Mean-field calculations with the Gogny force including the tensor force

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Motivation

- To understand exotic phenomena appearing in unstable nuclei
- To investigate, in particular, **Tensor-force** effect on single-particle energies (SPE)
- Its effect on them is different from that of the LS force

Brief description of the Tensor Force

Tensor force

- originates from the π- (and ρ-) meson exchange
- plays an important role in nuclear properties, such as binding energies
- can influence on SPE in the different way compared to the LS force

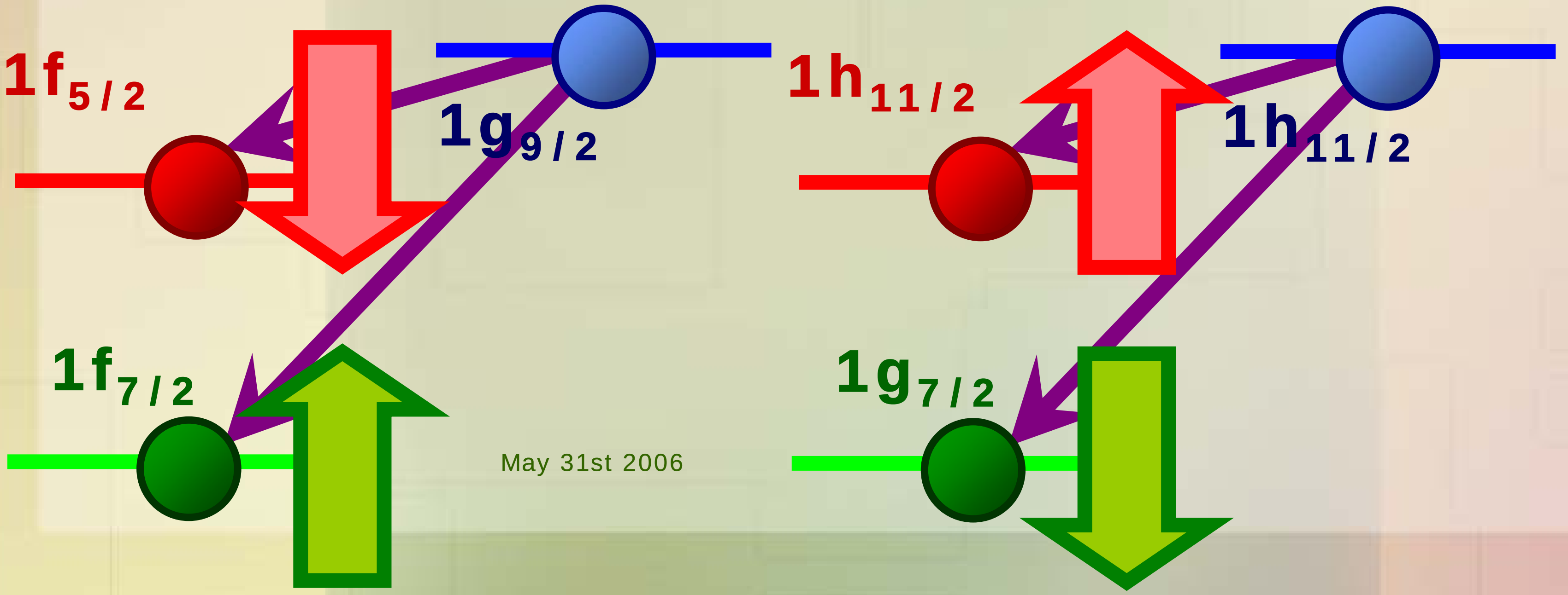
$$V_{\mathrm{T}} = V_{\mathrm{T}}(r) S_{12}$$

$$\begin{aligned} S_{12} &= 3(\boldsymbol{\sigma}_1 \cdot \hat{\boldsymbol{r}})(\boldsymbol{\sigma}_2 \cdot \hat{\boldsymbol{r}}) - (\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2) \\ &= 3\left([\sigma_1 \otimes \sigma_2]^{(2)} \cdot [r \otimes r]^{(2)} \right) \end{aligned}$$

Monopole Contribution of the Tensor Force

$$(2j_> + 1)V_{j'j_>} + (2j_< + 1)V_{j'j_<} = 0$$

- Repulsive $j_> j'_>$ or $j_< j'_<$
- Attractive $j_> j'_<$ or $j_< j'_>$



- **Stancu et al.** Phys. Lett. 68B, 108 (1977)
  Skyrme (SIII)
  + Tensor (zero range)

