三体計算によるK中間子重水素スペクトルの研究

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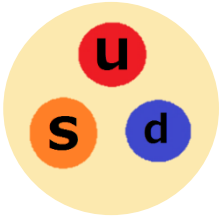
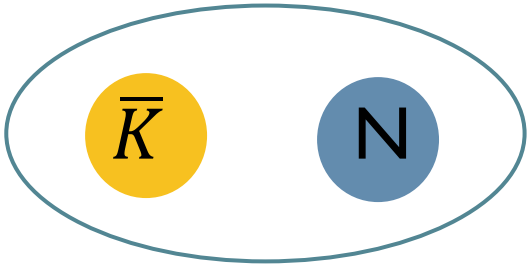
$\Lambda(1405)$

Quark model



- It is difficult to reproduce $\Lambda(1405)$ mass

Quasi-bound



Meson-Baryon description

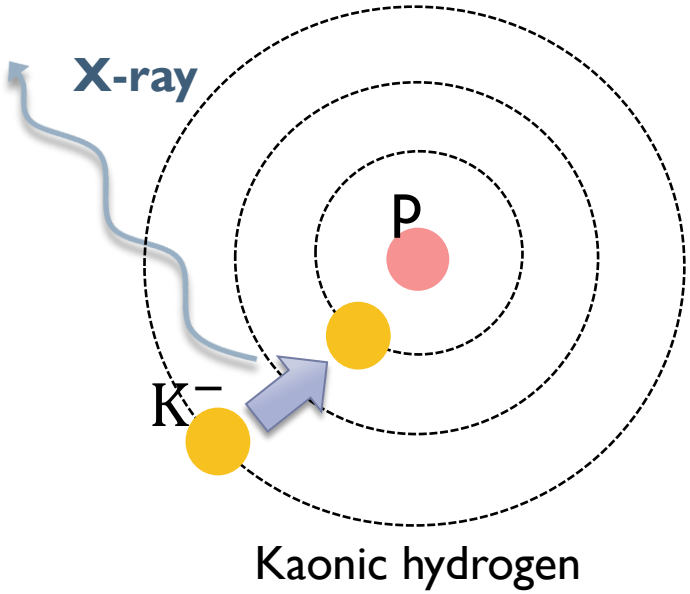
$\Lambda(1405)$ can be understand as a quasi-bound state of nucleon and anti-kaon R.H.Dalitz et al., PR153 (1967)

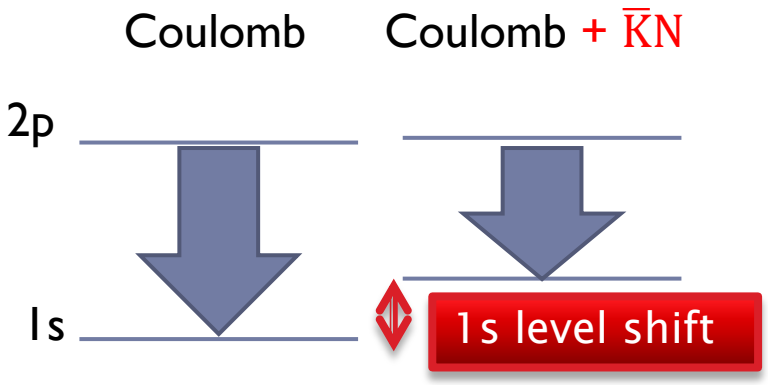
- Quasi-bound state → strong $\overline{\mathrm{K}}\mathrm{N}$ interaction
- Kaonic nucleus is suggested

Kaonic atom

- A kaonic atom can be de-excited with X-ray emissions like as an ordinary atom
- There is difference between calculated X-ray energy with only the Coulomb interaction and the experimental value

  →Short ranged $\bar{K}N$ interaction affects the X-ray energy





Studies for kaonic atoms

- Kaonic hydrogen was researched and measured its 1s level-shift and decay width precisely.

