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Can We Determine Lambda-Lambda Interaction from Two-Particle Momentum Correlation ?

A. Ohnishi[A], Y. Hirata[A], Y. Nara[B],
S. Shinmura[C], Y. Akaishi[D]
Hokkaido U.[A], JAERI[B], Gifu U.[C], KEK-IPNS[D]

1. Introducition

- $\star$ **$\Lambda\Lambda$ Inv. Mass Spec.**
- $\star$ **Two-Particle Correlation — How we can use it ?**

2. $(K^-, K^+\Lambda\Lambda)$ Reaction

- $\star$ **IntraNuclear Cascade model**
- $\star$ **Inclusive and Exclusive K^+ Spectra**
- $\star$ **$\Lambda\Lambda$ Inv. Mass Spectrum**

3. $\Lambda\Lambda$ Interaction

- $\star$ **Extracted $\Lambda\Lambda$ Int.**
- $\star$ **Does Λ-Λ System Bound ?**
- $\star$ **$\Lambda\Lambda$ Correlation at AGS, SPS, and RHIC**

4. Summary

Refs. of Ours

INC: Nara, Ohnishi, Harada, Engel, NPA614 (97), 433

JAM: Y.Nara, NPA638 ('98), 555c; nucl-th/9802016

Y.Nara et al., to be submitted.

Corr. to nn Int.

Slaus, Akaishi, Tanaka, PRep. 173, ('89), 257.

Corr. to $\Lambda\Lambda$ Int.

Ohnishi, Hirata, Nara, Shinmura, Akaishi, in preparation

Hirata, Ohnishi, Ohtsuka, Nara, in preparation

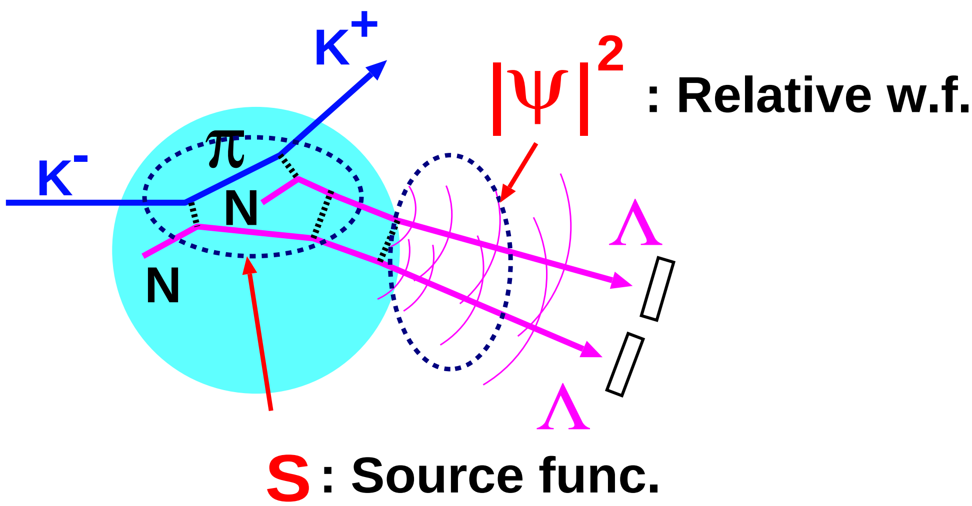
$\Lambda\Lambda$ Interaction

- ⋆ **IMPORTANT**
  Baryon-Baryon Int. with $SU_f(3)$,
  Double Hypernuclei, H particle, Neutron Star, ...
- ⋆ **but DIFFICULT to measure**
  - ∘ **Double Hypernuclei → 3 events/35 years, Only $^1S_0$**
  - ∘ **Scattering Exp. → Compact Collider**

• Enh. of Λ-Λ Inv. Mass Spec. at Low E.

Ahn et al. (KEK E224 coll.), KEK Preprint 98-24, 1998; PRL, in press

• Two-Particle Momentum Correlation
= Source Func. + Relative w.f.



