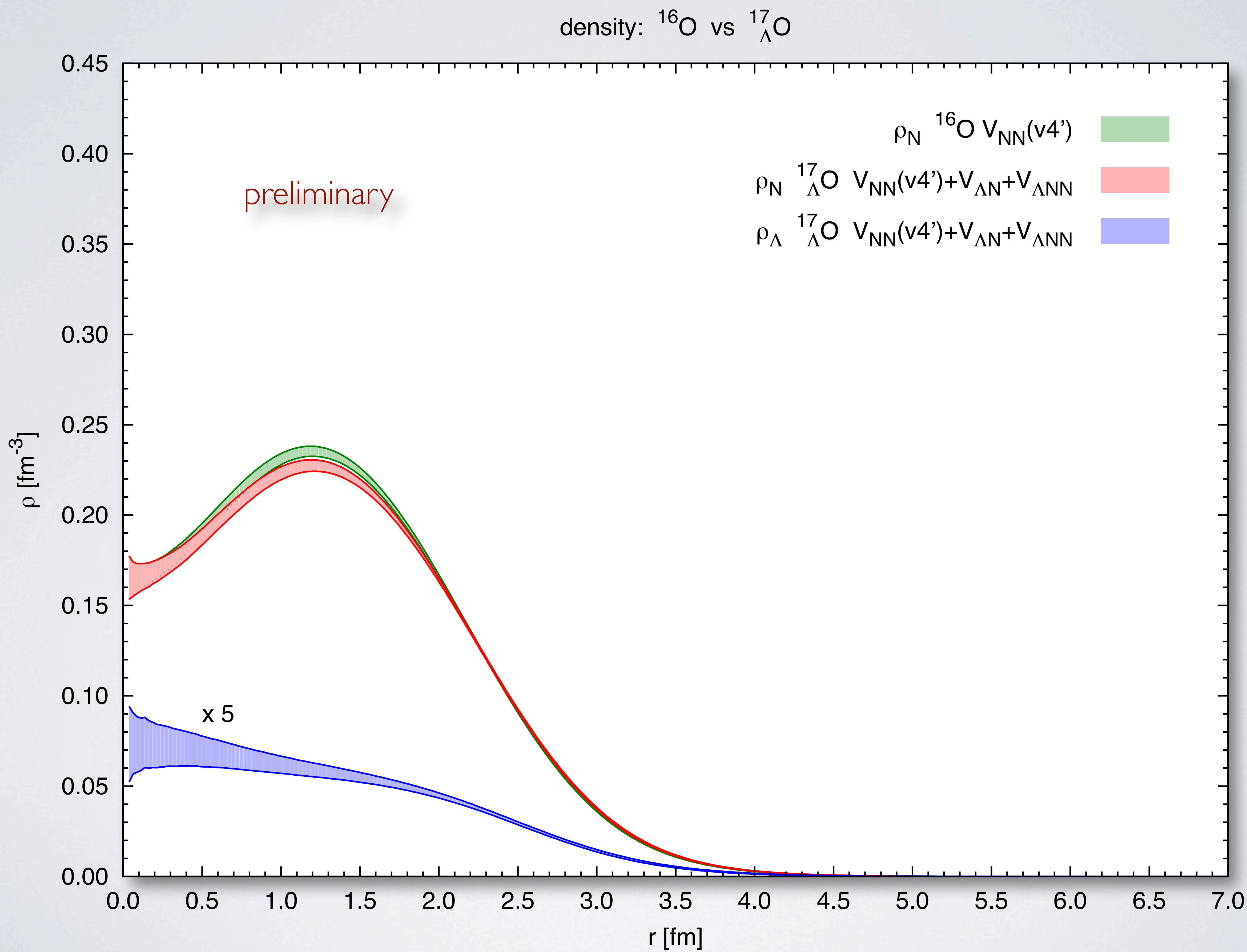
density: ^{4}He vs $^5_\Lambda$He
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
ρ [fm^{-3}]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
r [fm]
ρ_N ^{4}He V_{NN}(v4')
ρ_N $^5_\Lambda$He V_{NN}(v4')+$V_{\Lambda N}$
ρ_Λ $^5_\Lambda$He V_{NN}(v4')+$V_{\Lambda N}$
x 5

