Construction of $\bar{K}N$ potential and structure of $\Lambda(1405)$ based on chiral unitary approach

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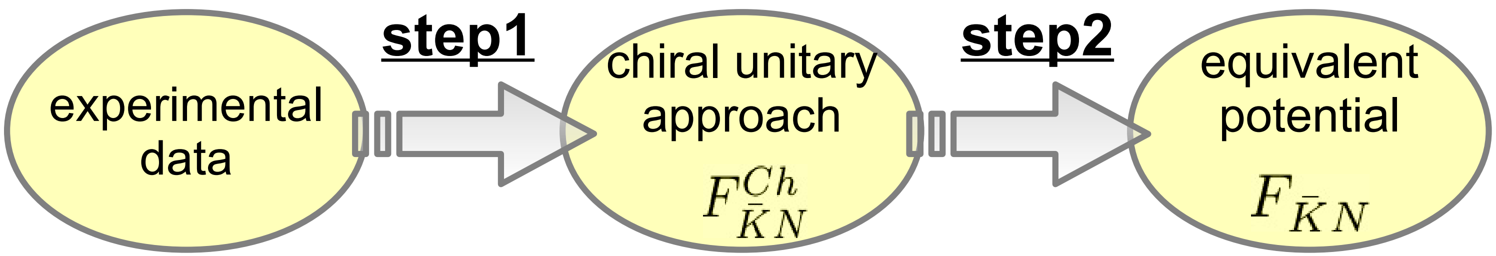
2. Previous work (construction of potential)



3. This work (new potential)
   - Improvement of construction procedure (step2)
   - New constraint from SIDDHARTA (step1)

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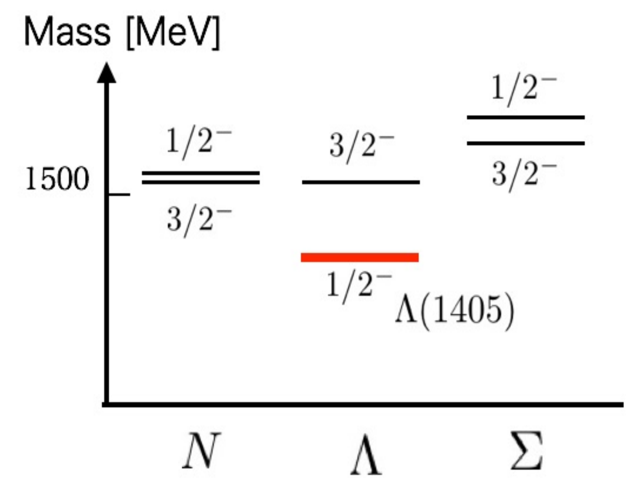
Motivation

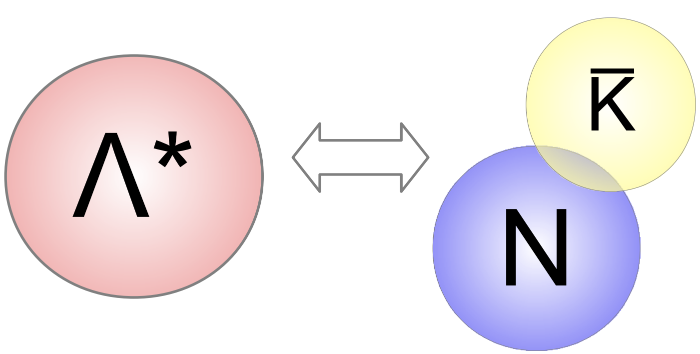
Λ(1405) ↔ quasi bound state of $\bar{K}N$.

$\bar{K}N$ interaction is **strongly attractive.**



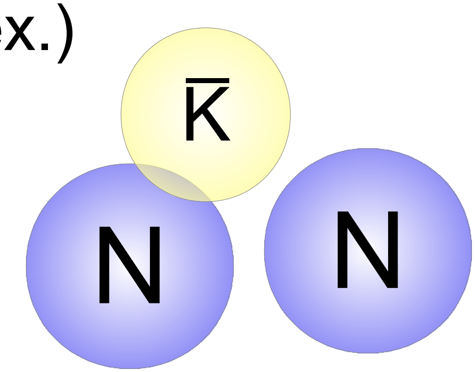
- Y. Akaishi and T. Yamazaki, Phys. Rev. C 65, 044005 (2002)
- T. Hyodo and D. Jido, Prog. Part. Nucl. Phys. 67, 55 (2012)

molecular state of Λ(1405)