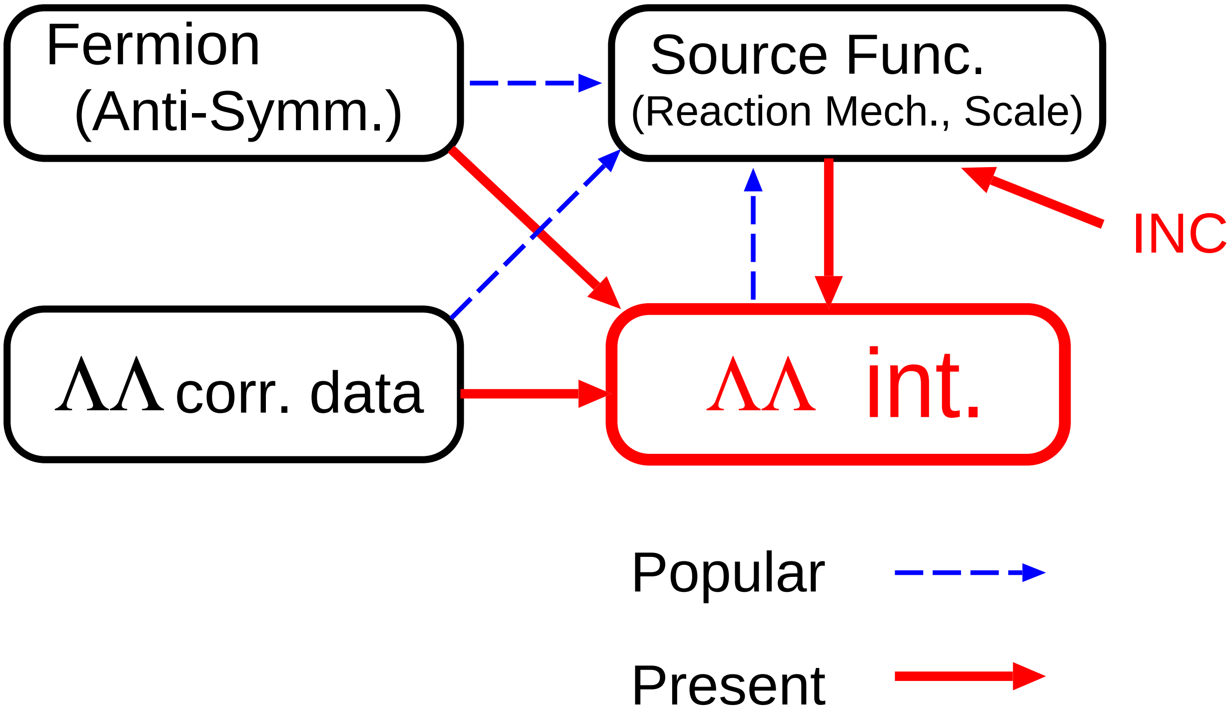
$$P(p_1, p_2) = \int dx_1 dx_2 S(p_1, x_1, p_2, x_2) |\psi^{(-)}(k, r_{12})|^2$$

$$\vec{r}_{12} = \vec{r}_1 - \vec{r}_2 + \vec{P}(t_2 - t_1)/2m\ , \quad \vec{P} = \vec{p}_1 + \vec{p}_2\ , \quad \vec{k} = \frac{1}{2}(\vec{p}_1 - \vec{p}_2)\ ,$$

W. G. Gong et al., PRC 43 ('91), 781.

Slaus, Akaishi, Tanaka, PRep. 173, ('89), 257.

How to Use Two-Particle Correlation



⋆ **If we have Realistic Source Func., we can extract info. of Λ-Λ int !**

→ **IntraNuclear Cascade calc.**

Nara,Ohnishi,Harada, Engel, NPA614 (97), 433.

c.f nn **Corr.** → r_{eff} (Slaus-Akaishi-Tanaka, 1989)

- **Specific Assumptions in this work**

  = **Spin Singlet dominance and** $L=0$ **Int. Only**

$$\psi^{(-)}(\vec{k},\vec{r}) \simeq \sqrt{2}\left[\cos(kr\cos\theta) - j_0(kr) + e^{-i\delta_0}u_0(r)\right]$$