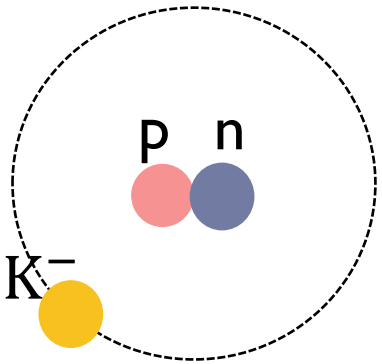
  (2011, SIDDHARTA experiment , DAΦNE) Bazzi et al., NPA881 (2012)

$$\epsilon_{1s} = 283 \pm 36(\text{stat}) \pm 6(\text{syst})\text{eV}$$
$$\Gamma_{1s} = 541 \pm 89(\text{stat}) \pm 22(\text{syst})\text{eV}$$

- $\bar{K}N$ interaction has isospin $I = 0$ and $I = 1$ components
- The data of a kaonic hydrogen and a kaonic deuterium may decompose isospin components of the $\bar{K}N$ interaction.

$$|K^- p\rangle = |\uparrow\downarrow\rangle$$
$$= |I = 0\rangle + |I = 1\rangle$$

$$|K^- n\rangle = |\uparrow\uparrow\rangle$$
$$= |I = 1\rangle$$



Kaonic deuterium

Method

Hamiltonian

- Hamiltonian

$$H = T + V = \sum_{i=1}^{3} \frac{\boldsymbol{p}_i^2}{2m_i} - T_{cm} + V^{NN} + V^{N\bar{K}} + V^{coul}$$

- V^{NN} (Minnesota potential) D. R. Thompson, M. Lemere and Y. C. Tang, NPA286 (1977)
- $V^{N\bar{K}}$ (MH potential) K.Miyahara, T.Hyodo, arXiv:1506.05724 [nucl-th]
  - It reproduces the scattering amplitude calculated by Y.Ikeda, T.Hyodo, W.Weise.
  - That amplitude derived from NLO chiral SU(3) dynamics.
    1. Scattering length extracted from the energy shift measured in SIDDHARTA experiment.
    2. Cross section of a $N\bar{K}$ two-body scattering
    3. Branching ratio of the $\bar{K}p$ decay

    Y.Ikeda, T.Hyodo, W.Weise, NPA881 (2012)

Three body calculation

Variational Method

- Wave function

K. Varga and Y. Suzuki, PRC52, 2885 (1995).

Correlated Gaussian basis

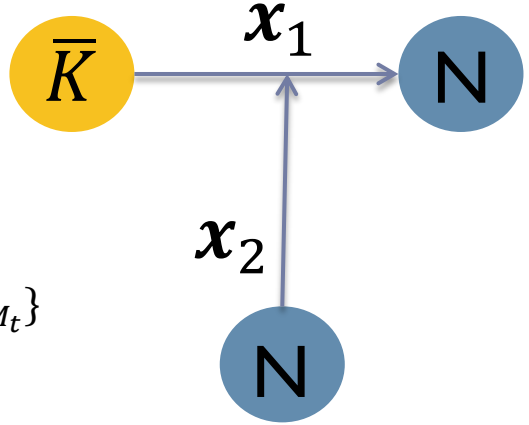
$$\Psi = \sum_{i=1}^{N} c_i \phi_i , \qquad \phi_i = A_{NN} \{ e^{-\frac{1}{2}\tilde{x} A_i x} y_{LM_L}(\tilde{u}x) \chi_{iJM} \eta_{iTM_t} \}$$

A_i: 2×2 matrix(paramaters of coordinates)

$\boldsymbol{x} = \{\boldsymbol{x}_1, \boldsymbol{x}_2\}$, $\boldsymbol{ux} = \sum_i^N u_i \boldsymbol{x_i}$

