Tokyo Intl Forum
June 4, 2007

Structure and production of the basic cluster $K^{-}pp$

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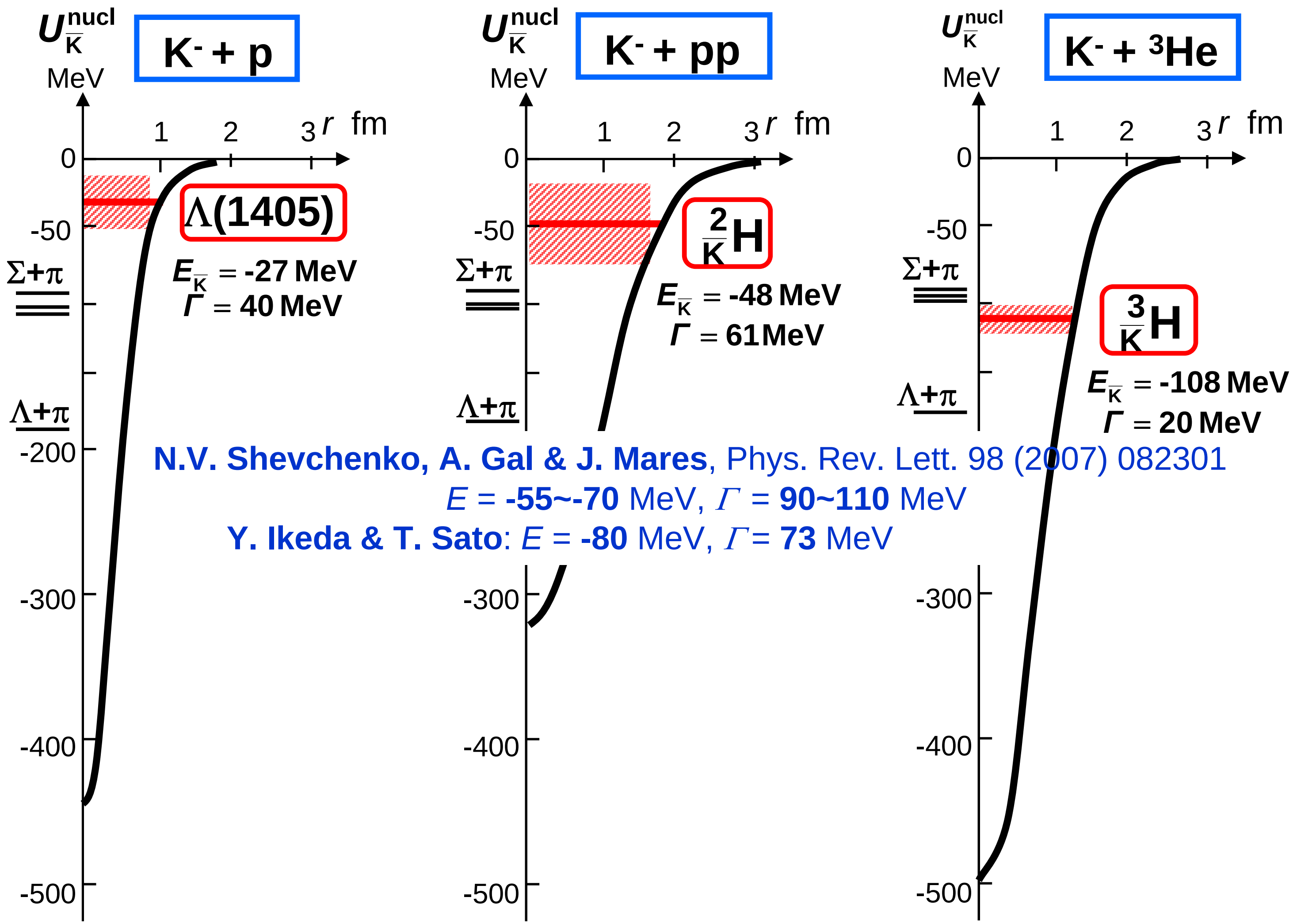
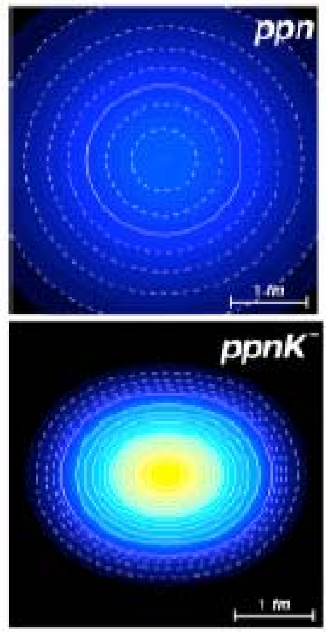
[1)] RIKEN, [2)] Nihon University, [3)] University of Tokyo

A. Dote et al.





Shrinkage!

N.V. Shevchenko, A. Gal & J. Mares, Phys. Rev. Lett. 98 (2007) 082301

E = **-55~-70** MeV, Γ = **90~110** MeV

Y. Ikeda & T. Sato: E = **-80** MeV, Γ = **73** MeV

Y. Akaishi & T. Yamazaki, Phys. Rev. C 65 (2002) 044005

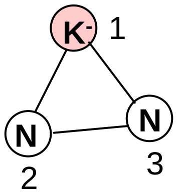
T. Yamazaki & Y. Akaishi, Phys. Lett. B 535 (2002) 70

Variational wave function of K$^-$pp

ATMS

Amalgamation of **T**wo-body correlations into **M**ultiple **S**cattering process

$$\Psi = \left[\left\{f^{I=0}(r_{12})\hat{P}_{12}^{I=0} + f^{I=1}(r_{12})\hat{P}_{12}^{I=1}\right\} f_{\mathrm{NN}}(r_{23}) f(r_{31}) + f(r_{12}) f_{\mathrm{NN}}(r_{23}) \left\{f^{I=0}(r_{31})\hat{P}_{31}^{I=0} + f^{I=1}(r_{31})\hat{P}_{31}^{I=1}\right\}\right] \left|T = 1/2\right\rangle$$



$$\hat{P}_{12}^{I=0} = \frac{1 - \vec{\tau}_{\mathrm{K}}\vec{\tau}_{\mathrm{N}}}{4}, \quad \hat{P}_{12}^{I=1} = \frac{3 + \vec{\tau}_{\mathrm{K}}\vec{\tau}_{\mathrm{N}}}{4}$$

$$\left|T = 1/2\right\rangle = \sqrt{\frac{3}{4}} \boxed{\left[\left(\bar{K}_1 N_2\right)^{0,0} p_3\right]} + \sqrt{\frac{1}{4}} \boxed{\left[-\sqrt{\frac{1}{3}}\left(\bar{K}_1 N_2\right)^{1,0} p_3 + \sqrt{\frac{2}{3}}\left(\bar{K}_1 N_2\right)^{1,1} n_3\right]}$$