u_0: s-wave Relative w.f. ⟵ Interaction

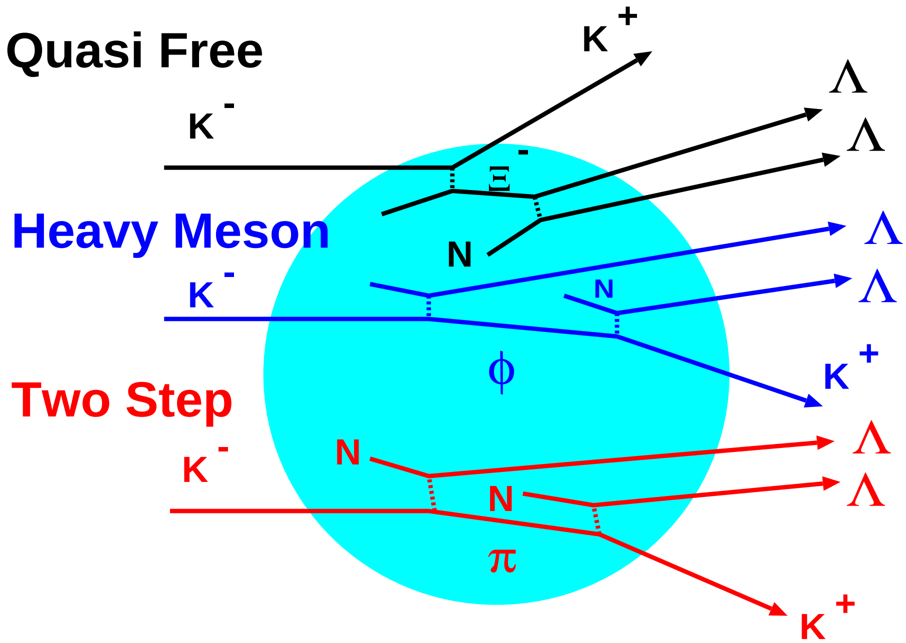
+ Usual Assumptions

1: Two-body Correlation is mainly determined by Two-body Int. (Mean Field Effects are Small)

2: Slow Dep. of Source Fun. on Momentum

Source Func. = IntraNuclear Cascade (INC)

Nara,Ohnishi,Harada, Engel, NPA614 (97), 433.



- **K^+ Production Mech.**

Quasi Free	$K^-N \to K^+\Xi^{(*)}$
Heavy-Meson (Gobbi-Dover-Gal)	$K^-N \to MY, M \to K^-K^+$ $MN \to K^+\Lambda$ $(M = \phi, f_0, a_0)$
Two-Step	$K^-N \to MY^{(*)}, MN \to K^+Y^{(*)}$ $(M = \pi, \eta, \rho, \omega, \phi, f_0, a_0)$

- **Baryon-Baryon Collision**

  ⋆ $NN \to NN$, $NY \to NY'$ (ND)