Results



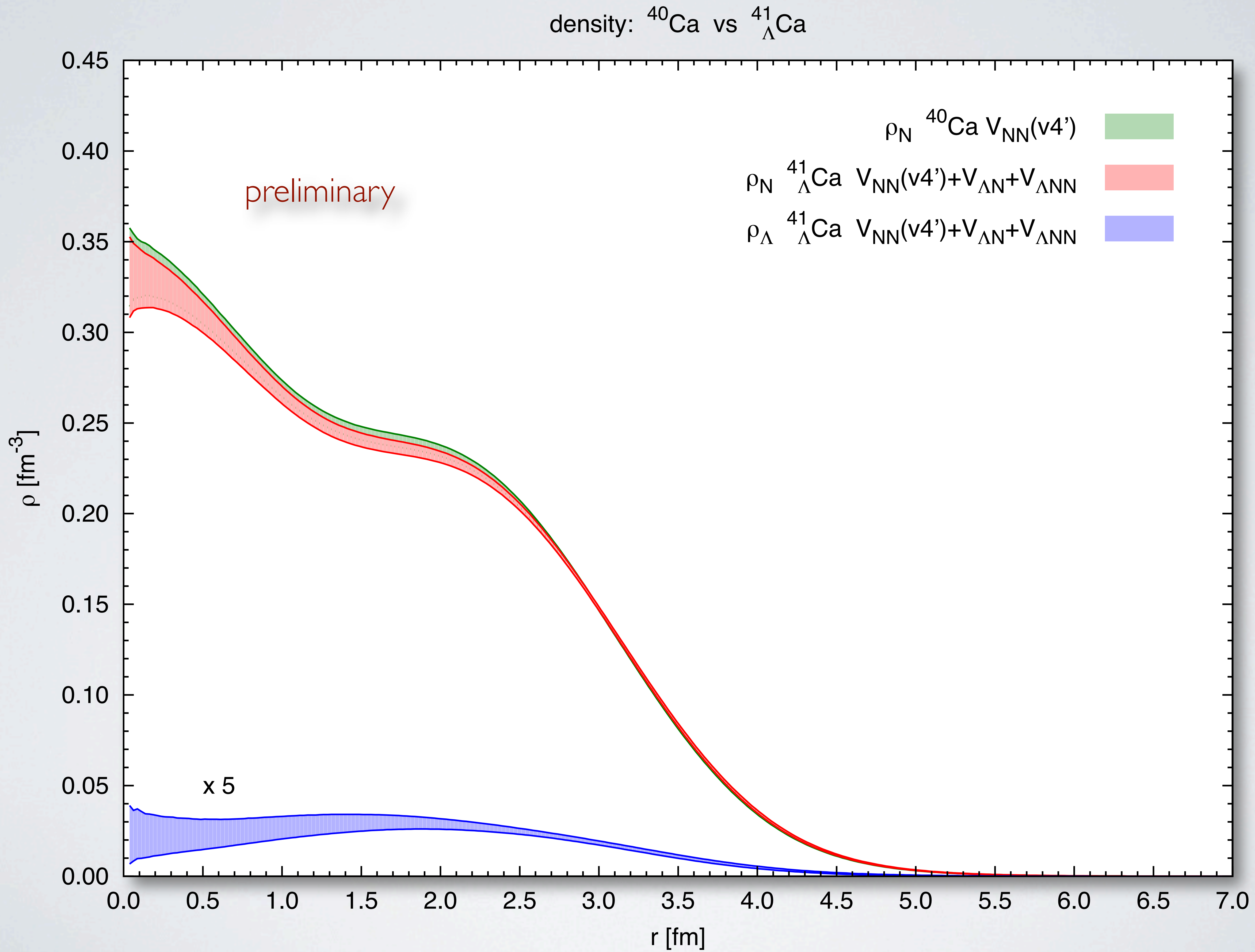
density: ^{4}He vs $^5_\Lambda$He
ρ_N ^{4}He V_{NN}(v4')
ρ_N $^5_\Lambda$He V_{NN}(v4')+$V_{\Lambda N}$+$V_{\Lambda NN}$
ρ_Λ $^5_\Lambda$He V_{NN}(v4')+$V_{\Lambda N}$+$V_{\Lambda NN}$
x 5
ρ [fm^{-3}]
r [fm]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