$\Lambda^* p$

Euler-Lagrange equation

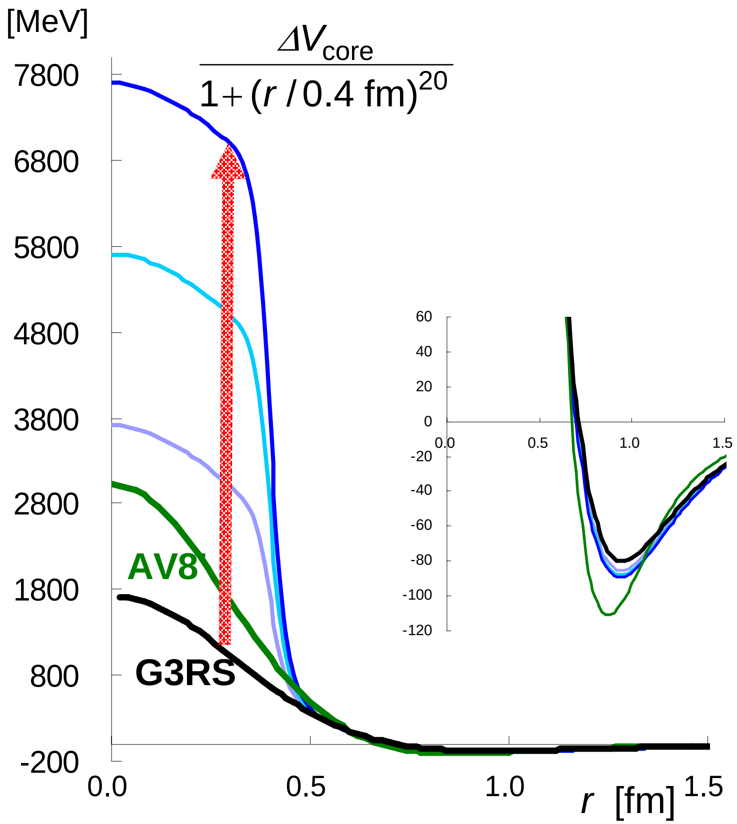
$$\delta_f \left\{\left\langle \Psi \middle| H \middle| \Psi \right\rangle - \lambda \left\langle \Psi \middle| \Psi \right\rangle\right\} = 0$$

$$v_{\bar{\mathrm{K}}\mathrm{N}}^{T=0}(r) = \{-595 - i83\}_{\mathrm{MeV}} \exp\left\{-(r/0.66_{\mathrm{fm}})^2\right\}$$

$$v_{\bar{\mathrm{K}}\mathrm{N}}^{T=1}(r) = \{-175 - i105\}_{\mathrm{MeV}} \exp\left\{-(r/0.66_{\mathrm{fm}})^2\right\}$$

$$v_{\mathrm{NN}}(r) = 2000_{\mathrm{MeV}} \exp\left\{-(r/0.447_{\mathrm{fm}})^2\right\} - 270_{\mathrm{MeV}} \exp\left\{-(r/0.942_{\mathrm{fm}})^2\right\} - 5_{\mathrm{MeV}} \exp\left\{-(r/2.5_{\mathrm{fm}})^2\right\}$$

NN repulsive core effect on K^-pp



K^-pp energy

[MeV]

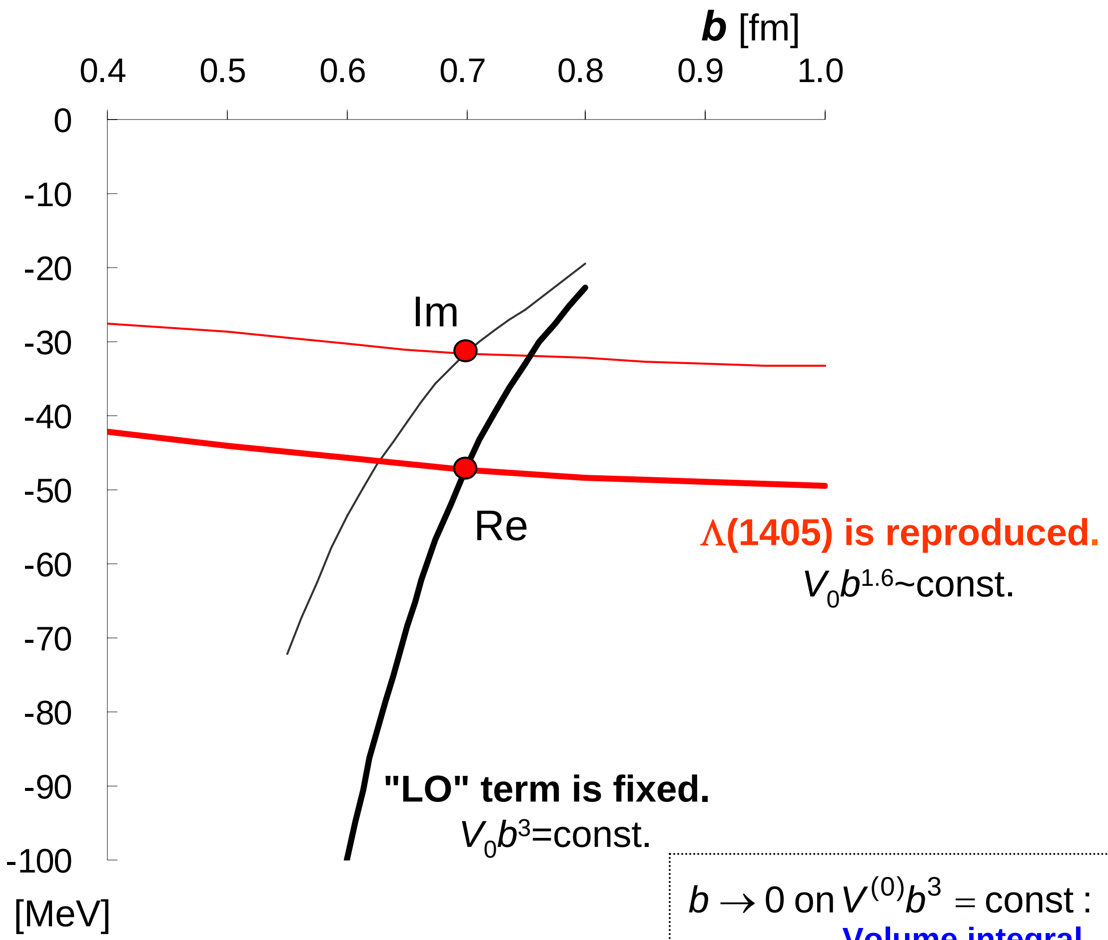
$V_0 e^{-(r/0.66\ \mathrm{fm})^2}$		ΔV_{core}: 0	2000	4000	6000
Original KN	E	**-47.7**	**-46.6**	**-46.2**	**-45.9**
	Γ	61	59	59	58
~17% enhanced	E	**-86.1**	**-83.9**	**-83.2**	**-82.7**
	Γ	53	51	50	50

Binding energy is saturating.

Tamagaki's G3RS: $v_{NN} = 2000e^{-(r/0.447)^2} - v_2 e^{-(r/0.942)^2} - 5e^{-(r/2.5)^2}$ [MeV, fm]

V_2 = 270, 284, 291, 295 MeV : **Scattering length is fixed.**

$K^{bar}N$ interaction-range dependence of $E(K^-pp)$



$$b \to 0 \text{ on } V^{(0)}b^3 = \text{const}: \quad |s| \propto V^{(0)}b^2 = \frac{\text{const}}{b} \to \infty$$