[zero-range Tensor Force]

$$V_{\mathrm{T}} = \frac{1}{2}T\Big\{ \Big[(\boldsymbol{\sigma}_1\cdot\overleftarrow{\boldsymbol{k}})(\boldsymbol{\sigma}_2\cdot\overleftarrow{\boldsymbol{k}}) - \frac{1}{3}(\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)\overleftarrow{k}^2\Big]\delta(\boldsymbol{r})$$

$$+\delta(\boldsymbol{r})\Big[(\boldsymbol{\sigma}_1\cdot\overrightarrow{\boldsymbol{k}})(\boldsymbol{\sigma}_2\cdot\overrightarrow{\boldsymbol{k}}) - \frac{1}{3}(\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)\overrightarrow{k}^2\Big]\Big\}$$

$$+U\Big\{(\boldsymbol{\sigma}_1\cdot\overleftarrow{\boldsymbol{k}})\delta(\boldsymbol{r})(\boldsymbol{\sigma}_2\cdot\overrightarrow{\boldsymbol{k}}) - \frac{1}{3}(\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)\Big(\overleftarrow{\boldsymbol{k}}\cdot\delta(\boldsymbol{r})\overrightarrow{\boldsymbol{k}}\Big)\Big\}$$

Gogny-type Interaction

- **D1S** J. F. Berger, et al., Nucl. Phys. A428 (1984) 23c
- **GT2** T. Matsuo, Ph.D. Thesis, University of Tokyo (2004)

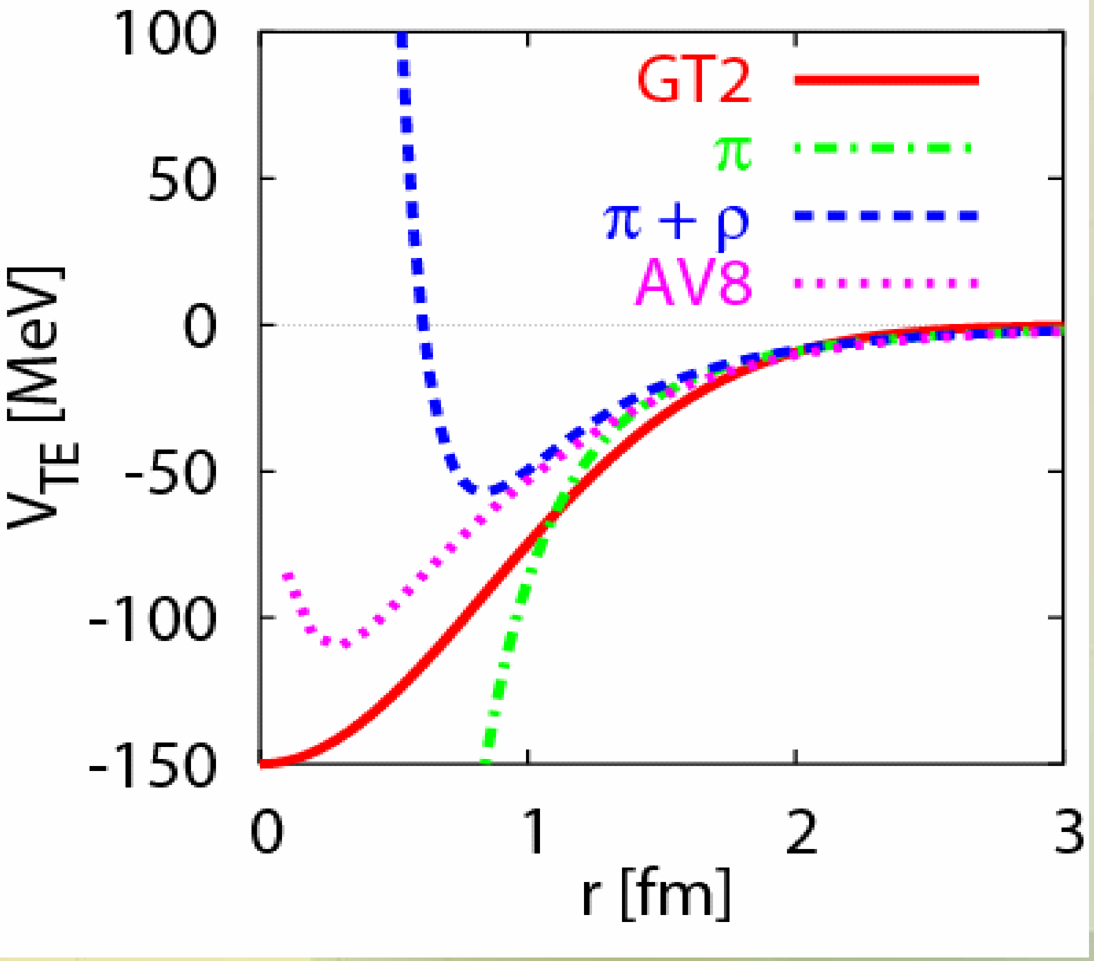
Central | Spin-orbit | Density-dependent

Tensor

$$V_T = (\boldsymbol{\tau}_1 \cdot \boldsymbol{\tau}_2) V_T(r) S_{12}$$
$$V_T(r) = V_T^0 \exp(-r^2/\mu^2)$$