$\bar{K}$ nuclei

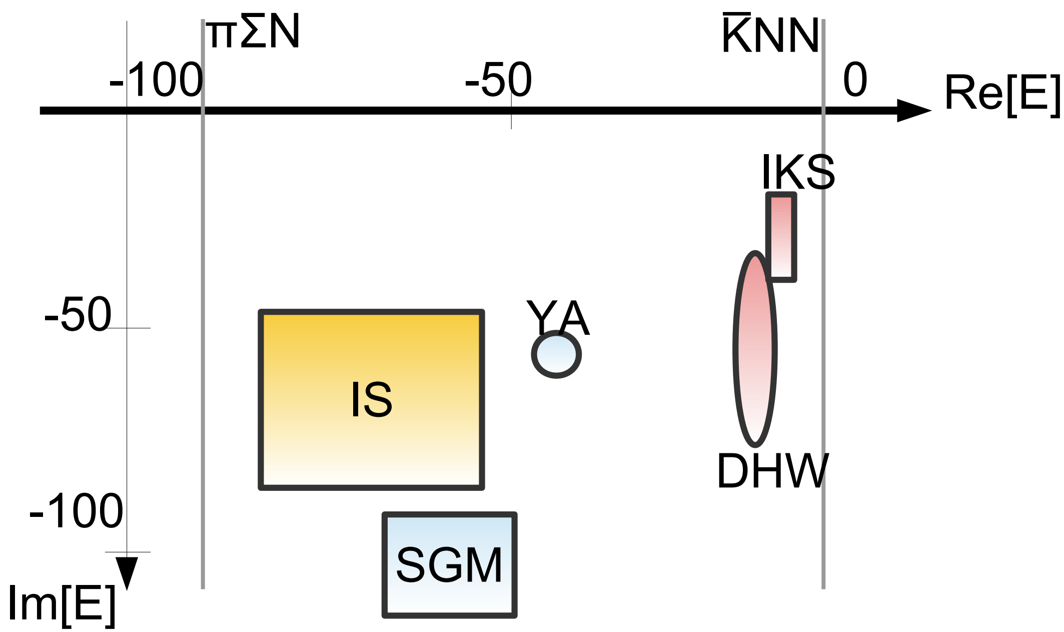
ex.)



ex.) deeply binding?
compact state?

Motivation

Theoretical calculation of $\bar{K}NN$ ($I=1/2, J^p=0^-$)

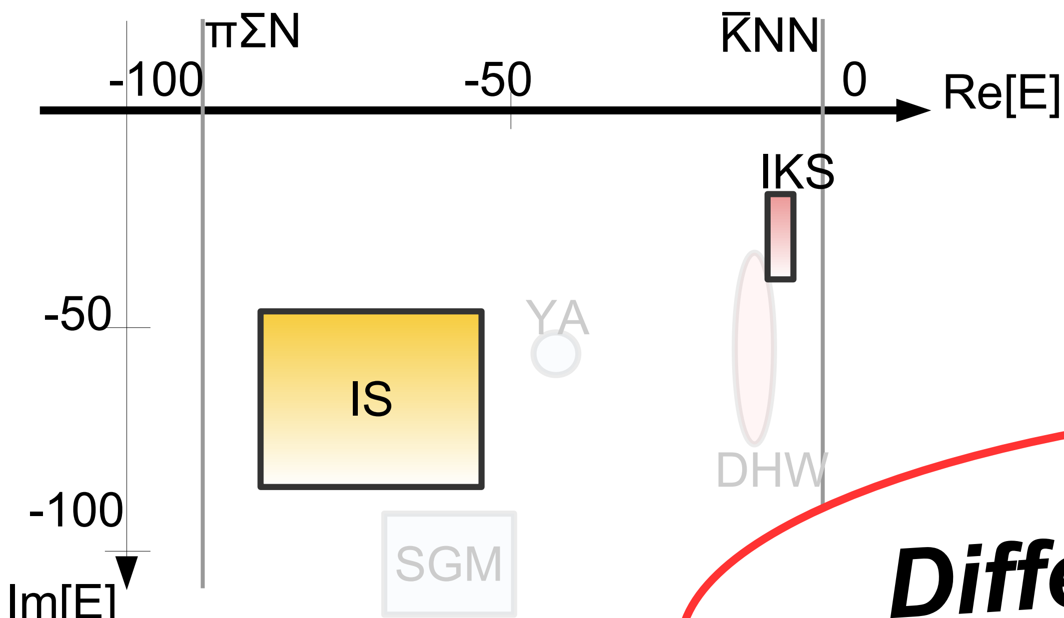


- [SGM] : Shevchenko, Gal, Mares, Phys. Rev. C 76, 044004 (2007)
- [YA] : Yamazaki, Akaishi, Phys. Rev. C 76, 045201 (2007)
- [IS] : Ikeda, Sato, Phys. Rev. C 76, 035203 (2007)
- [DHW] : Dote, Hyodo, Weise, Phys. Rev. C 79, 014003 (2009)
- [IKS] : Ikeda, Kamano, Sato, Prog. Theor.Phys. 124, 3 (2010)

Conclusive result has not been achieved in theoretical calculations

Motivation

Theoretical calculation of $\bar{K}NN$ ($I=1/2, J^p=0^-$)



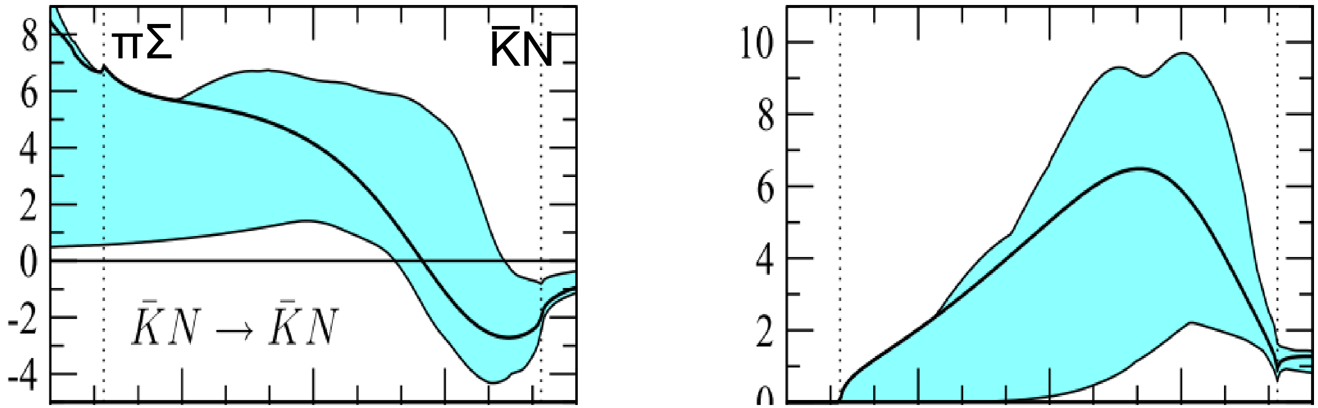
- [SGM] : Shevchenko, Gal, Mares, Phys. Rev. C 76, 044004 (2007)
- [YA] : Yamazaki, Akaishi, Phys. Rev. C 76, 045201 (2007)
- [IS] : Ikeda, Sato, Phys. Rev. C 76, 035203 (2007)
- [DHW] : Dote, Hyodo, Weise, Phys. Rev. C 79,