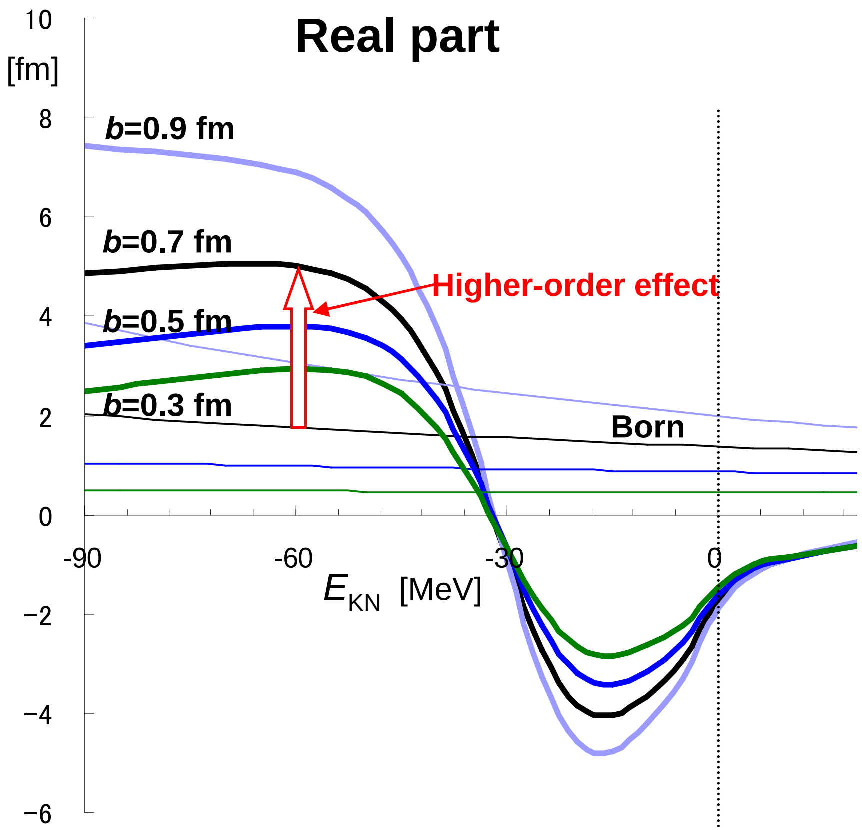
Volume integral

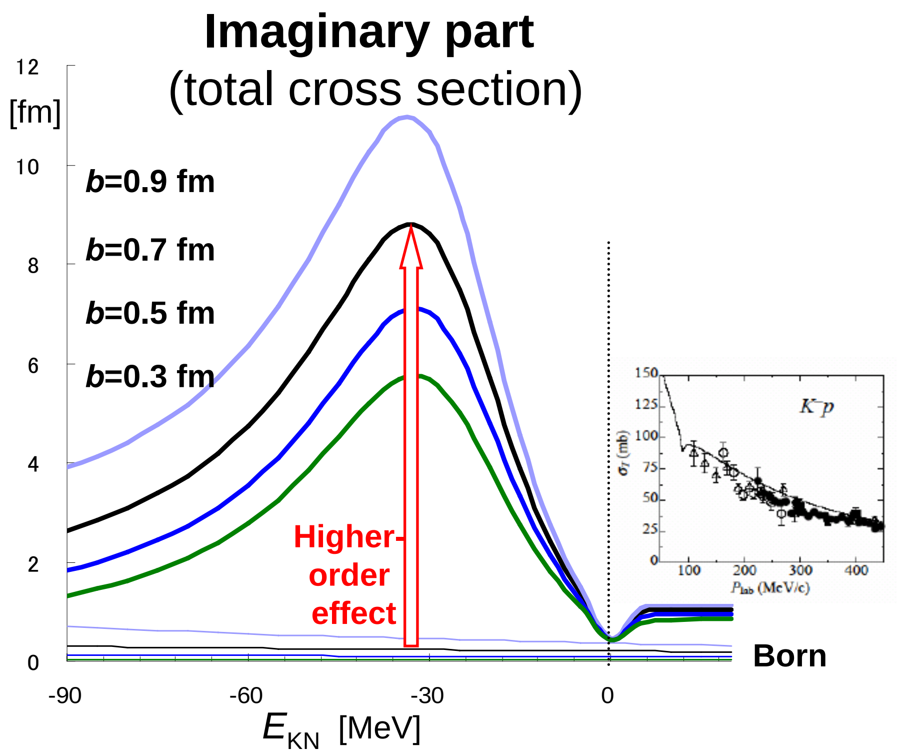
$$\delta \text{ interaction} \quad \Rightarrow \quad E_B \to -\infty$$

$K^{bar}N$ scattering amplitude

$$f^{T=0}(k) = -2\pi^2 \frac{2\mu}{\hbar^2} t^{T=0}(k)$$

$$v_{\bar{K}N} = (V_0 + iW_0)\exp\{-(r/b)^2\}$$

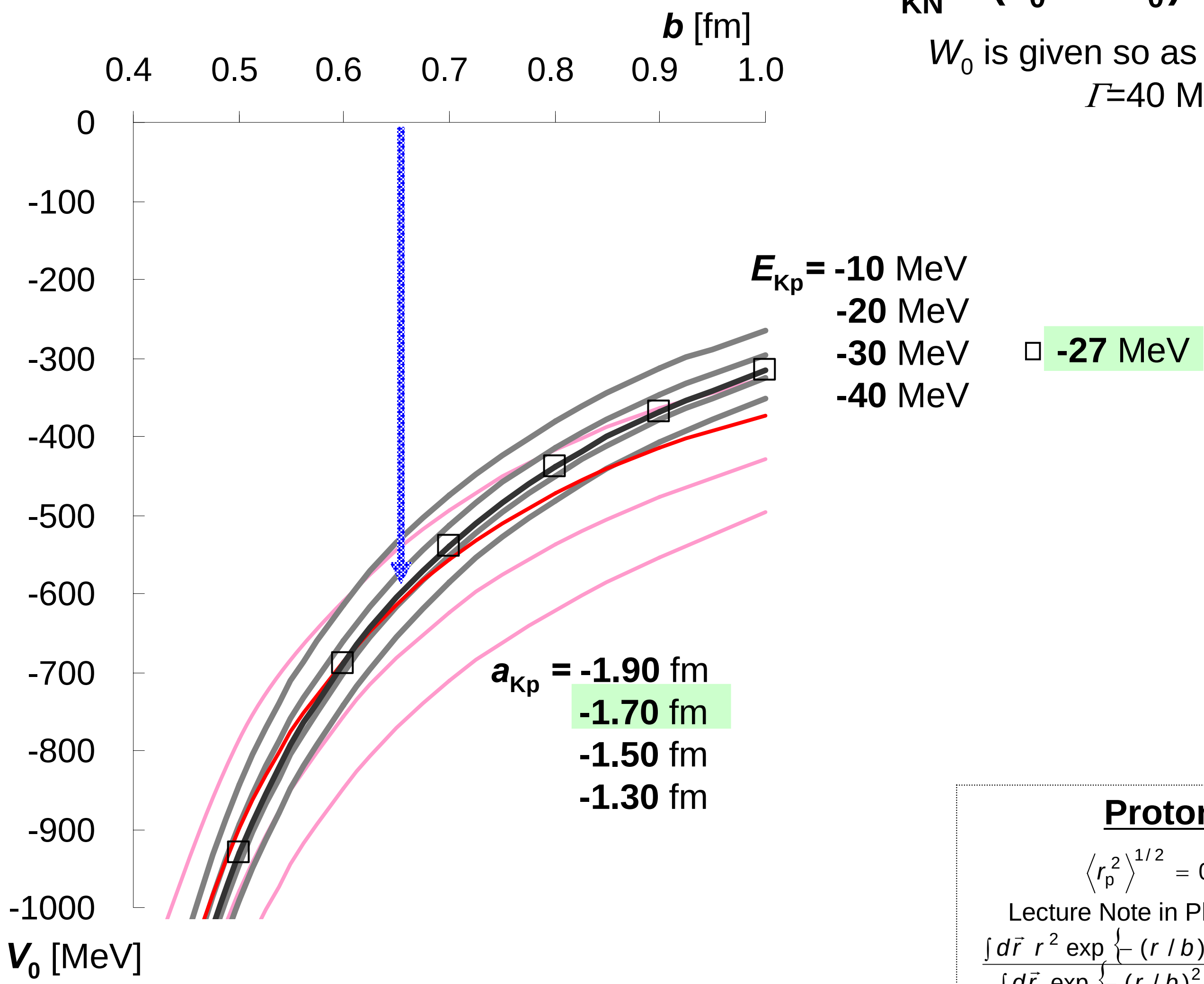




Depth and range of $K^{bar}N$ potential

$$v_{\bar{K}N} = (V_0 + iW_0)\exp\{-(r/b)^2\}$$

W_0 is given so as to reproduce Γ=40 MeV.