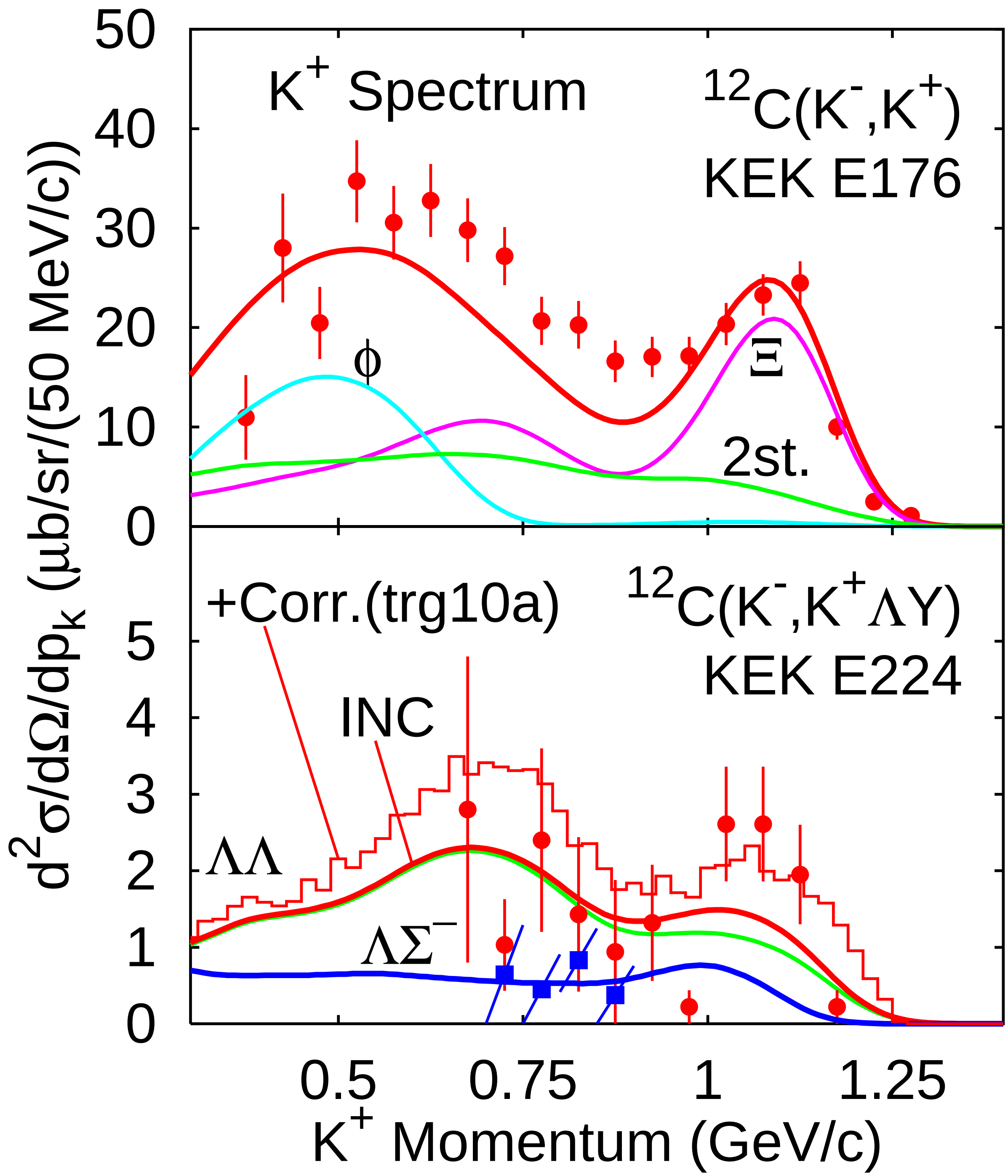
  ⋆ $\Xi N \to \Lambda\Lambda$ (ND, r_c=0.5 fm)

- **Mean Field Effects**

  ⋆ $U_\Lambda = -30$ MeV, $U_\Sigma = -10$ MeV
  $U_\Xi = -16$ MeV

(Fukuda et al. PRC58 (98) 1306)