Different results are caused by $\bar{K}N$ interaction

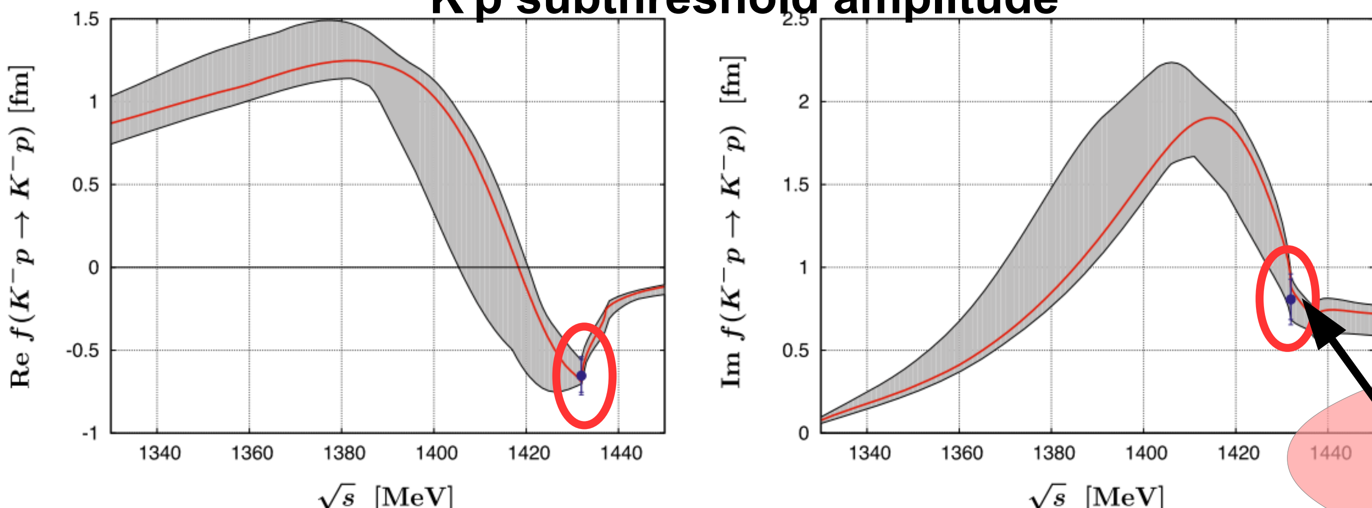
Conclusive result has not been achieved in theoretical calculations

Motivation

$\bar{K}N$ subthreshold amplitude



K^-p subthreshold amplitude



- Borasoy et al. Phys. Rev. C 74, 055201 (2006)
- R.Nissler, Ph.D thesis (2007)

(I=0)

large uncertainty

$$F_{K^-p} \sim \frac{1}{2}(F^{I=0}_{\bar{K}N} + F^{I=1}_{\bar{K}N})$$

- Ikeda, Hyodo, Weise Nucl. Phys. A 881, 98 (2012)

(K^-p)

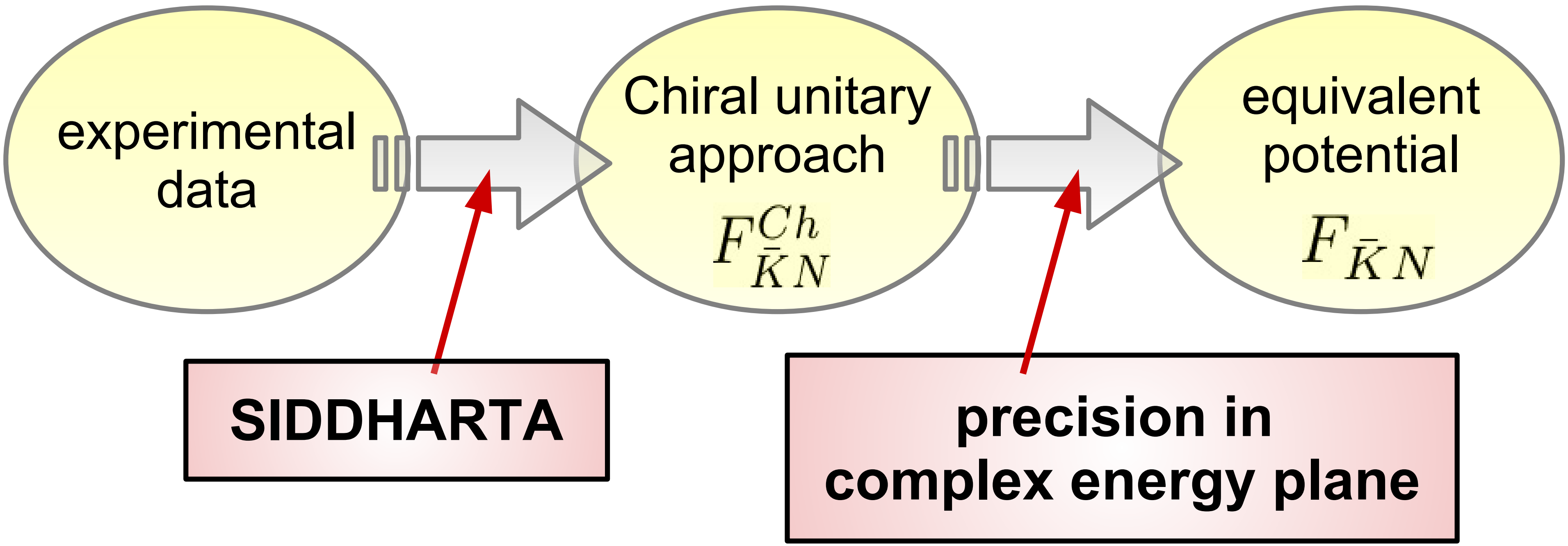
Bazzi et al. Phys. Lett. B 704, 113 (2011)