Proton size

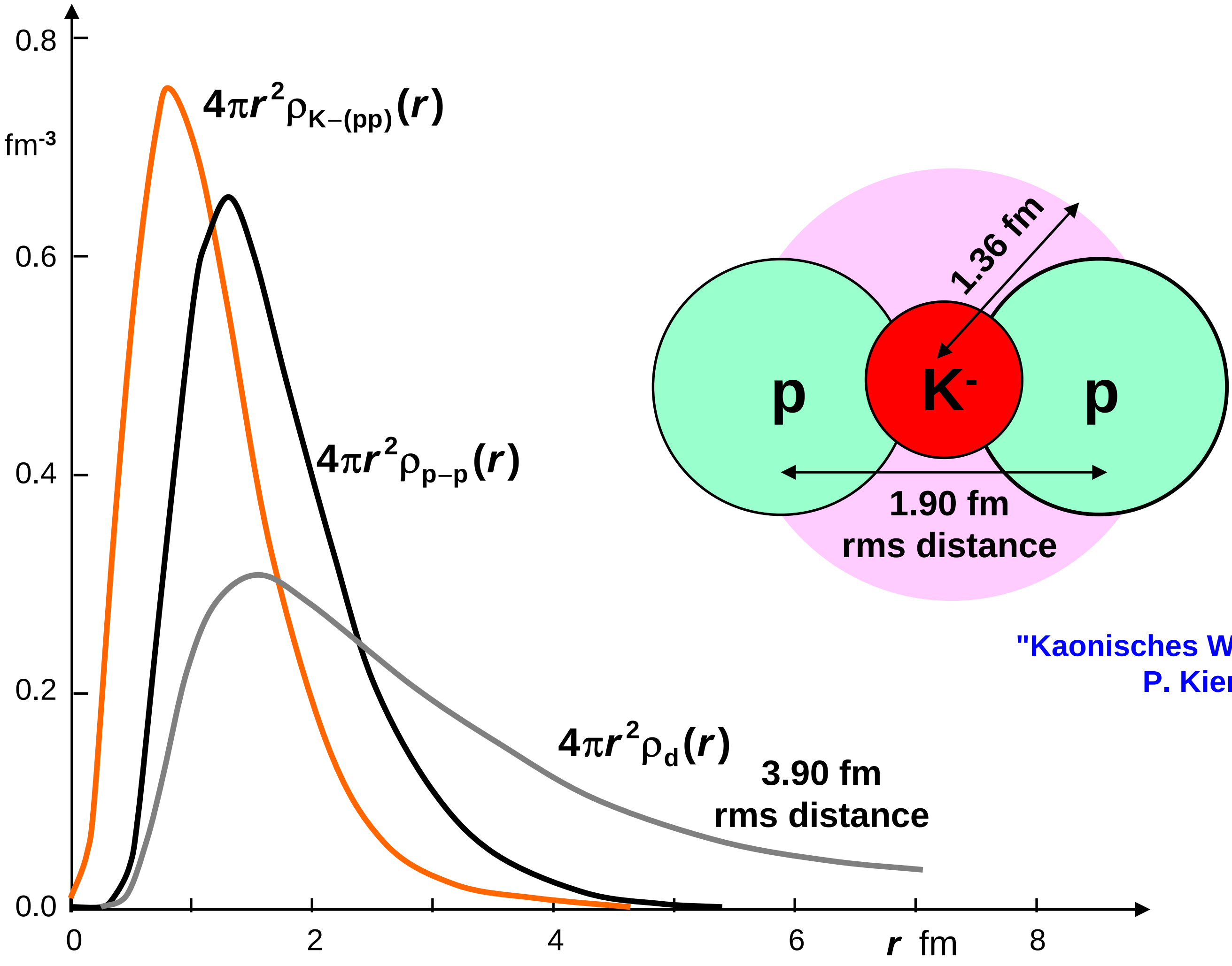
$$\langle r_p^2 \rangle^{1/2} = 0.862 \ \text{fm}$$

Lecture Note in Physics 86 (1978) 27

$$\frac{\int d\vec{r}\ r^2 \exp\{-(r/b)^2\}}{\int d\vec{r}\ \exp\{-(r/b)^2\}} = \frac{3}{2} b^2 = (0.862\ \text{fm})^2$$

***b* = 0.70 fm**

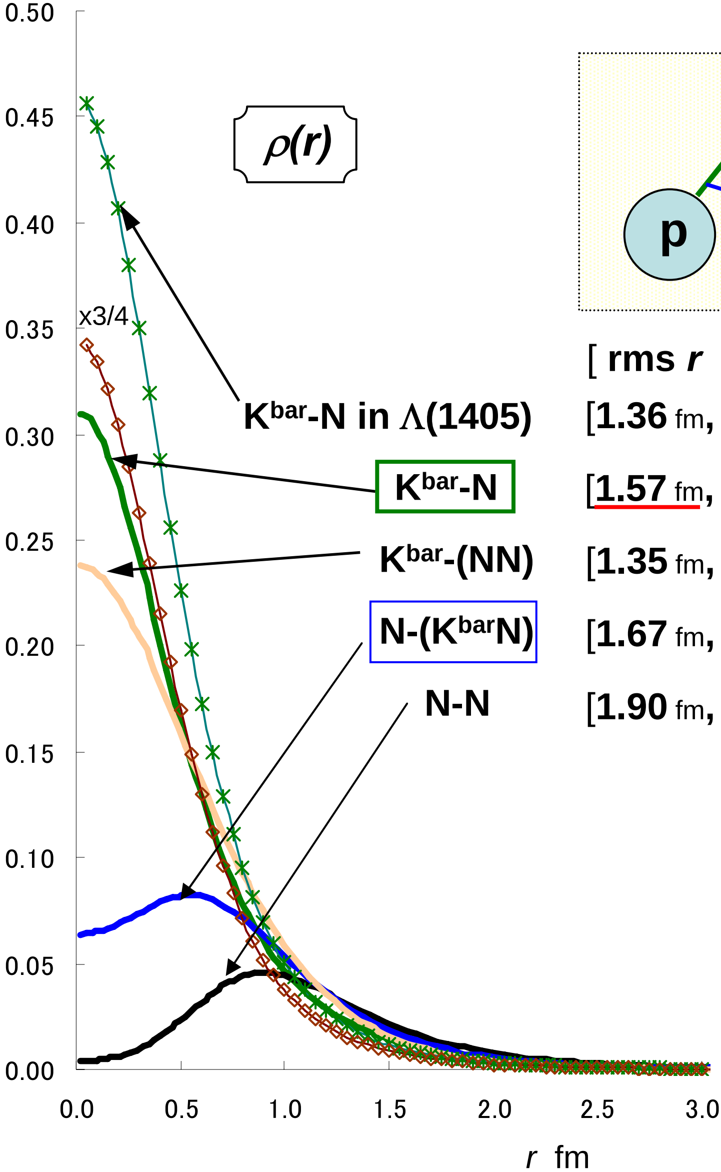
Structure of ppK$^-$

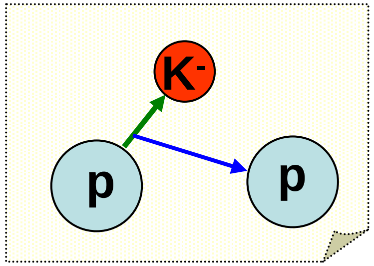


"Kaonisches Wasserstoff-Molekül"
P. Kienle, EXA05

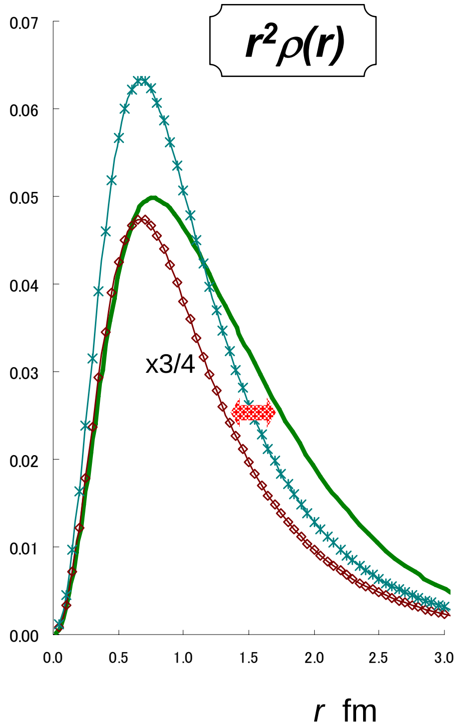
T. Yamazaki & Y. Akaishi, Phys. Lett. B535 (2002) 70.