Radial dependences of various interactions

V_{TE}: Triplet-Even



$\mu_{\mathrm{T}} = 1.2[\mathrm{fm}]$

$V_{\mathrm{T}}^{0} = 50[\mathrm{MeV}]$

$$V_{\mathrm{LS}} = V_{\mathrm{LS}}(r)\boldsymbol{L}_{12}\cdot(\boldsymbol{s}_1+\boldsymbol{s}_2)$$
$$\simeq iW_0(\boldsymbol{\sigma}_1+\boldsymbol{\sigma}_2)\cdot\overleftarrow{\boldsymbol{k}}\times\delta(\boldsymbol{r})\overrightarrow{\boldsymbol{k}}$$

Proton

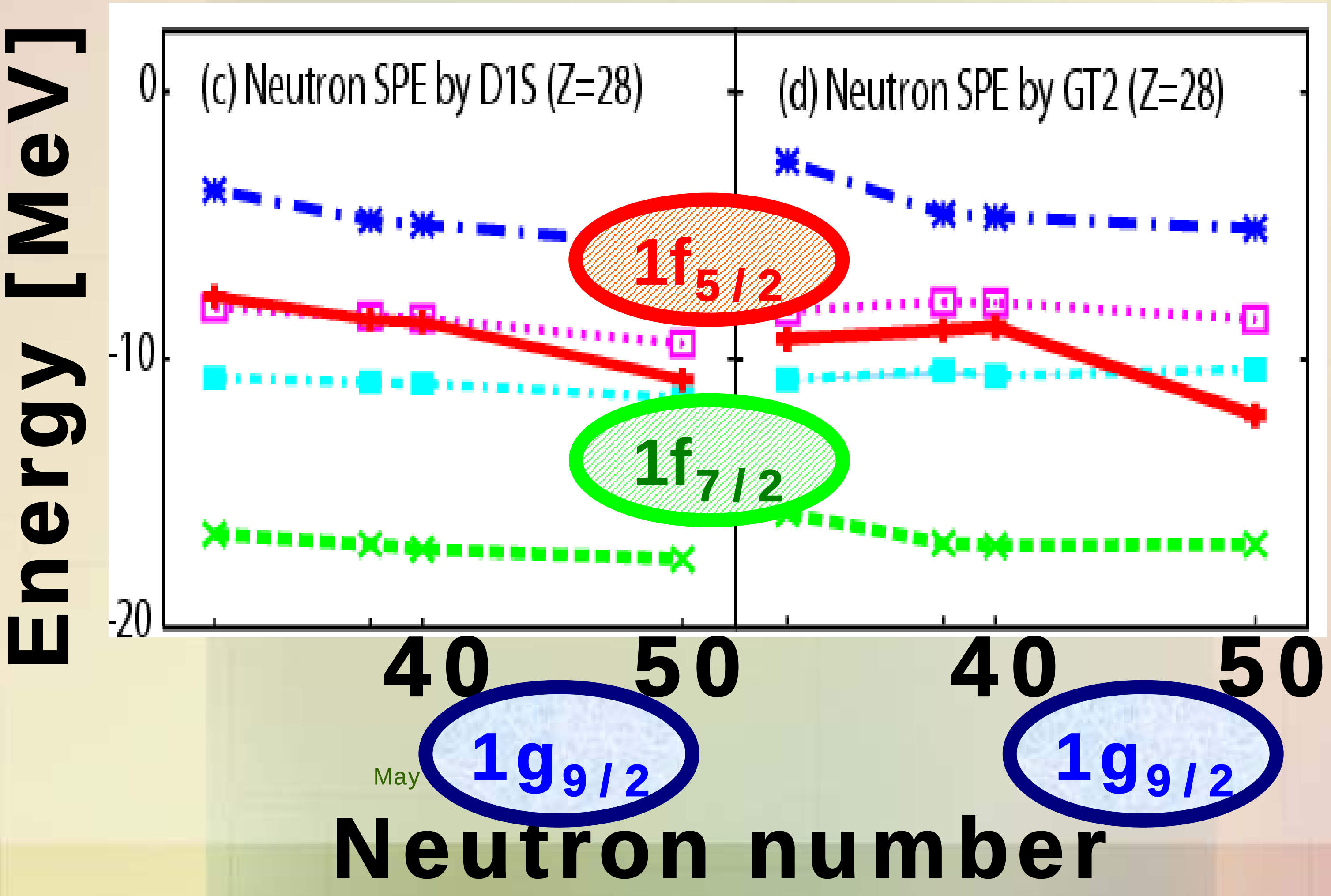
Neutron

One-body potential

$$U_{\mathrm{p}} \propto \frac{d}{dr}(\rho_{\mathrm{n}}+2\rho_{\mathrm{p}})$$
$$U_{\mathrm{n}} \propto \frac{d}{dr}(2\rho_{\mathrm{n}}+\rho_{\mathrm{p}})$$