$y_{lm} = (\boldsymbol{ux})^l Y_{lm}(\widehat{\boldsymbol{ux}})$

χ_{iJM}: spin function, η_{iTM_t}: isospin function



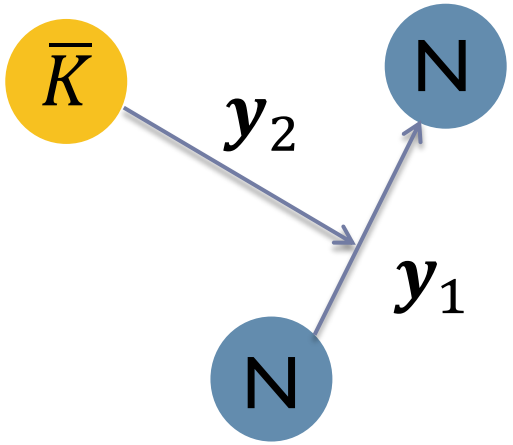
Configuration, I

- Geometric progression

E. Hiyama Y. Kino and M. Kamimura, PPNP51 (2003)

- $|K^- pn\rangle = |\uparrow\downarrow\uparrow\rangle$
- $|\overline{K^0} nn\rangle = |\downarrow\uparrow\uparrow\rangle$

} **5MeV**



Configuration,2

Results

2body ($\boldsymbol{p}$-$\boldsymbol{K^-}$)

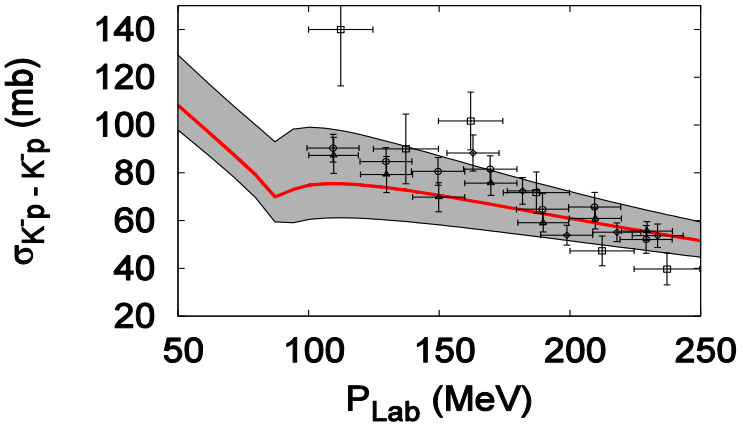
Results (kaonic hydrogen)

- $V^{\bar{K}N} = V_{I=0} + \alpha_{I=1} \cdot V_{I=1}$

	Energy shift（eV）	Decay width (eV)
Experiment (SIDDHARTA)	283 ±36(stat) ±6(syst)	541±89(stat) ±22(syst)
Bare ($\alpha_{I=1} = 1.00$)	307	606
$\alpha_{I=1} = 1.12$	320	652
$\alpha_{I=1} = 0.37$	293	430