Density distributions in K^-pp

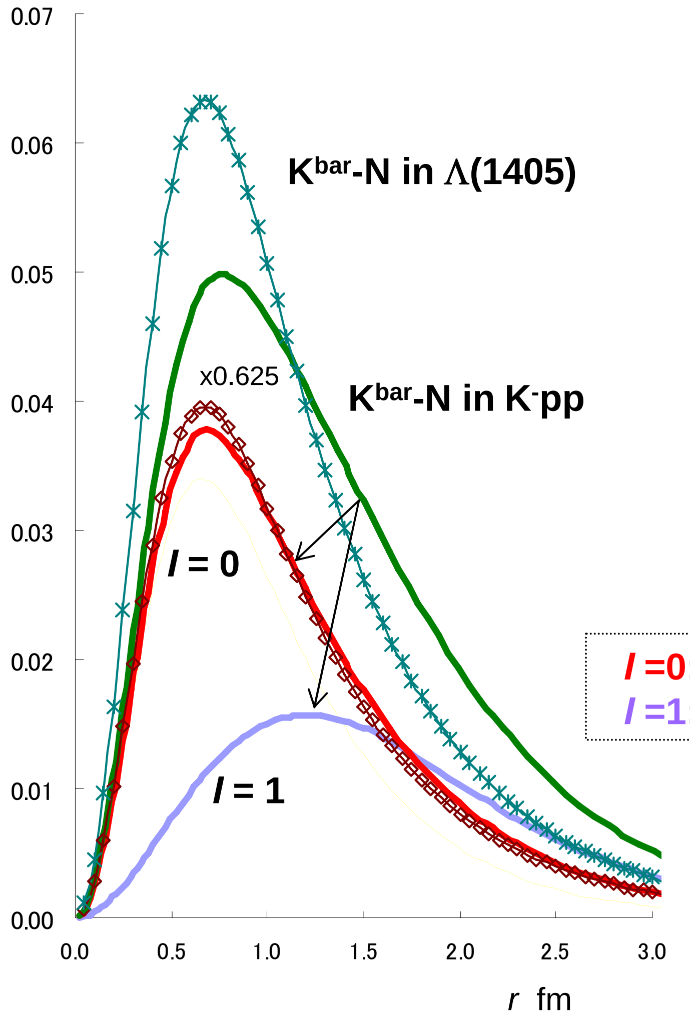


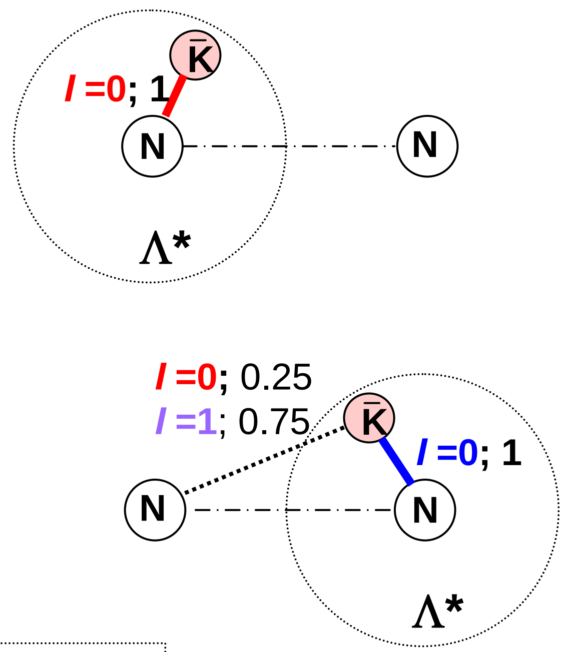


	[rms r , rms p]
K^{bar}-N in $\Lambda(1405)$	[1.36 fm, 272 MeV/c]
K^{bar}-N	[1.57 fm, 226 MeV/c]
K^{bar}-(NN)	[1.35 fm, 233 MeV/c]
N-(K^{bar}N)	[1.67 fm, 193 MeV/c]
N-N	[1.90 fm, 183 MeV/c]