SIDDHARTA

Uncertainty is significantly reduced by SIDDHARTA

Motivation

Construction of *r*-dep. local potential



high precision
$\bar{K}N$ local potential

reliable prediction ⟹

- spatial structure of Λ(1405)
- few-body calculation

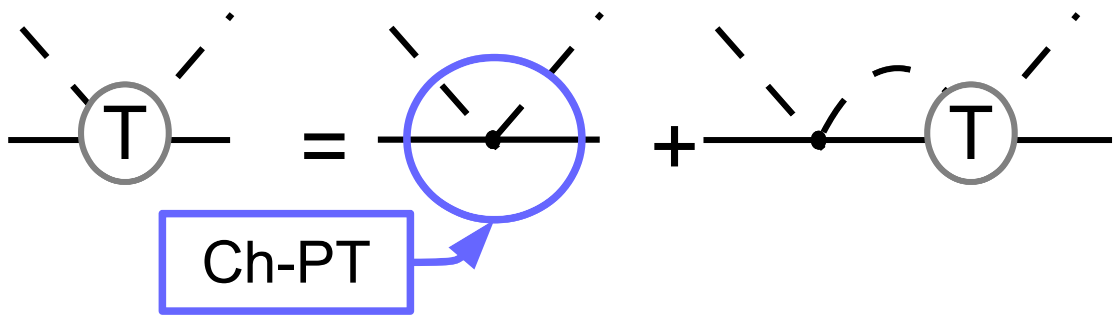
Previous work

$\bar{K}N$ potential from Ch-U

T. Hyodo and W. Weise, Phys. Rev. C 77, 035204 (2008)

➢ $\bar{K}N$ amplitude from chiral unitary approach

- chiral unitary approach

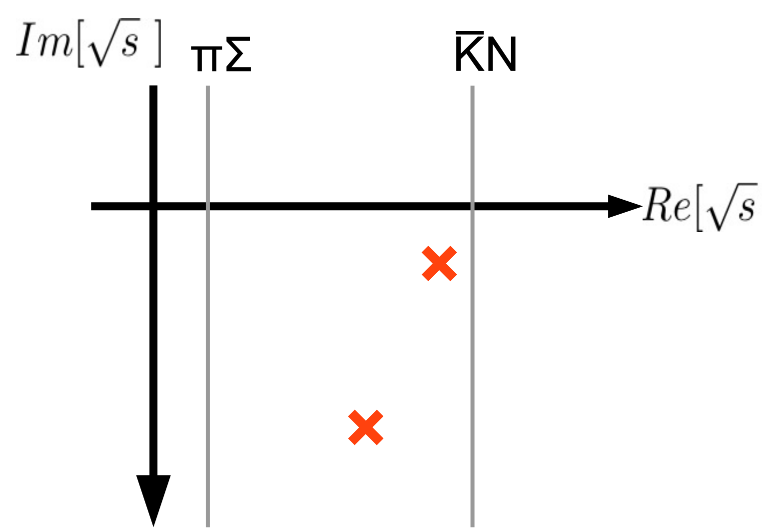


Jido et al. Nucl. Phys. A 725, 181 (2003)