Results

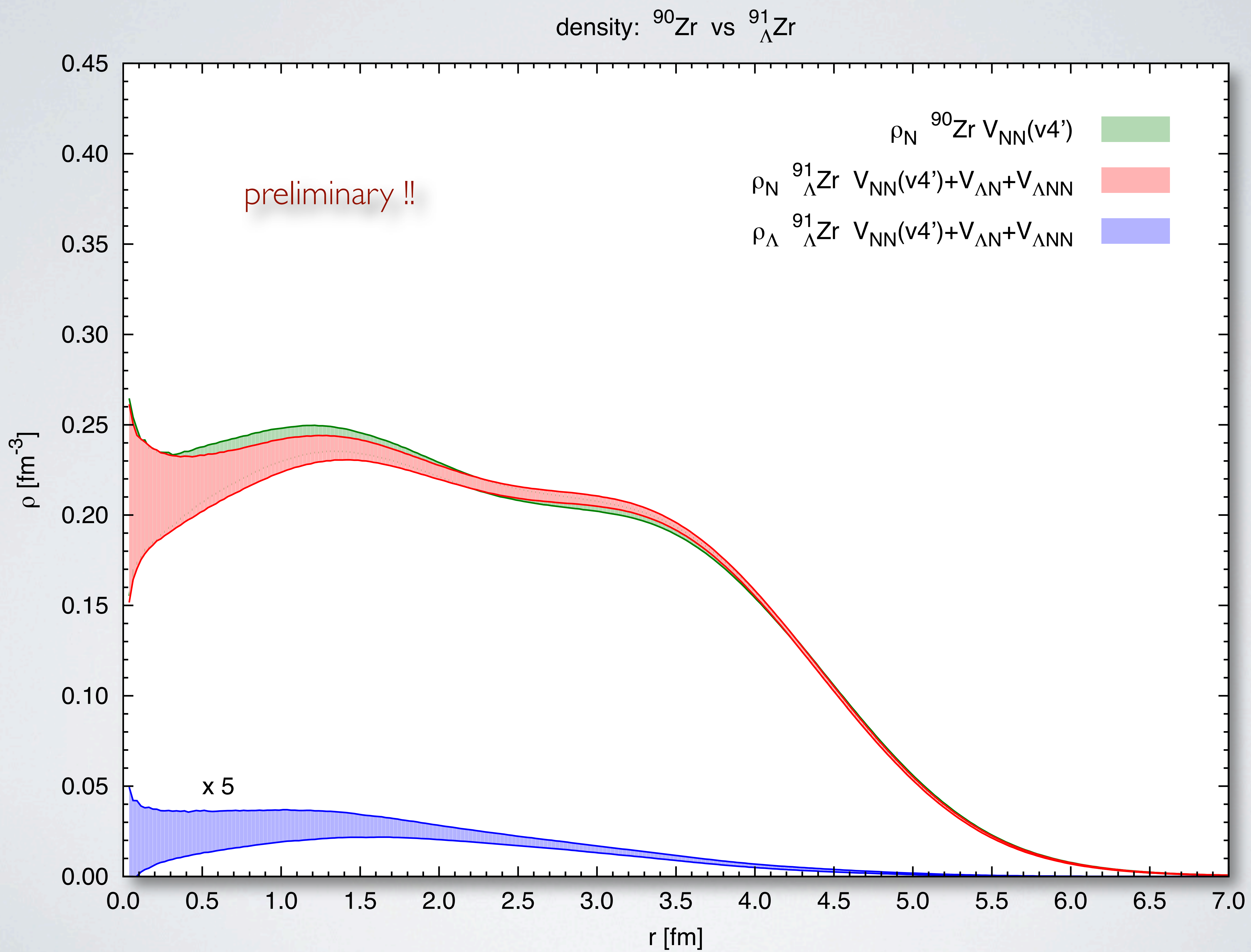


density: ^{16}O vs $^{17}_{\Lambda}O$
ρ_N ^{16}O $V_{NN}(v4')$
ρ_N $^{17}_{\Lambda}O$ $V_{NN}(v4')+V_{\Lambda N}+V_{\Lambda NN}$
ρ_Λ $^{17}_{\Lambda}O$ $V_{NN}(v4')+V_{\Lambda N}+V_{\Lambda NN}$
preliminary
x 5
ρ [fm^{-3}]
r [fm]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