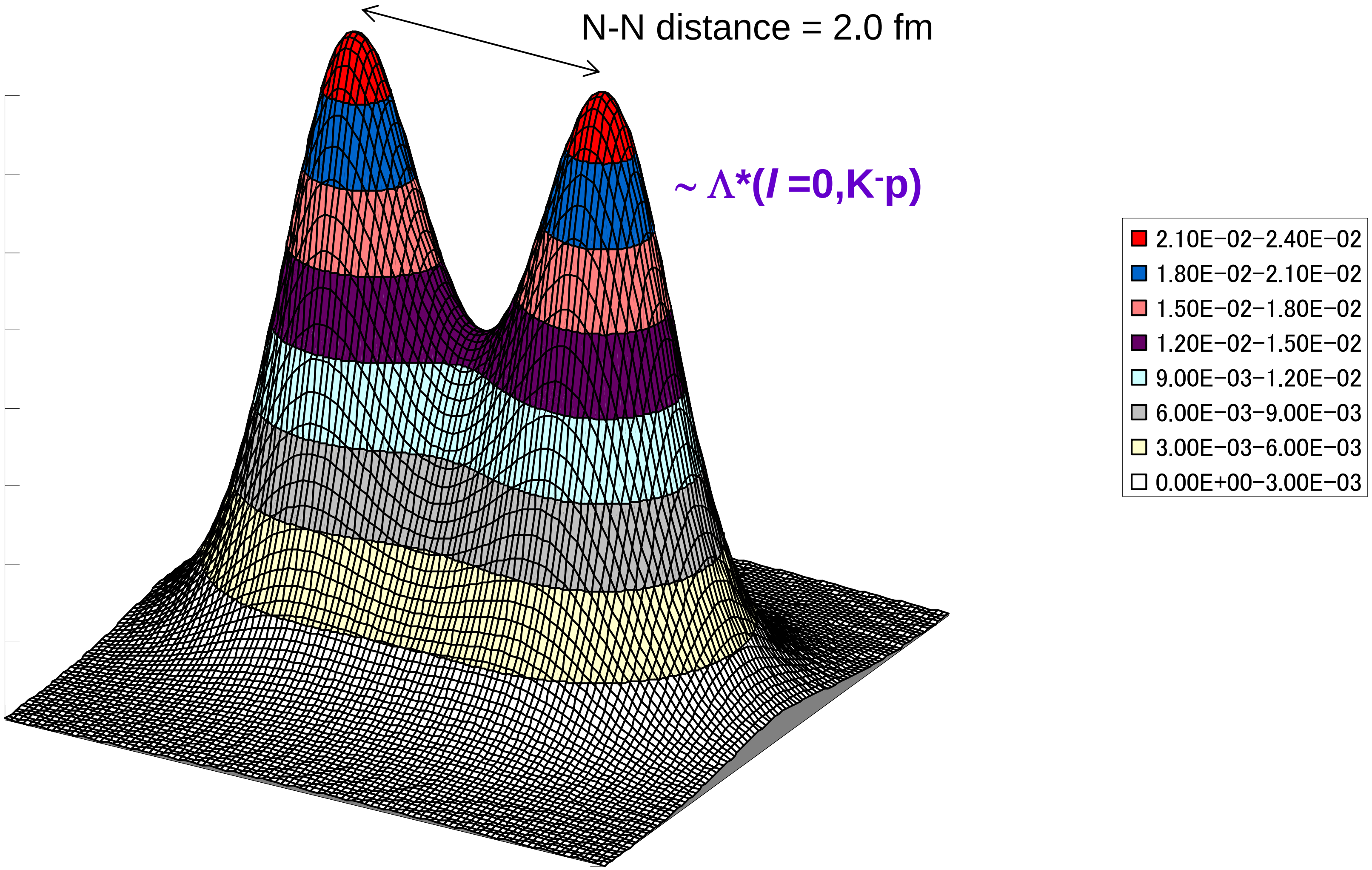
Density distributions of K^{bar}-N



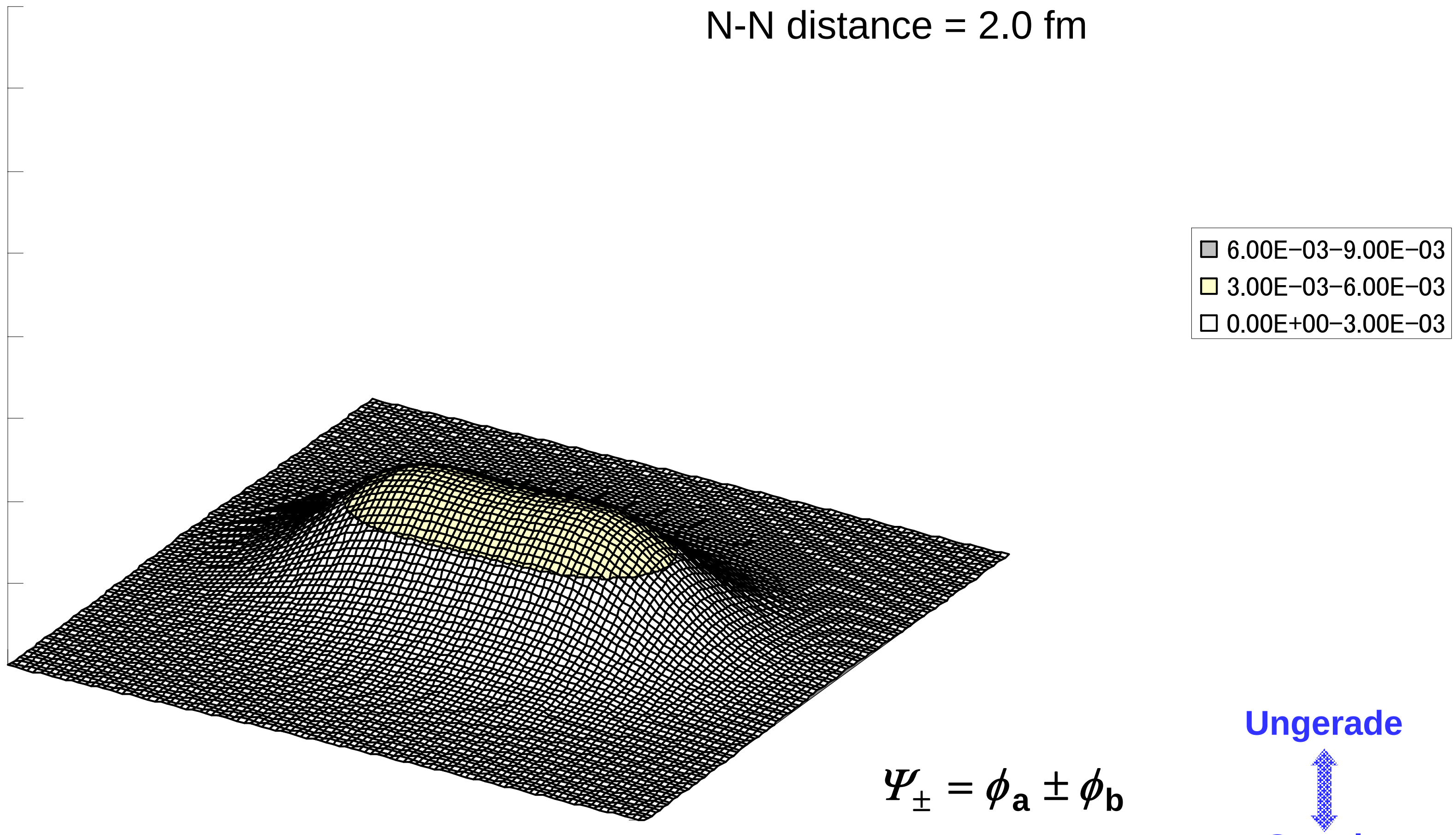


I =0: 0.5x(1+0.25)=**0.625**
I =1: 0.5x0.75= **0.375**

K$^-$ distribution in K$^-$pp



Covalent part of K^- distribution



$$\Psi_\pm = \phi_a \pm \phi_b$$

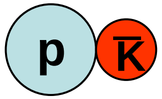
Ungerade

Gerade

$$\int d\vec{\tau}\, |\Psi_\pm|^2 = \int d\vec{r}_a\, |\phi_a(\vec{r}_a)|^2 + \int d\vec{r}_b\, |\phi_b(\vec{r}_b)|^2 \pm \int d\vec{\tau} \left| \phi_a^*(\vec{r}_a)\,\phi_b(\vec{r}_b) + \phi_b^*(\vec{r}_b)\,\phi_a(\vec{r}_a) \right|$$

Covalent bonding

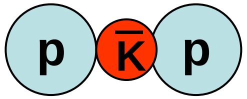
Heitler-London picture of K^-pp



Λ(1405)

[MeV]

E	−27.8	−20.0*i*
KE	115.3	
PE	−143.1	−20.0*i*



K^-pp

[MeV]

E	−47.5	−30.6*i*
KE	167.0	
PE	−214.5	−30.6*i*
$\langle v_{NN} \rangle$	−19.0	
$\langle 2v_{\bar{K}N} \rangle$	−195.5	−30.6*i*
$\langle 2v_{\bar{K}N}^{I=0} \rangle$	−188.2	−26.2*i*
$\langle 2v_{\bar{K}N}^{I=1} \rangle$	−7.3	−4.4*i*
$\langle 2v_{\bar{K}N}^{dir} \rangle$	−143.0	−23.3*i*
$\langle 2v_{\bar{K}N}^{exc} \rangle$	−52.6	−7.3*i*