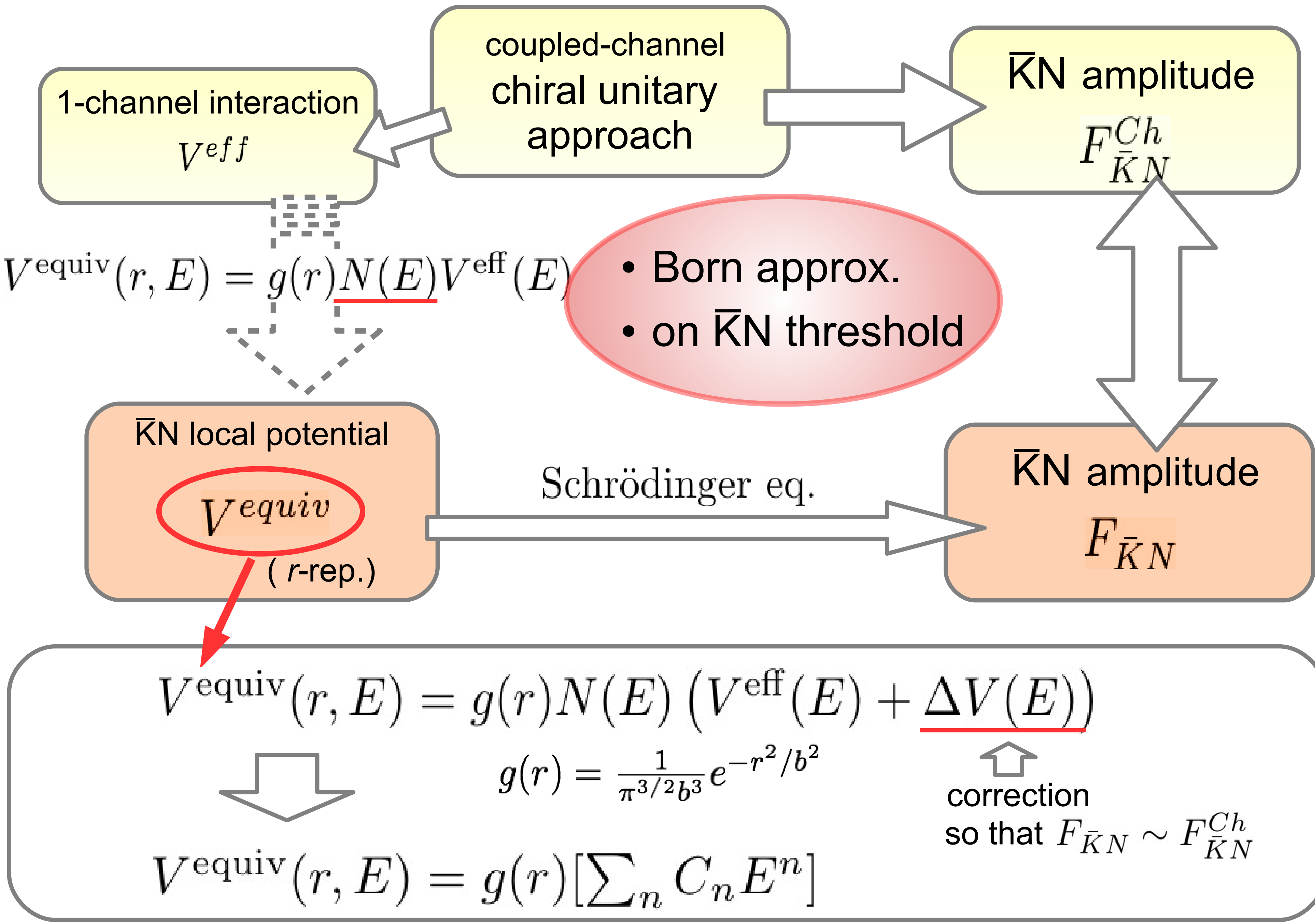
- channel coupling

in S=-1 , I=0 sector

Attractions in $\bar{K}N$ and πΣ
leads to **double pole** structure



equivalent local potential



- **equivalent local potential**

Gaussian : $g(r) = \frac{1}{\pi^{3/2} b^3} e^{-r^2/b^2}$

way to decide "b"

$$V^{\text{equiv}}(r, E) = g(r) N(E) V^{\text{eff}}(E)$$

$$\Rightarrow \quad F_{\bar{K}N} = F_{\bar{K}N}^{\text{Ch}}$$

- Born approx.
- on $\bar{K}$N threshold

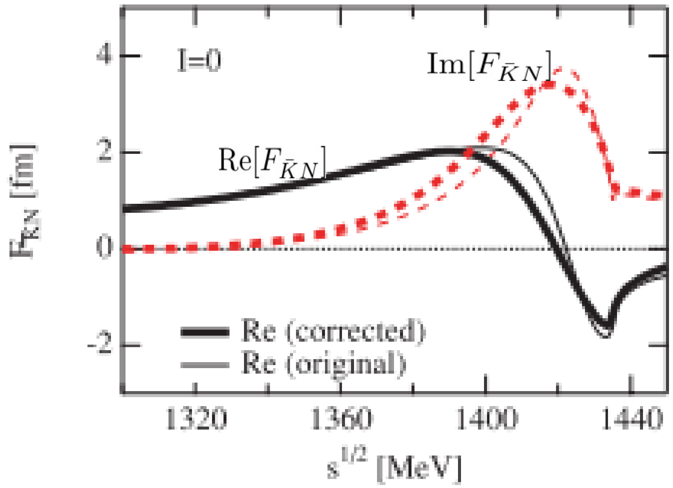
- Previous work: at resonance energy ⇒ $b = 0.47\ \mathrm{fm}$
- This work: on $\bar{K}$N threshold ⇒ $b = 0.46\ \mathrm{fm}$