Results


density: ^{40}Ca vs $^{41}_{\Lambda}$Ca
ρ_N ^{40}Ca V_{NN}(v4')
ρ_N $^{41}_{\Lambda}$Ca V_{NN}(v4')+$V_{\Lambda N}$+$V_{\Lambda NN}$
ρ_Λ $^{41}_{\Lambda}$Ca V_{NN}(v4')+$V_{\Lambda N}$+$V_{\Lambda NN}$
preliminary
x 5
ρ [fm^{-3}]
r [fm]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

Results



density: ^{90}Zr vs $^{91}_{\Lambda}$Zr
ρ_N ^{90}Zr V_{NN}(v4')
ρ_N $^{91}_{\Lambda}$Zr V_{NN}(v4')+$V_{\Lambda N}$+$V_{\Lambda NN}$
ρ_Λ $^{91}_{\Lambda}$Zr V_{NN}(v4')+$V_{\Lambda N}$+$V_{\Lambda NN}$
preliminary !!
x 5
ρ [fm^{-3}]
r [fm]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

Conclusions & Perspectives

- AFDMC algorithm can be extended to hypernuclear systems: study of the hyperon-nucleon interaction
- 3-body ΛNN interaction fundamental for the computation of the hyperon separation energy — fine tuning of the parameters
- CSB interaction needed — work in progress
- 3-body ΛNN interaction repulsive in hypernuclei: extrapolation for nuclear matter $\longrightarrow$ NS EOS with Λ — next step (LANL)
- possible inclusion of a $\Lambda\Lambda$ interaction: AFDMC hypernuclear code ready — future work
- possible application to neutron drops: study of exotic systems — (future work)

Thank you for your attention

The interaction

$$T_\pi(x) = \left(1 + \frac{3}{x} + \frac{3}{x^2}\right) Y_\pi(x)\xi(r)$$

$$Y_\pi(x) = \frac{\mathrm{e}^{-x}}{x}\xi(r) \qquad \xi(r) = 1 - \mathrm{e}^{-cr^2}$$