K^+ Spectrum in $^{12}\mathbf{C}(K^-, K^+)$

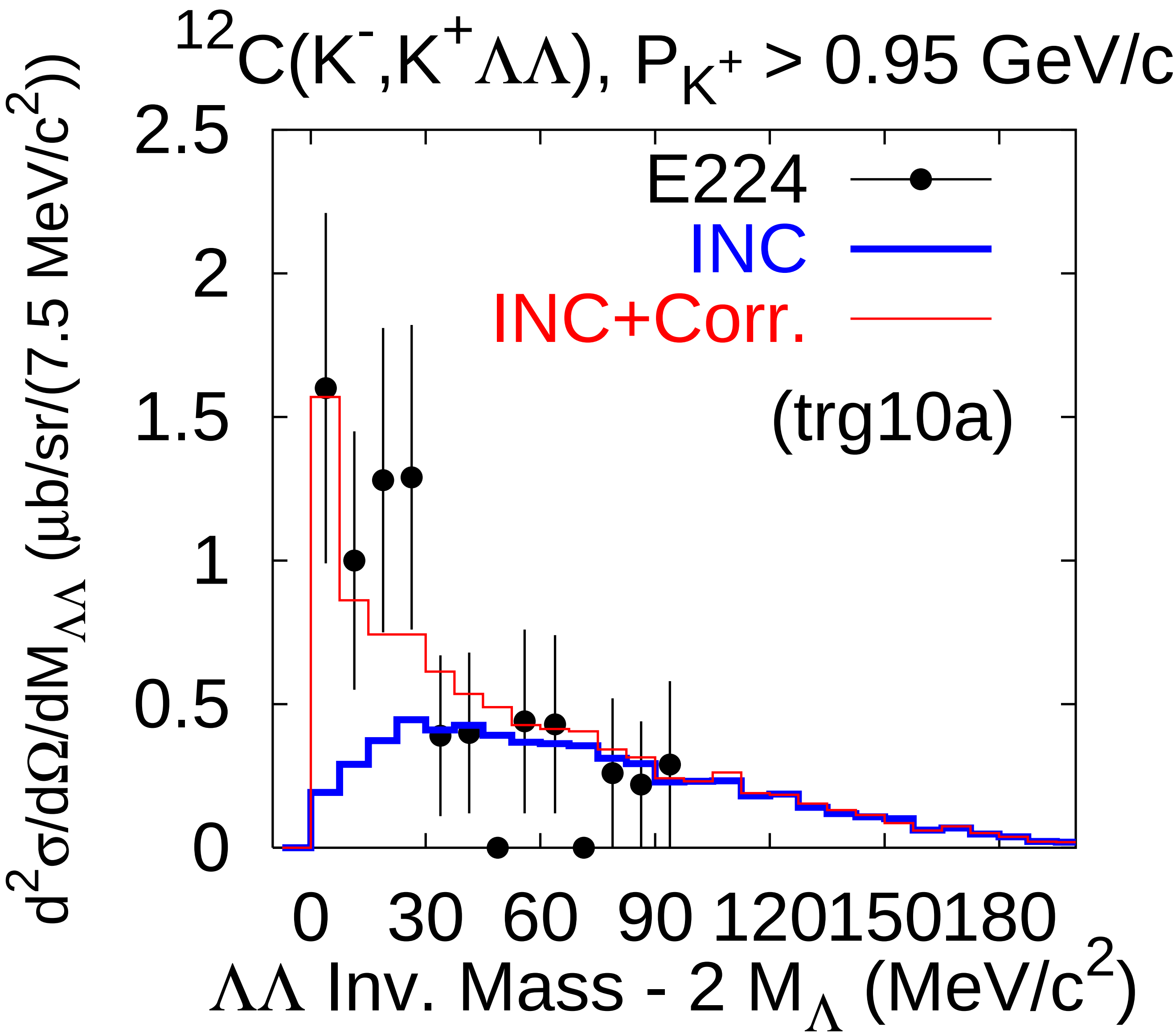


- **INC** results of $(K^-, K^+\Lambda\Lambda)$

  ⋆ **Underestimate of around 3 μb ($P(K^+) > 0.95$ GeV/c)**

  ⋆ **Two-Step Processes are dominant even in QF region.**

Λ-Λ Inv. Mass Spectrum



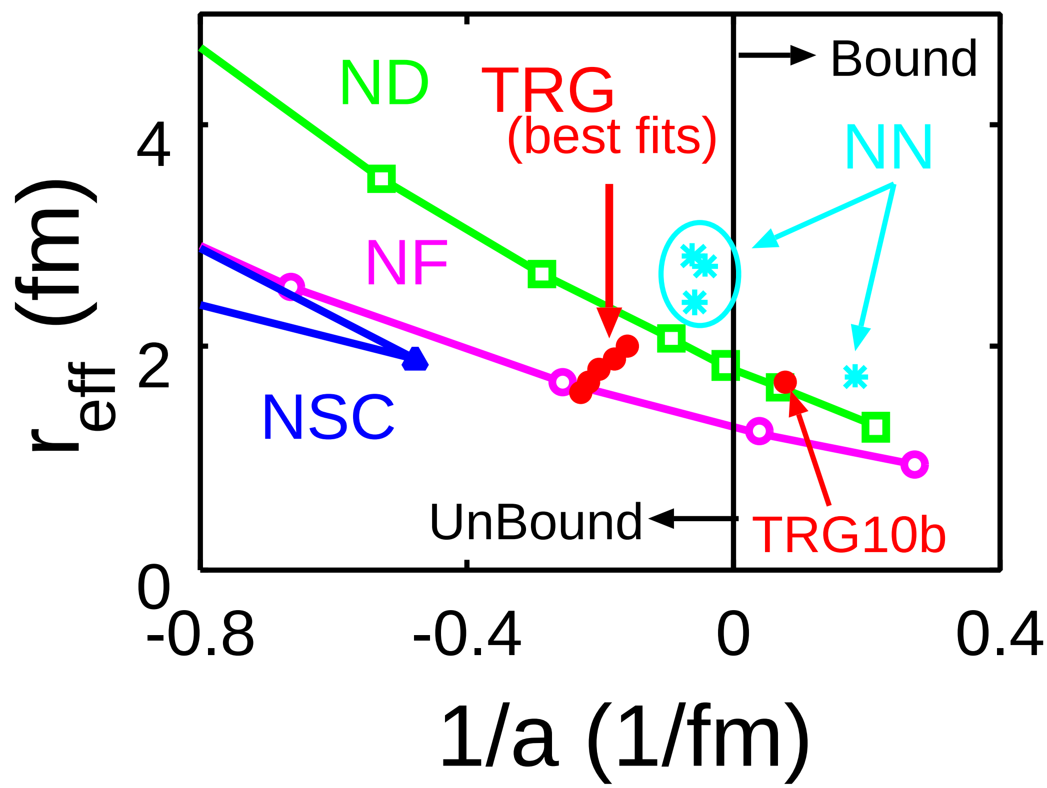
- **INC results**
  - ⋆ **Underestimate of around 3 μb** $\sim (K^-, K^+\Lambda\Lambda)$
  - ⋆ **Reproduces at** $E_{\Lambda\Lambda} > 50$ **MeV** $\cdots$ **Source Size $\leq$ 3 fm**
- **INC+Corr. results**
  - ⋆ **Attr. ΛΛ Int.** $\rightarrow$ **Fast Growth of W.F.**
    $\rightarrow$ **Enh. of Inv. Mass Spec.**