Cross section

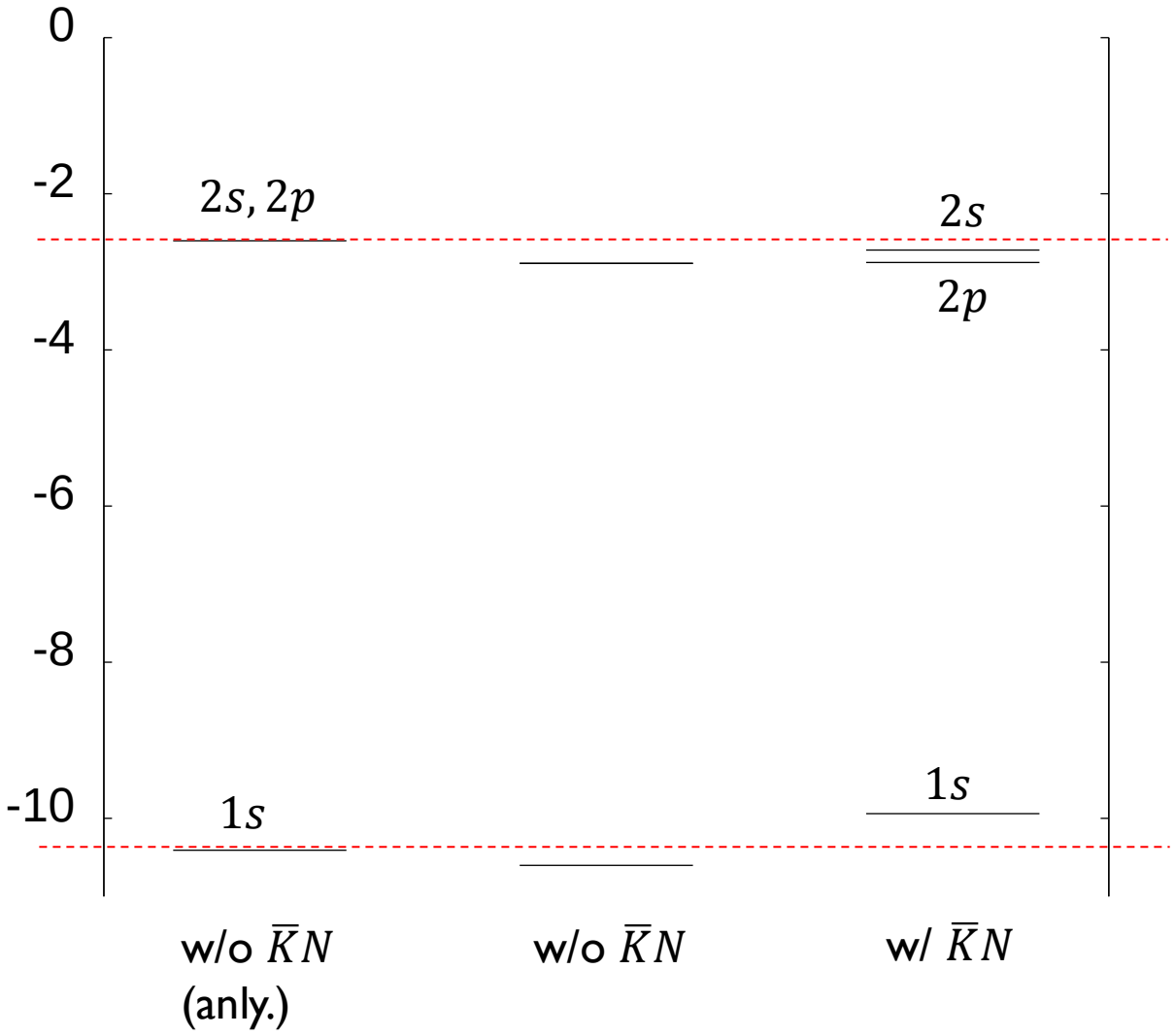
- $\alpha_{I=1} = 1.12 \sim 0.9$