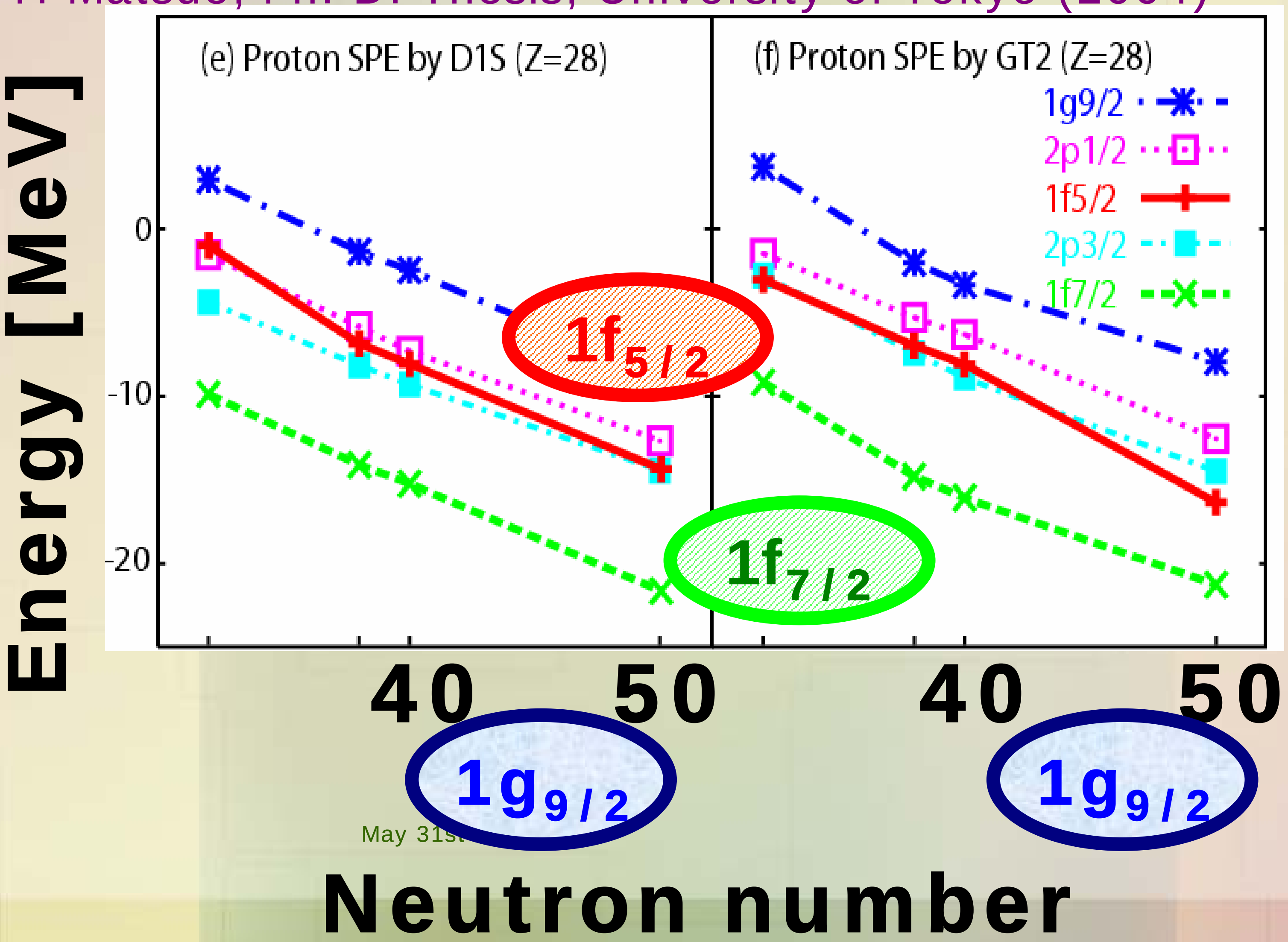
^{68}Ni and ^{78}Ni (Neutron)