Extracted Λ-Λ Interaction

• χ^2-Fit within Two-Range Gauss Interaction

	μ_l (fm)	v_l (MeV)	v_s (MeV)	a (fm)	$r_{\rm eff}$ (fm)	χ^2 /DOF	B.E. (MeV)
TRG06	0.6	-900	1440	-4.4	1.6	0.32	U.B.
TRG07	0.7	-400	750	-4.6	1.7	0.33	U.B.
TRG08	0.8	-230	470	-5.0	1.8	0.34	U.B.
TRG09	0.9	-150	310	-5.6	1.9	0.36	U.B.
TRG10a	1.0	-110	240	-6.3	2.0	0.38	U.B.
TRG10b	1.0	-140	260	13.1	1.7	0.40	0.22

($\mu_s = 0.45$ fm is fixed for simplicity.)

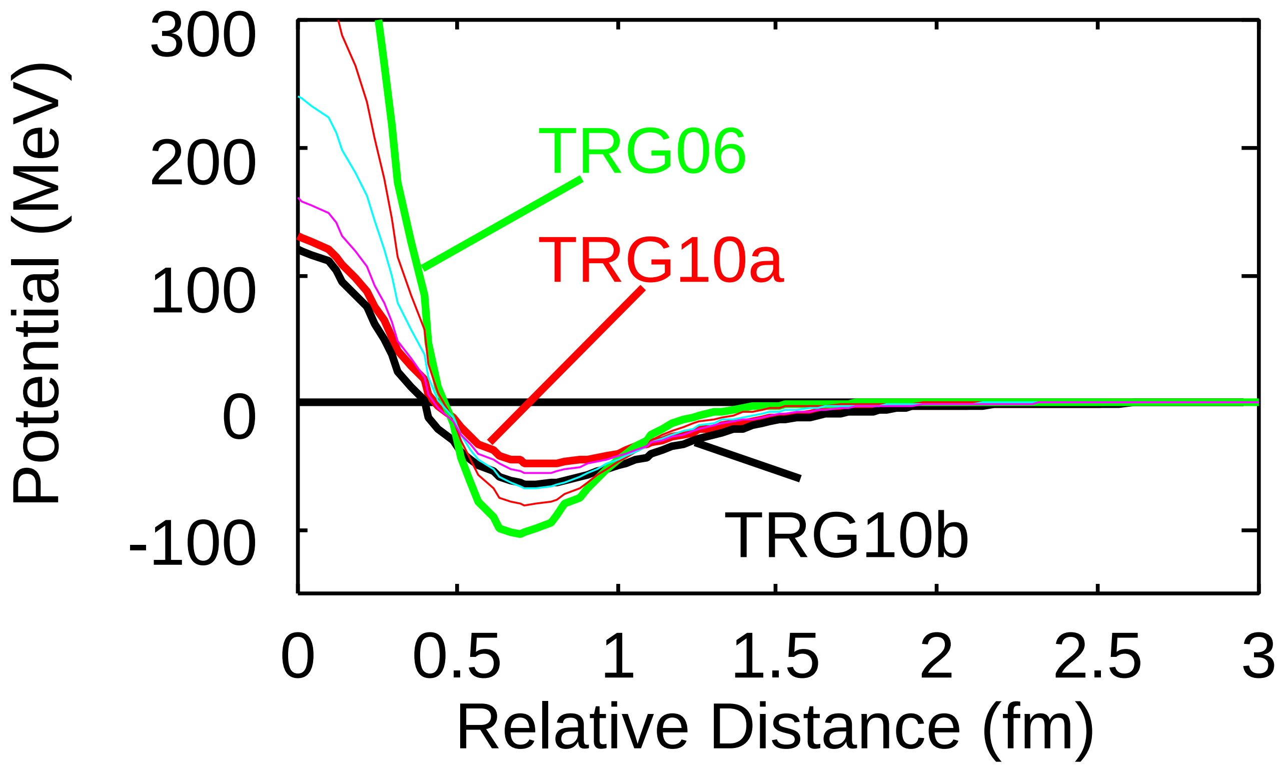


⋆ **Strongly attractive and short range**

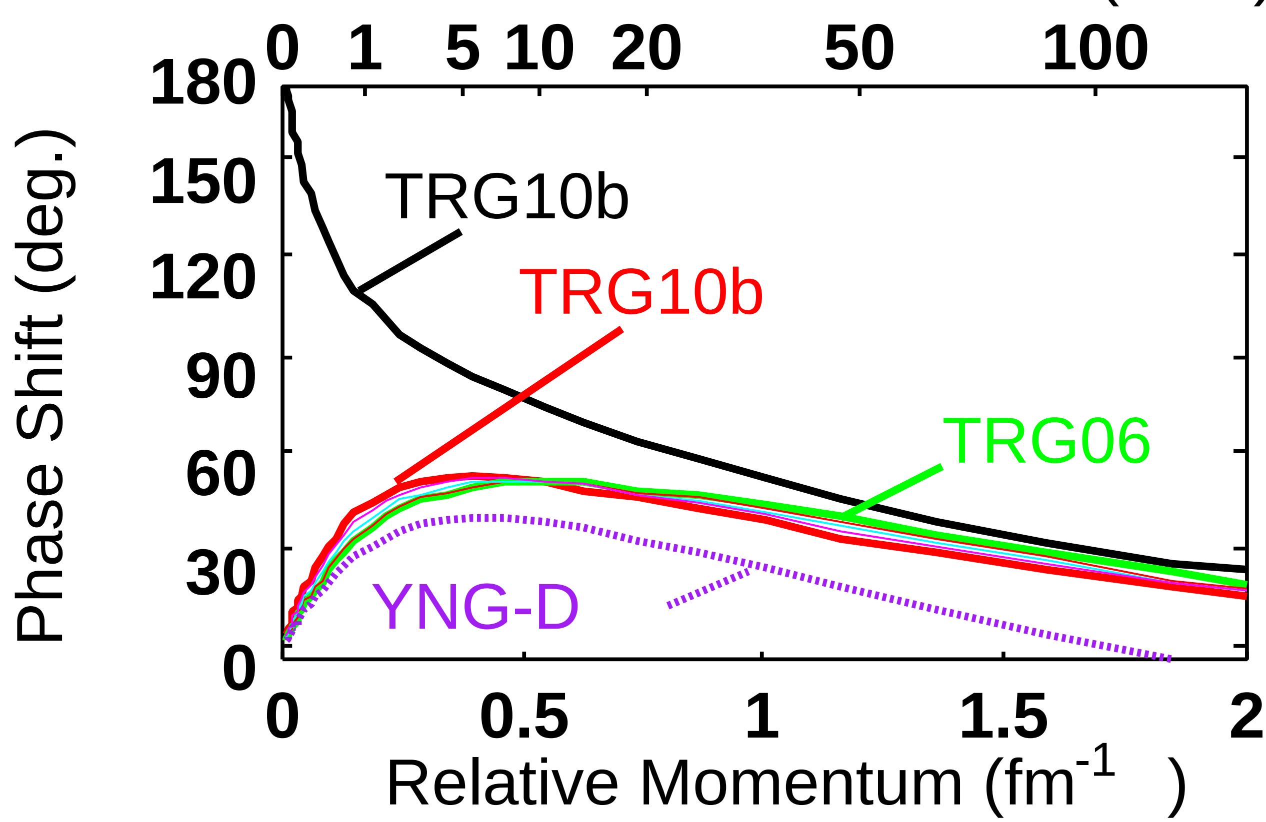
⋆ **TRG10a ≃ ND with** $r_c = 0.5 \sim 0.52$ **fm.**