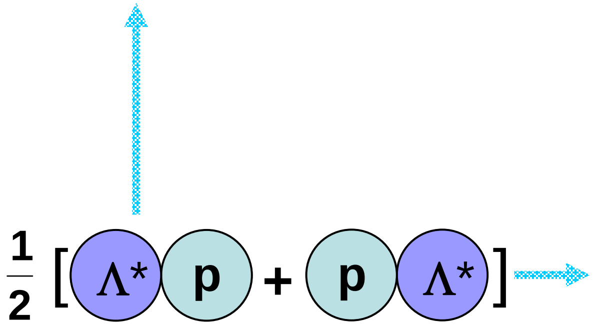
ΔE = -20

ΔKE = 49 $+3_K$

$(+20_{NN})$

ΔV_{NN} = -19

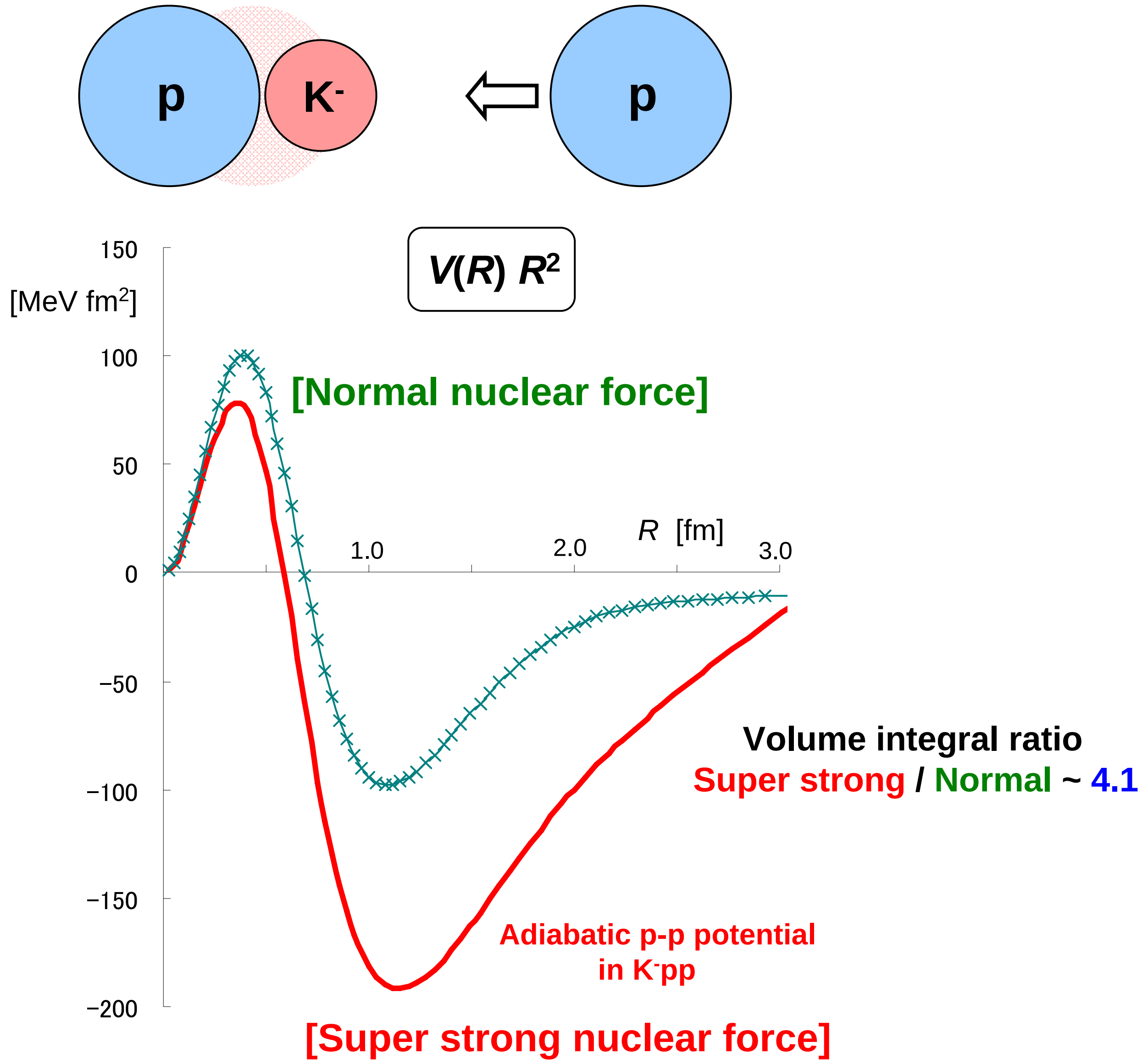
ΔV^{exc} = -53

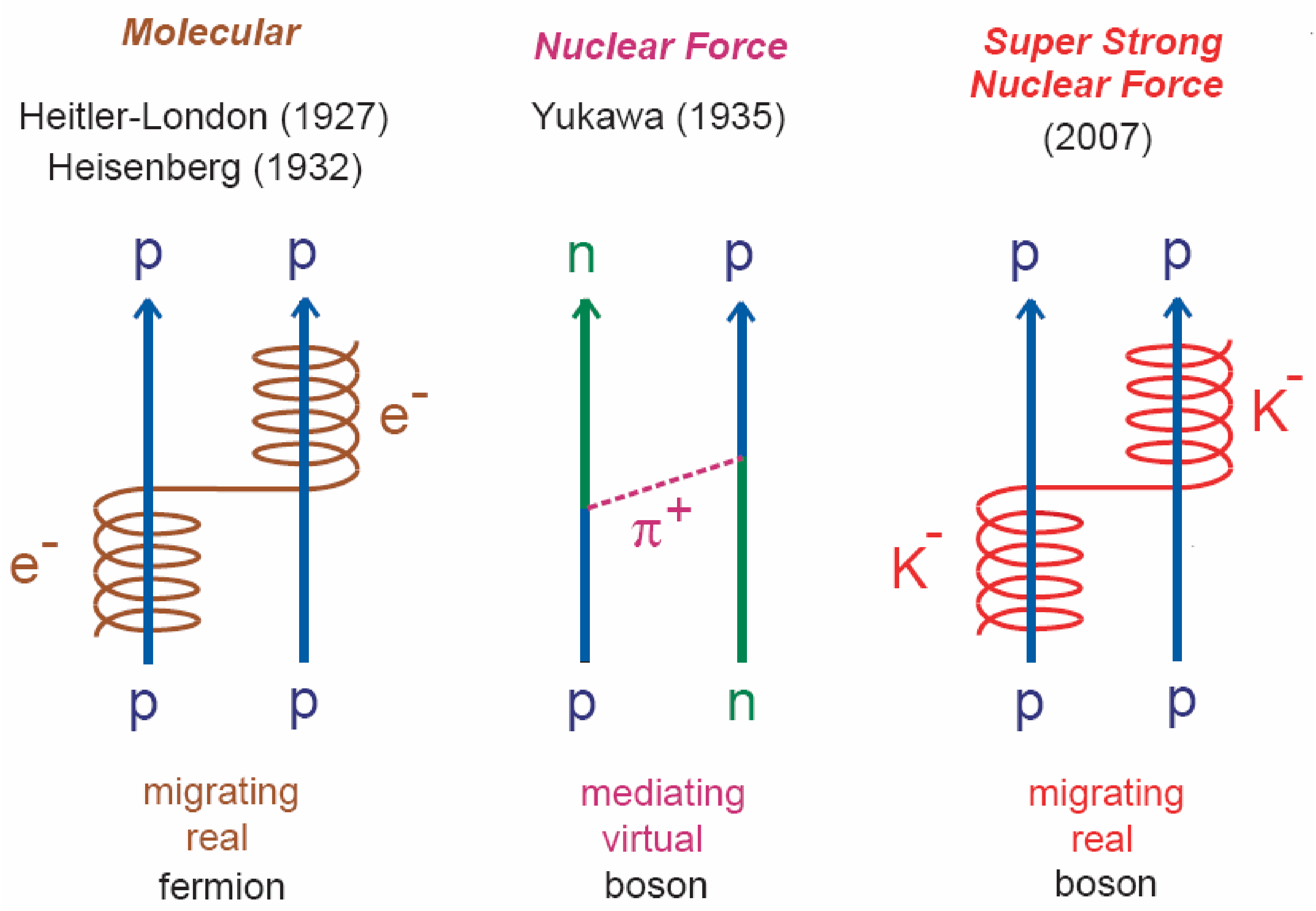


Real K^{bar} exchange attraction

T. Yamazaki

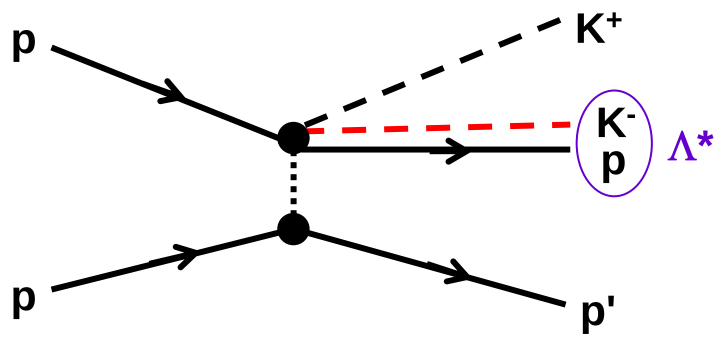
Adiabatic p-p potential in K^-pp





T. Yamazaki & Y. Akaishi,
Proc. Japan Academy B 83 (2007) 144

Production of K^-pp by $p(p,K^+)$ reaction



The p --> $p+K^-+K^+$ process, where a K^+K^- pair is assumed to be created at zero range from a proton, is of highly off-energy shell ($\Delta E \sim 2m_K$). This process is realized with a large momentum transfer to the second proton, which is done efficiently by the pp short-range interaction, $\exp(-m_B r)/r$.