T. Matsuo, Ph. D. Thesis, University of Tokyo (2004)

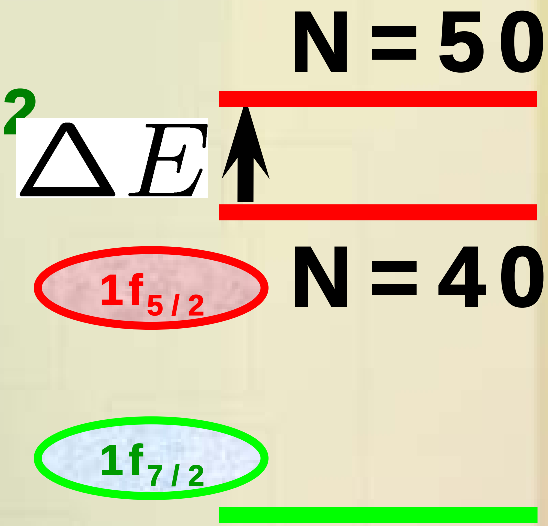


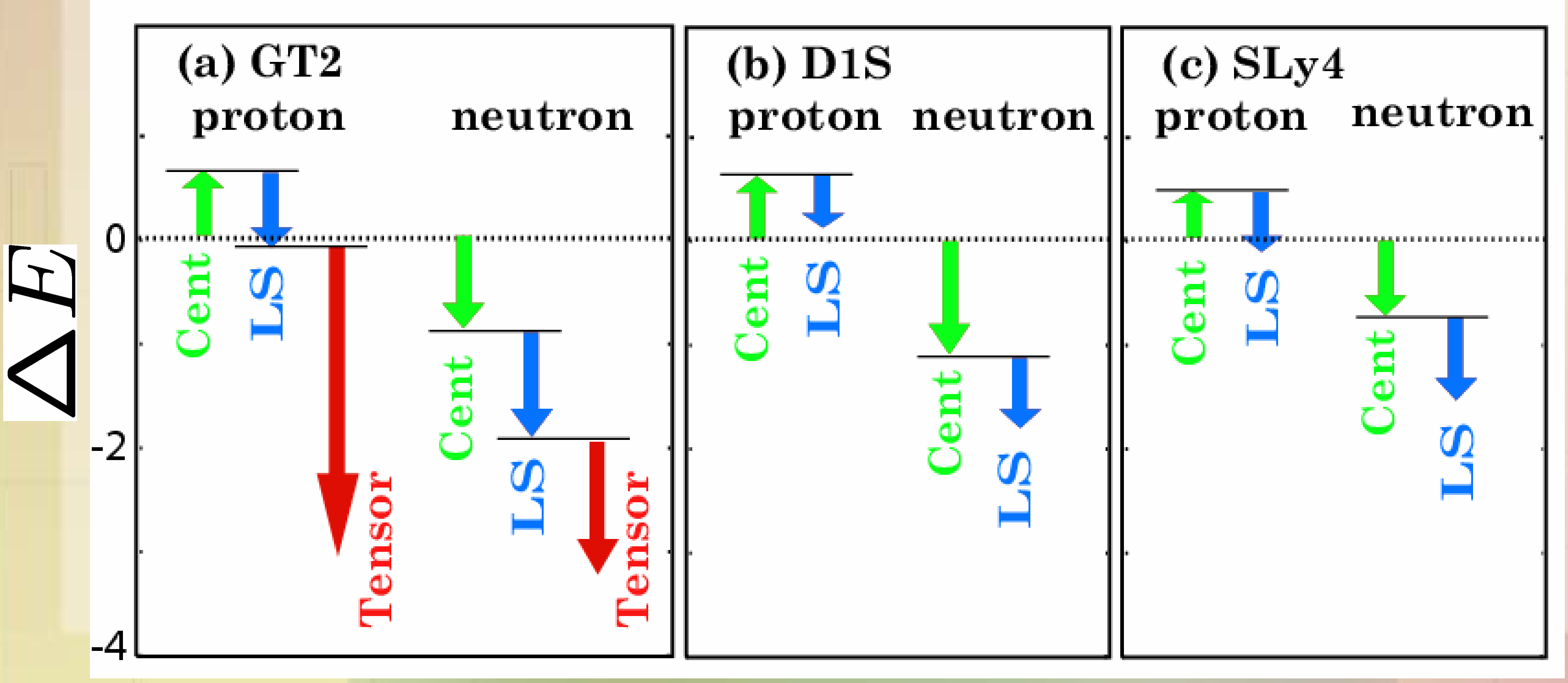
^{68}Ni and ^{78}Ni (Proton)