Consistent with original strategy

Determination of "b" is improved

- **problem**

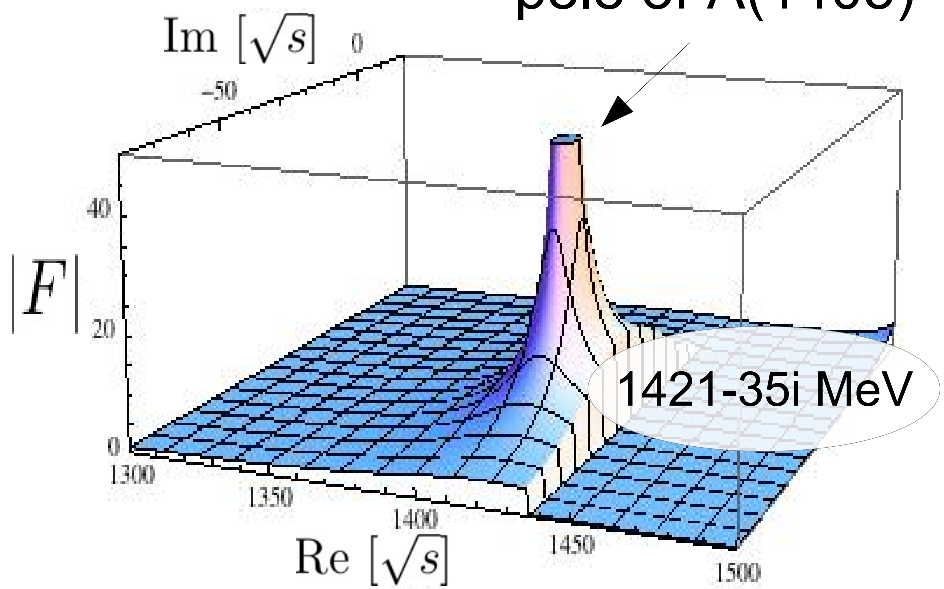
amplitude on $\mathrm{Re}\,[\sqrt{s}]$

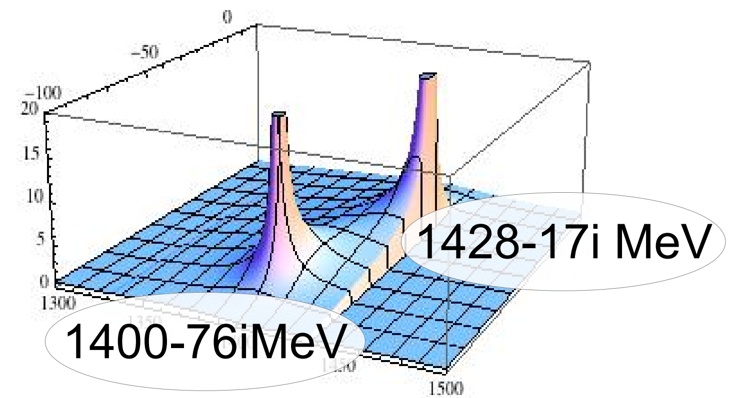


$F_{\bar{K}N}$ almost reproduced $F^{Ch}_{\bar{K}N}$

- analytic continuation of $F_{\bar{K}N}$ with V^{equiv} to the complex energy plane

pole of Λ(1405)





$F^{Ch}_{\bar{K}N}$ from chiral unitary approach

V^{equiv} **does not reproduce the pole structure of** $F^{Ch}_{\bar{K}N}$

This work

$$\Delta F_{\rm real} = \frac{\int d\sqrt{s}\,|F^{\rm Ch}_{\bar{K}N}(\sqrt{s}) - F_{\bar{K}N}(\sqrt{s})|}{\int d\sqrt{s}\,|F^{\rm Ch}_{\bar{K}N}|} \times 100$$

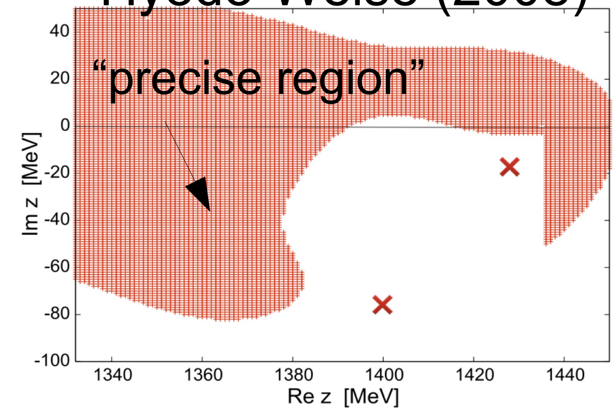
- **Improvement ($\bar{K}$N pole)**

  ——— deviation of the amplitude on the real axis

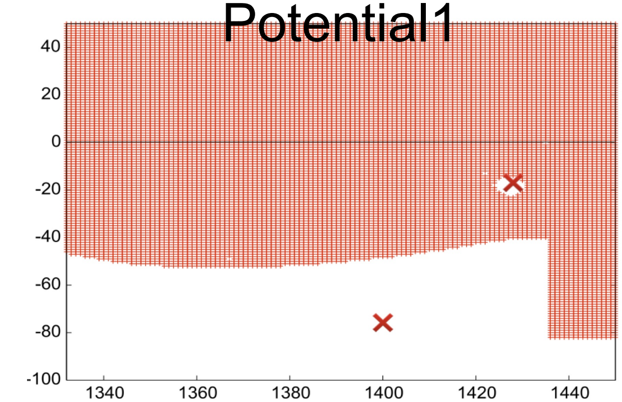
  ——— change ΔV and fitting range

	Hyodo-Weise	Potential1 (This work)	Chiral unitary
ΔV	real	complex	
fit range [MeV]	1300~1410	1332~1450	
ΔFreal [%]	14	0.48	
Pole [MeV]	1421-35i	1427-17i	1428-17i 1400-76i

Hyodo-Weise (2008)