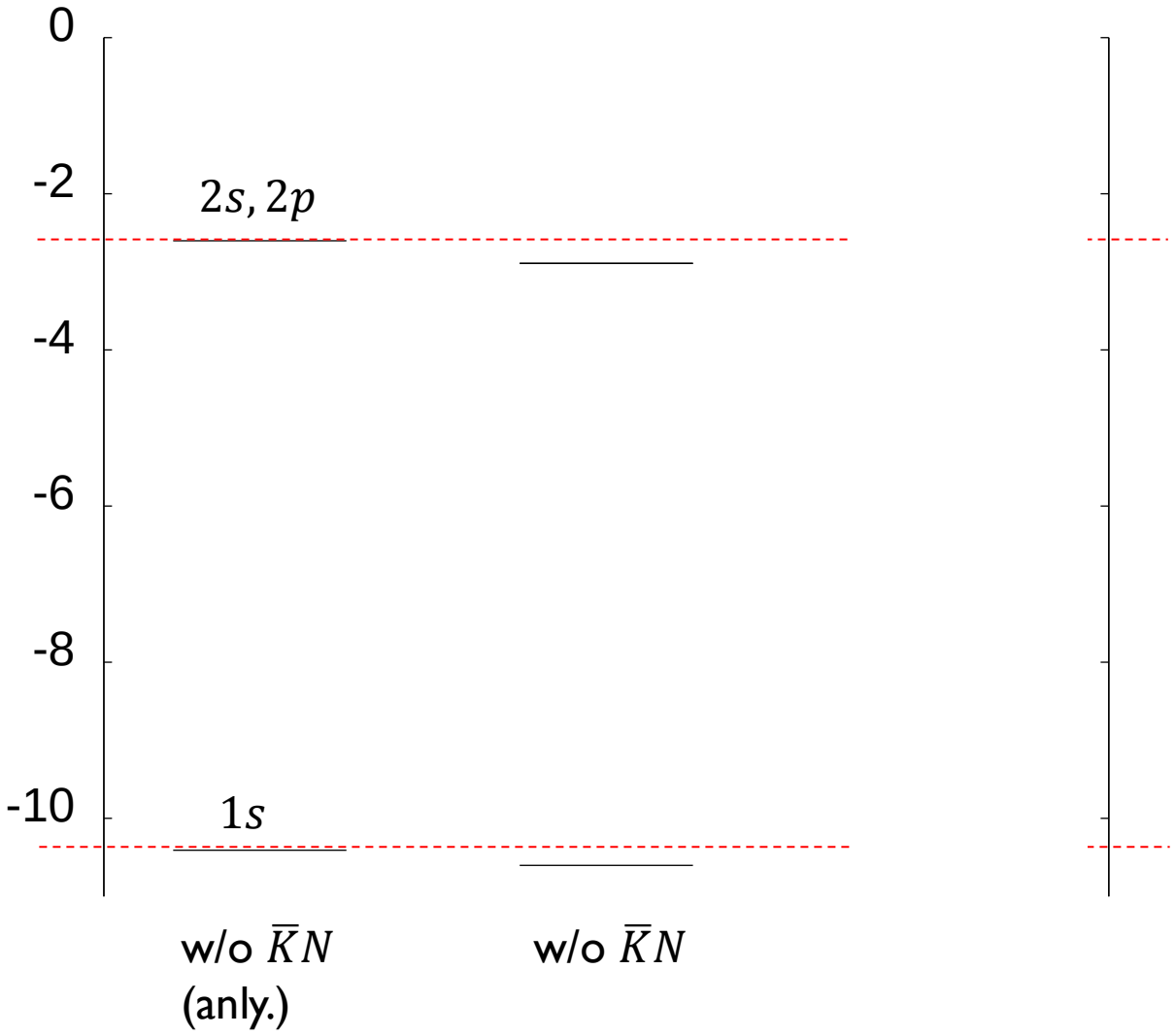
Results

3body (pn-K^-)

Results (kaonic deuterium)