T. Matsuo, Ph. D. Thesis, University of Tokyo (2004)

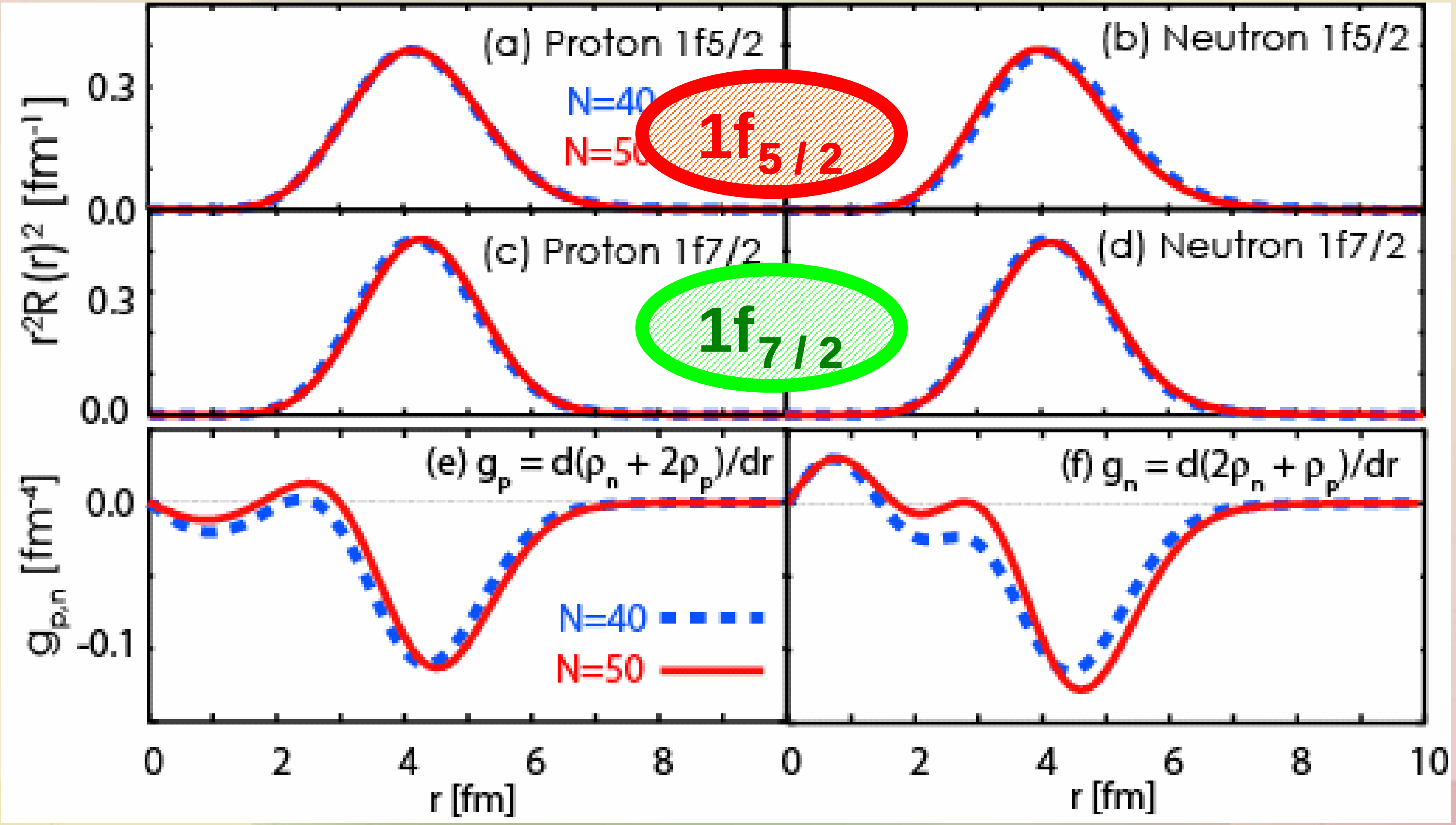


Variation of the gap between $1f_{5/2}$ and $1f_{7/2}$ (N= 40-50)