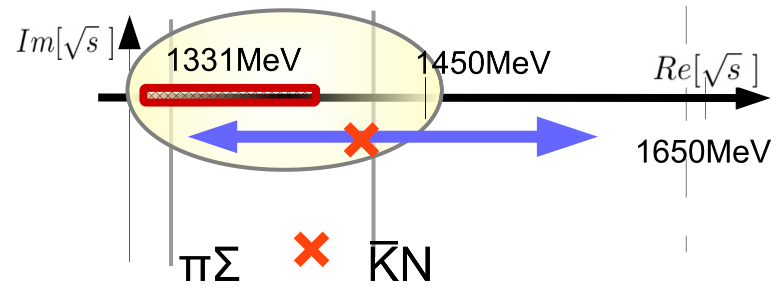


Potential1



ΔFreal and $\bar{K}$N pole position are improved

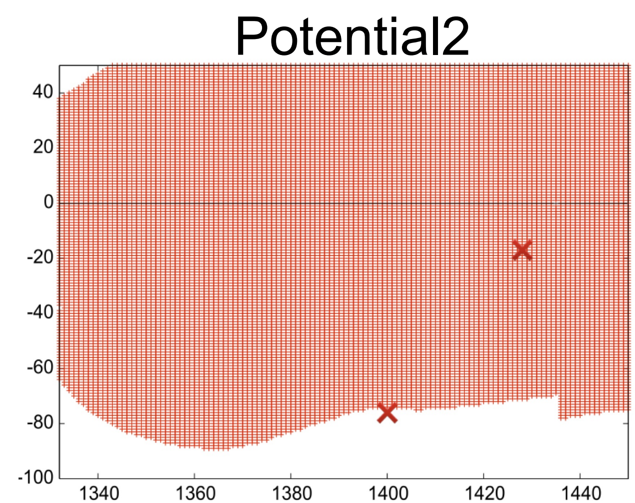
➢ Improvement (πΣ pole)



second pole did not appear

⟶ change fit range and polynomial type of V^{equiv}

	Potential1	Potential2	Chiral unitary
polynomial type in E	3rd order	10th order	
fit range [MeV]	1332~1410	1332~1520	
Pole [MeV]	1427-17i	1428-17i 1400-77i	1428-17i 1400-76i



πΣ pole appears at correct position

➢ Results with SIDDHARTA

I=0

b = 0.38 fm

fit function : 10^{th} order in $\sqrt{s}$

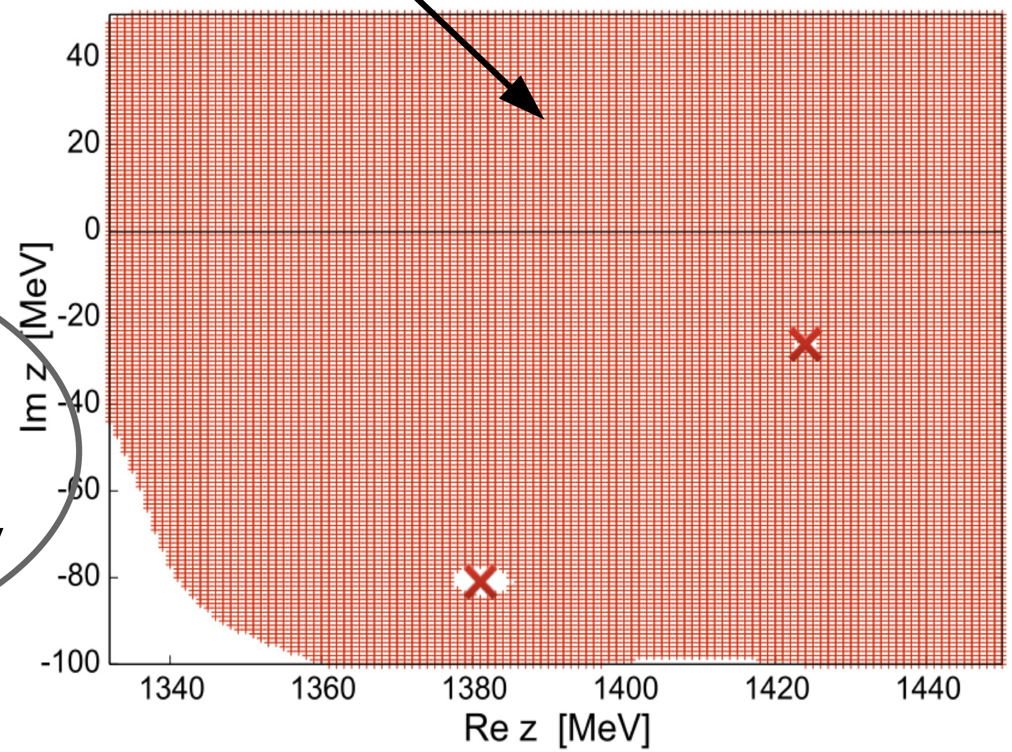
fit range : 1332~1657 MeV

→ $\Delta F_{\mathrm{real}} = 0.53\ \%$

pole : 1424-26i MeV
1381-81i MeV

original pole
1424-26i
1381-81i

"precise region"