$$Z_\pi(x) = \frac{x}{3}\left[Y_\pi(x) - T_\pi(x)\right]$$

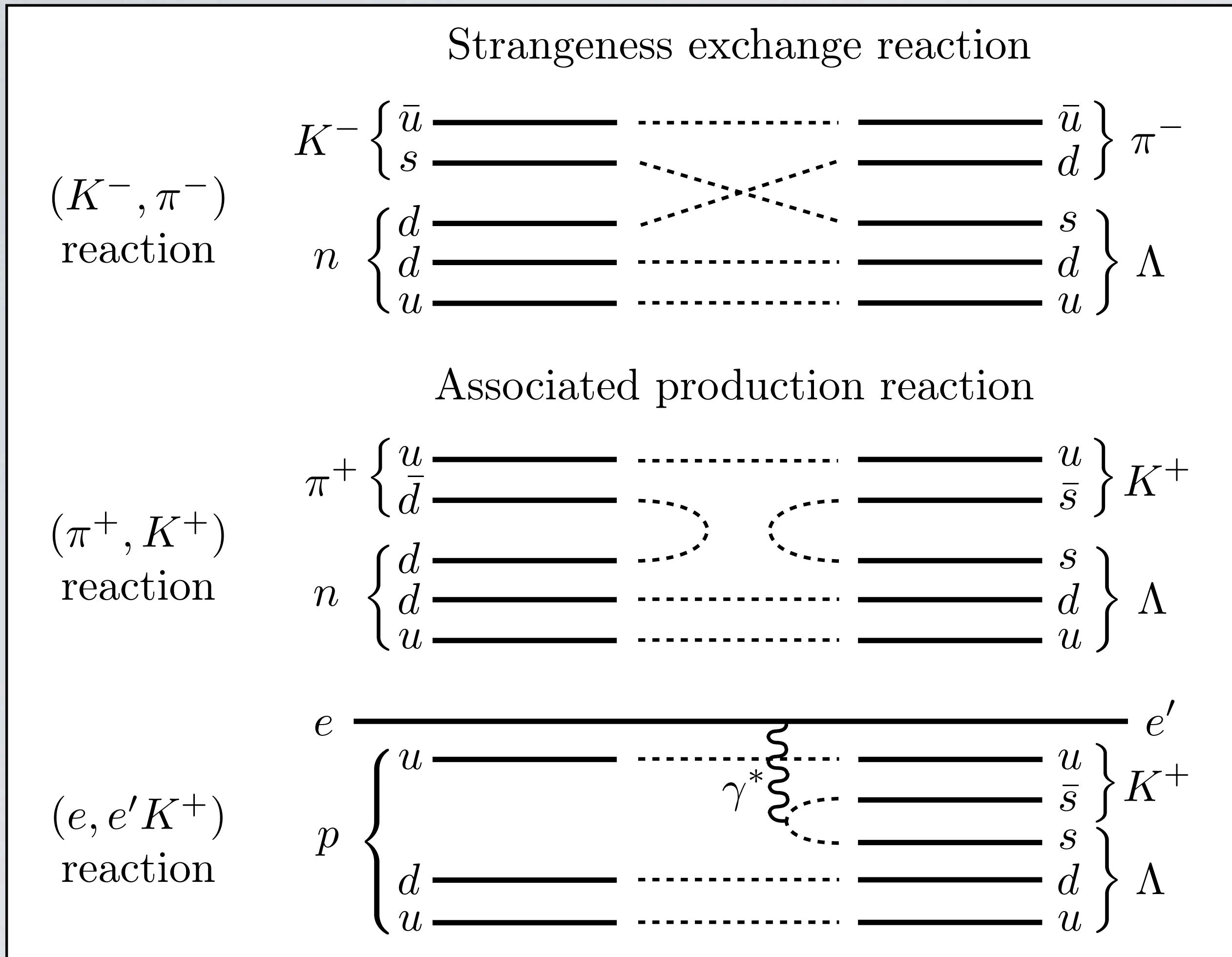
$$X_{\Lambda i} = (\boldsymbol{\sigma}_\Lambda \cdot \boldsymbol{\sigma}_i)\, Y_\pi\left(m_\pi r_{\Lambda i}\right) + S_{\Lambda i}\, T_\pi\left(m_\pi r_{\Lambda i}\right)$$

$$S_{\Lambda i} = 3\left(\boldsymbol{\sigma}_\Lambda \cdot \hat{\boldsymbol{r}}_{\Lambda i}\right)\left(\boldsymbol{\sigma}_i \cdot \hat{\boldsymbol{r}}_{\Lambda i}\right) - \boldsymbol{\sigma}_\Lambda \cdot \boldsymbol{\sigma}_i$$

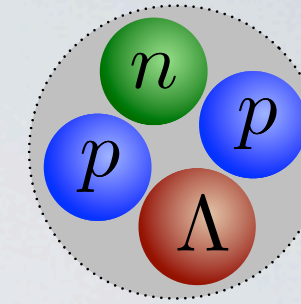
The interaction

Constant	Value	Unit
$m_{\pi^\pm}$	139.57018(35)	MeV
m_{π^0}	134.9766 (6)	MeV
W_c	2137	MeV
r_0	0.5	fm
a	0.2	fm
ε	$0.1 \div 0.38$	–
$\bar{v}$	6.15(5)	MeV
v_s	6.33, 6.28, 6.23	MeV
v_t	6.09, 6.04, 5.99	MeV
v_σ	0.24	MeV
c	2.0	fm^{-2}
W^D	$0.01 \div 0.05$	MeV
C^P	$0.4 \div 2.0$	MeV
C^S	~ 1.5	MeV

Motivations: experimental interest

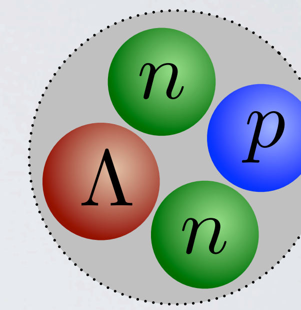


$$^{A}Z(K^-, \pi^-)^{A}_{\Lambda}Z$$



$$^{A}Z(\pi^+, K^+)^{A}_{\Lambda}Z$$

$$^{A}Z(e, e'K^+)^{A}_{\Lambda}[Z-1]$$



hypernuclear
fine structure

$\gamma-$ ray spectroscopy