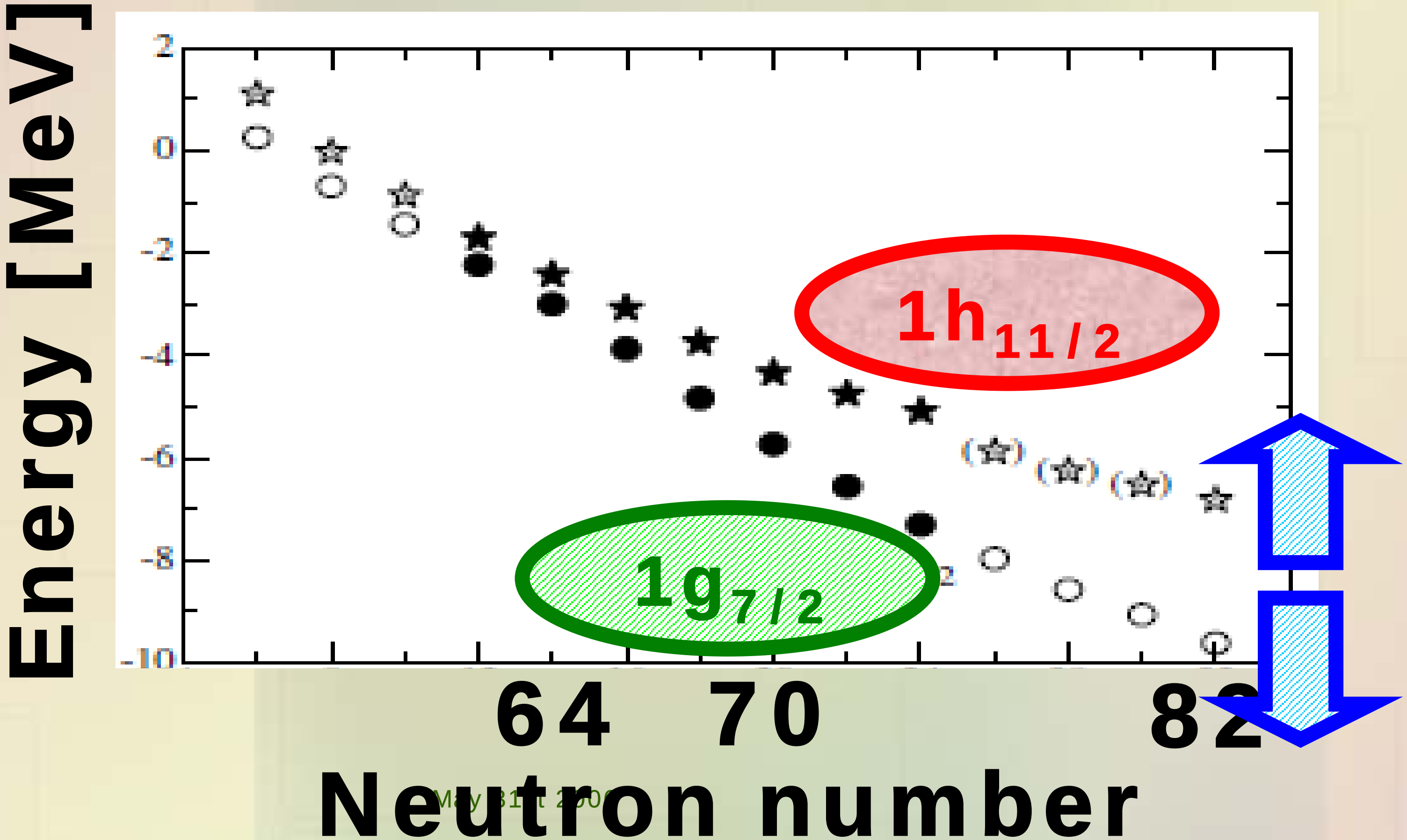


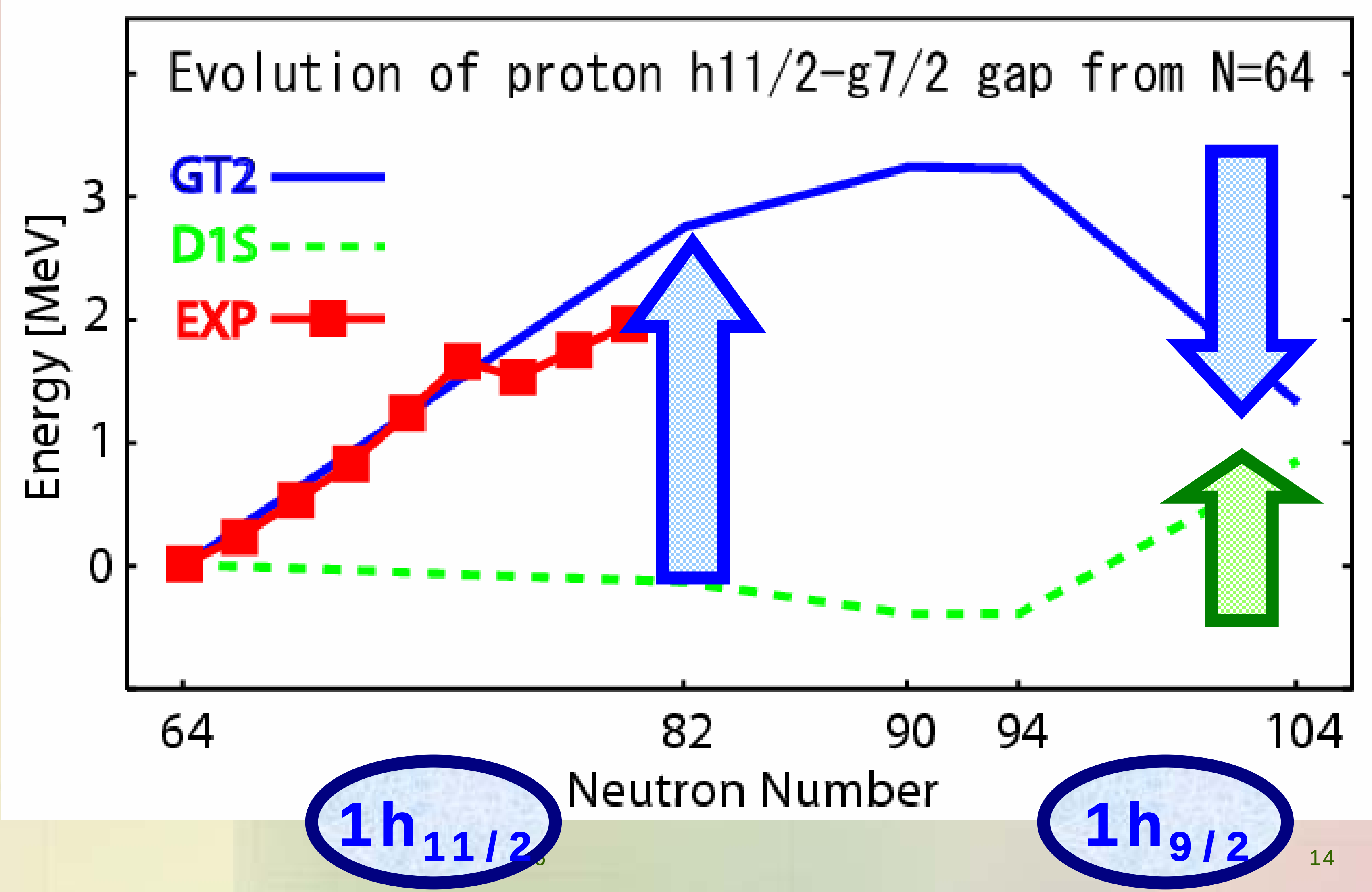
Density and spin-orbit potential



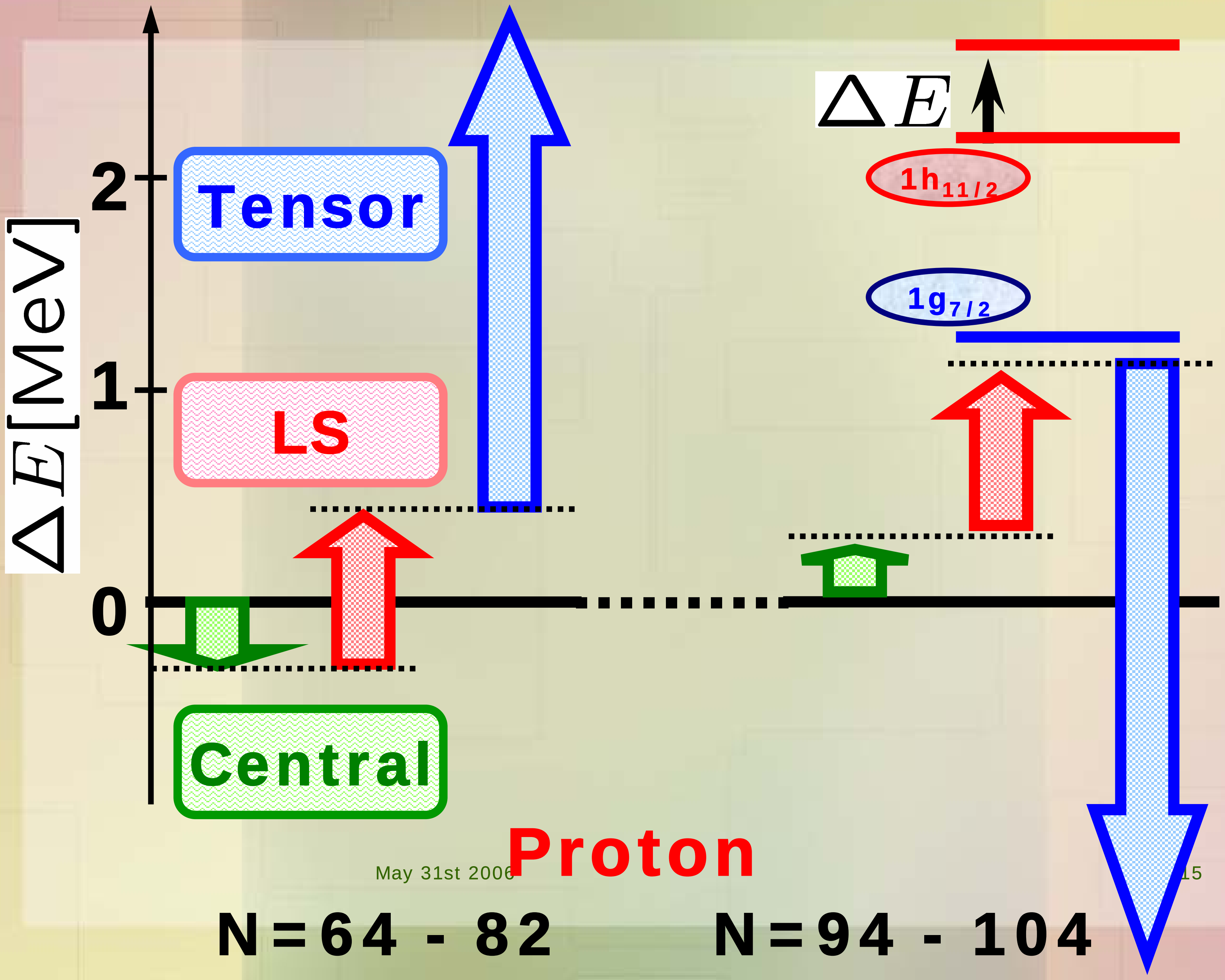
Proton $1h_{11/2}$ and $1g_{7/2}$ of $_{51}$Sb isotopes

J. P. Schiffer et al., Phys. Rev. Lett. 92 162501 (2004)





Evolution of proton h11/2-g7/2 gap from N=64
GT2
D1S
EXP
Energy [MeV]
3
2
1
0
64
82
90
94
104
Neutron Number
1h11/2
1h9/2



ΔE [MeV]
2
1
0
Tensor
LS
Central
ΔE
1h11/2
1g7/2
Proton
N=64 - 82
N=94 - 104

Summary

- Tensor force can influence on single-particle energies in the different way compared to the LS force
- For example,
  - Gap between $1f_{7/2}$ and $1f_{5/2}$ of Ni isotopes
  - Gap between $1h_{11/2}$ and $1g_{7/2}$ of Sb isotopes