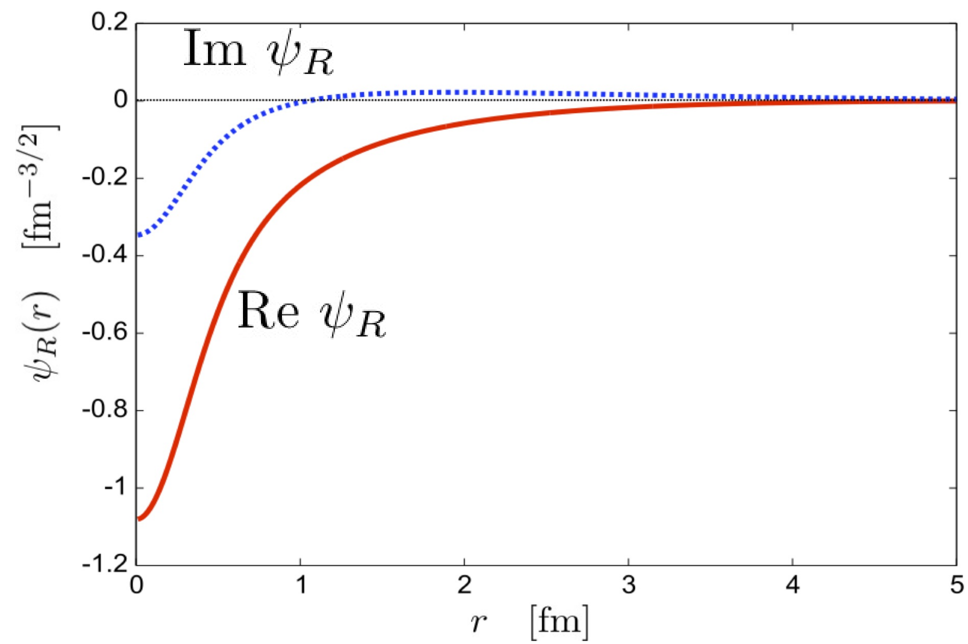
I=1 (with same framework)

→ $\Delta F_{\mathrm{real}} = 1.1\ \%$

Precise potential with SIDDHARTA

Discussion

➢ Wave function

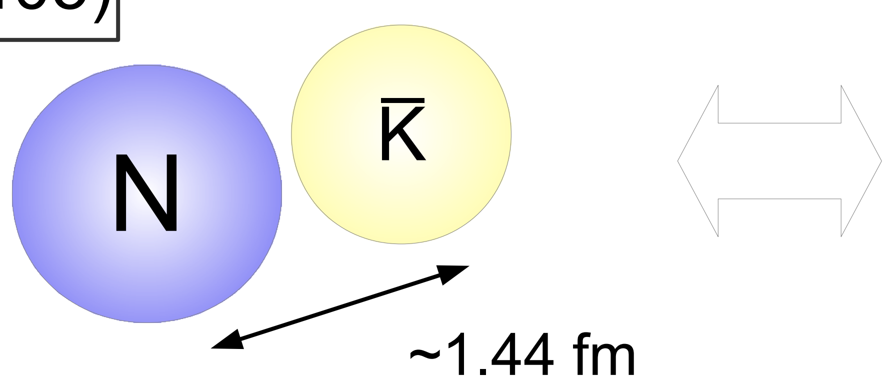


$$< r^2 >= \int d\mathbf{r}\ r^2 |\psi(\mathbf{r})|^2$$

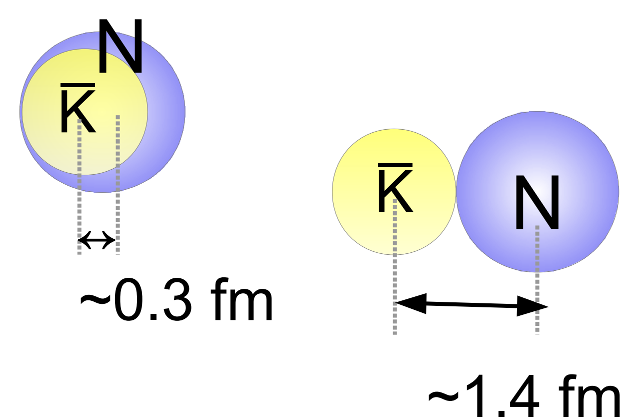
$$\sqrt{< r^2 >} = 1.44 \text{ fm}$$

p : ~0.85fm
K⁻ : ~0.55fm

Λ(1405)



cf.



Summary

- We have improved the potential construction procedure by changing ΔV, fit range, and fit function

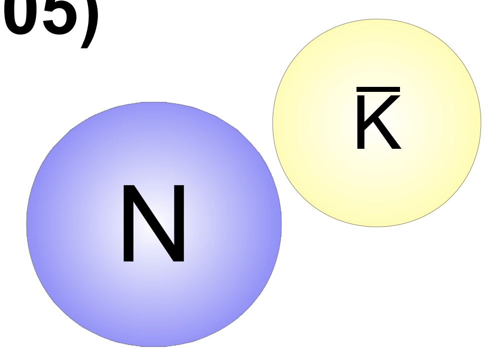
  ⇒ $F^{Ch}_{\bar{K}N}$ is reproduced **precisely in complex E plane**

- We have constructed the new $\bar{K}N$ equivalent potentials in both I=0 and I=1 channels with **SIDDHARTA** constraint

- We have discussed the **structure of Λ(1405)**

  ⇒ $\sqrt{< r^2 >} = 1.44\ \mathrm{fm}$

  molecular state of Λ(1405)



Future work

- Examine the influence of the ambiguity of the potential by evaluating $< r^2 >$ from various potentials with different spatial structure.
- Study the pole stability against the change of $F_{\bar{K}N}$ in connection with the experimental uncertainty.

- Calculate **$\bar{K}$NN** system with the new equivalent potential.
- Construct $\bar{K}$N-πΣ **coupled-channel** equivalent potential to treat πΣ-channel explicitly.