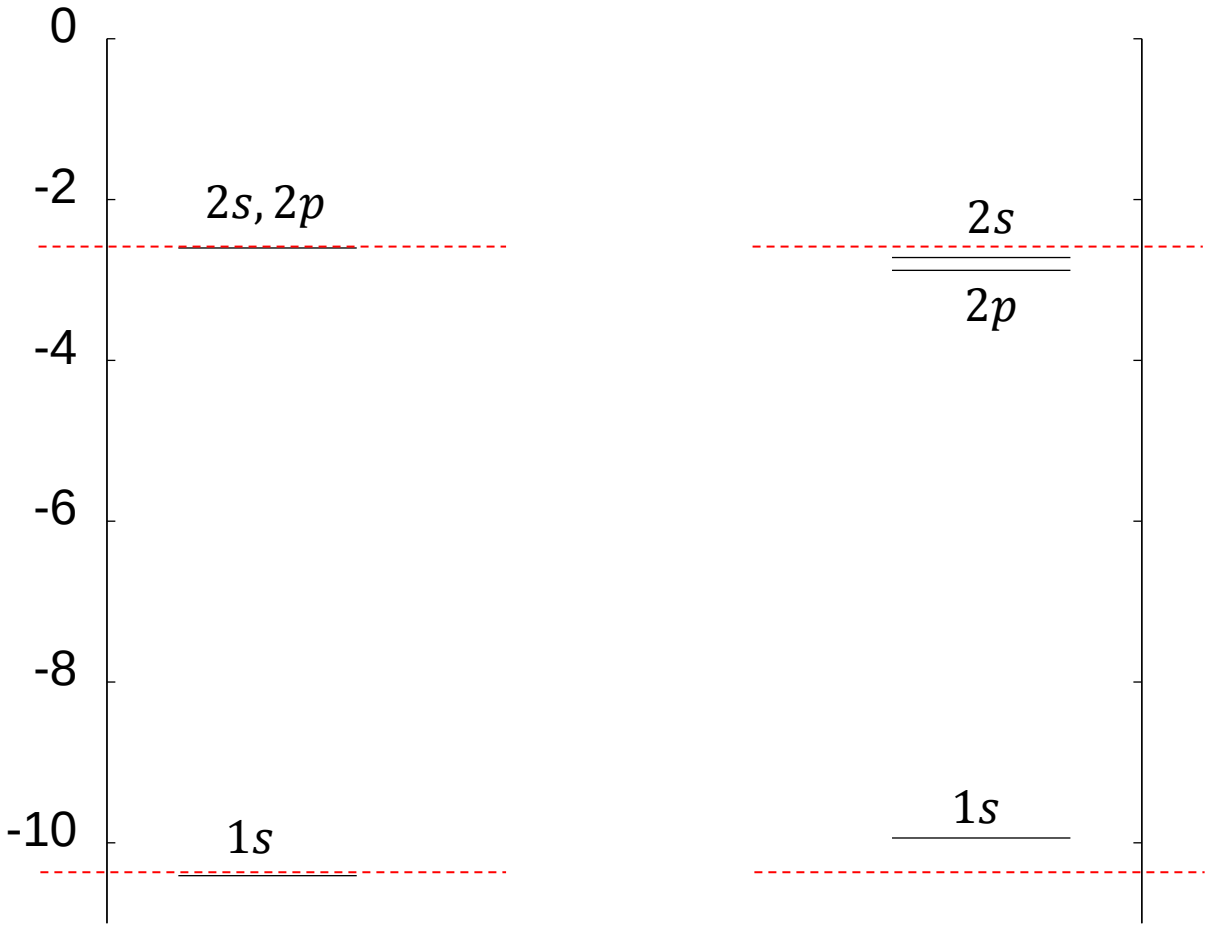


Results (kaonic deuterium)



- Energy shift from deuteron structure
  $\Delta E = 95.3$ eV

Results (kaonic deuterium)



- Energy shift from deuteron structure
  $\Delta E = 95.3$ eV
- Energy shift of
  $2p \rightarrow 1s$
  $\Delta E = 747$ eV

- Energy shift originated in $\bar{K}N$ int.
  $\Delta E = 651$ eV

Results (kaonic deuterium)

Kaonic deuterium	Energy shift (eV)	Decay width (eV)
$\boldsymbol{\alpha_{I=1} = 1.00}$	651	1030
$\alpha_{I=1} = 1.12$	668	999
$\alpha_{I=1} = 0.90$	647	1022

- Range of the basis function is 0.1~300 fm.
- The number of basis is about 3000.
- Energy shift may change about 3% originated in ambiguity of $I = 1$ component .

Summary

- Three-body calculation for the kaonic deuterium is performed.

$$\epsilon_{1s} = 747\text{eV},$$
$$\Gamma_{1s} = 1030\text{eV}$$

- The effect originated in a structure of the deuteron is $95.3\ \text{eV}$
- Energy shift may change about 3% from an ambiguity of $\mathrm{I} = 1$ component .

Future work

- More particles systems ($^3\mathrm{He} + \mathrm{K}^-$, $^4\mathrm{He} + \mathrm{K}^-$)