Effective interaction for the elementary process

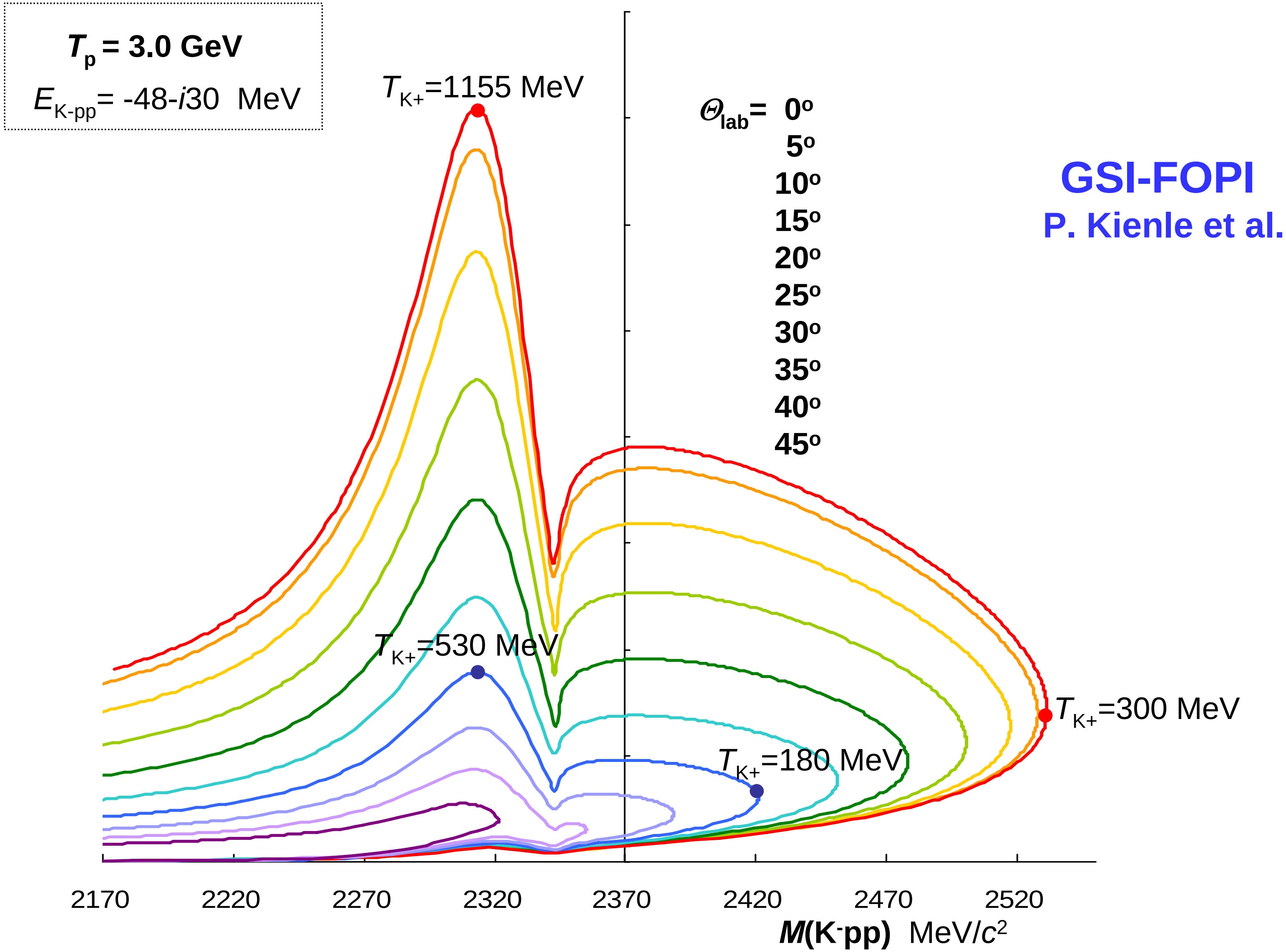
$$\left\langle \vec{r}_{K^+(K^-pp')}, \vec{r}_{(K^-p)p'}, \vec{r}_{K^-p} \middle| t \middle| \vec{r}_{pp'} \right\rangle = V_0 \int d\vec{r}\; F(\vec{r})\; \delta(\vec{r}_{K^+(K^-pp')} - \eta \vec{r})\; \delta(\vec{r}_{(K^-p)p'} - \vec{r})\; \delta(\vec{r}_{K^-p})\; \delta(r_{pp'} - \vec{r}),$$

$$\eta = \frac{M_p}{M_{K^-pp}}$$

$$F(\vec{r}) = \frac{\beta}{r} \exp\left(-\frac{r}{\beta}\right), \qquad \beta = \frac{\hbar}{m_B c}$$

Differential cross section of

p + p → (Λ*+ p) + K⁺

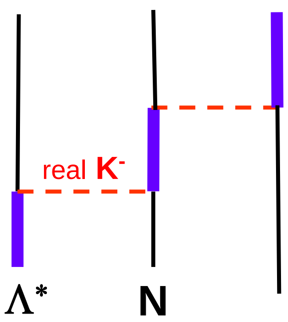


Conclusion

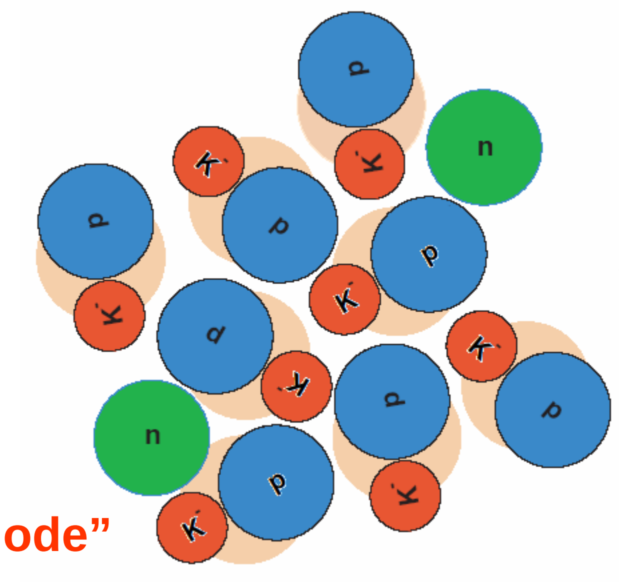
The Λ(1405) plays an essential role in forming "K^{bar} Nuclear Clusters".

⇩ ⇩

Λ*–hole mode



K^{-}p (Λ*)- condensed matter



"Kaon migrating mode"

T. Yamazaki

Acknowledgements:

P. Kienle

Thank you very much!