⋆ **TRG06 ≃ NF with** $r_c = 0.46$ **fm.**

● ΛΛ Potential



● ΛΛ $^1S_0$ Phase Shift



Does Λ-Λ System Bound ?

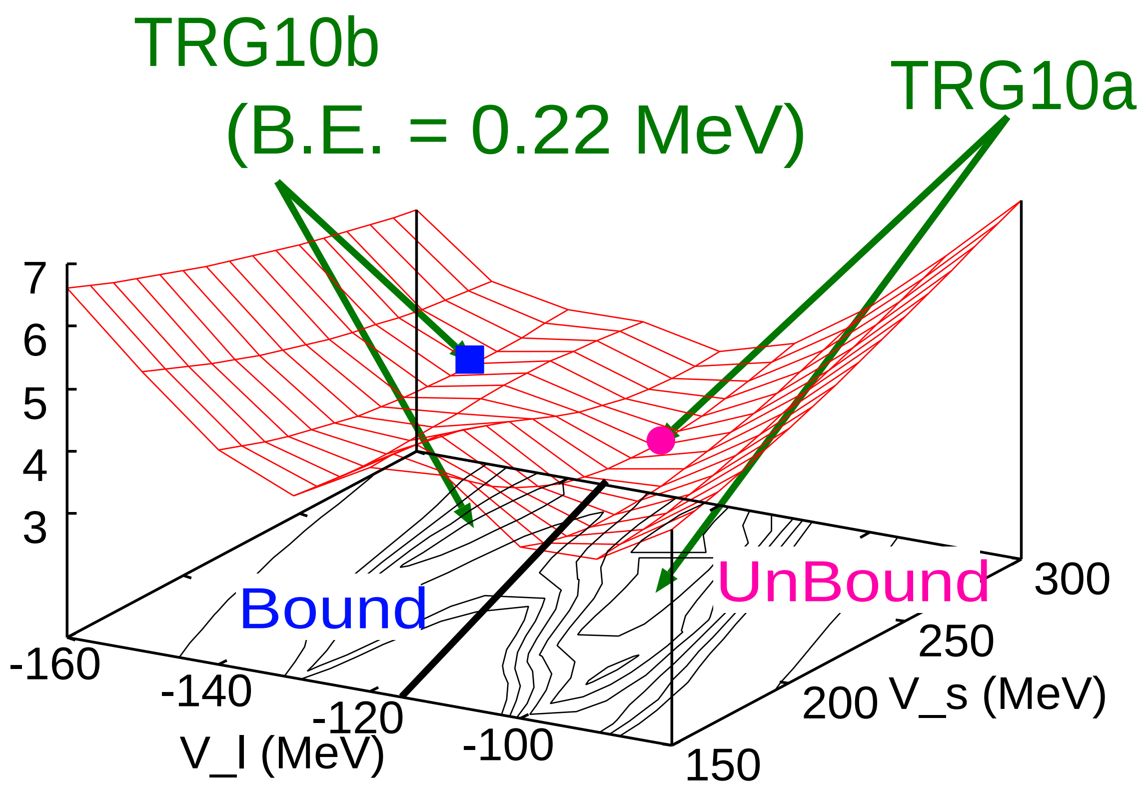
- **Corr. Formula + Long Wave Approx.**
  → Enhancement Factor

$$P(\vec{p}_1, \vec{p}_2) = 2\ F(k)\ P_c(\vec{p}_1, \vec{p}_2)\ ,$$
$$P_c(\vec{p}_1, \vec{p}_2) = \int d^4x_1\, d^4x_2\, S(\vec{p}_1, x_1, \vec{p}_2, x_2)\ ,$$

$$F(k) = \left|\frac{\sin(kb+\delta_0)}{\sin kb}\right|^2 \xrightarrow{k\to 0} \left(1-\frac{a}{b}\right)^2 - ck^2$$

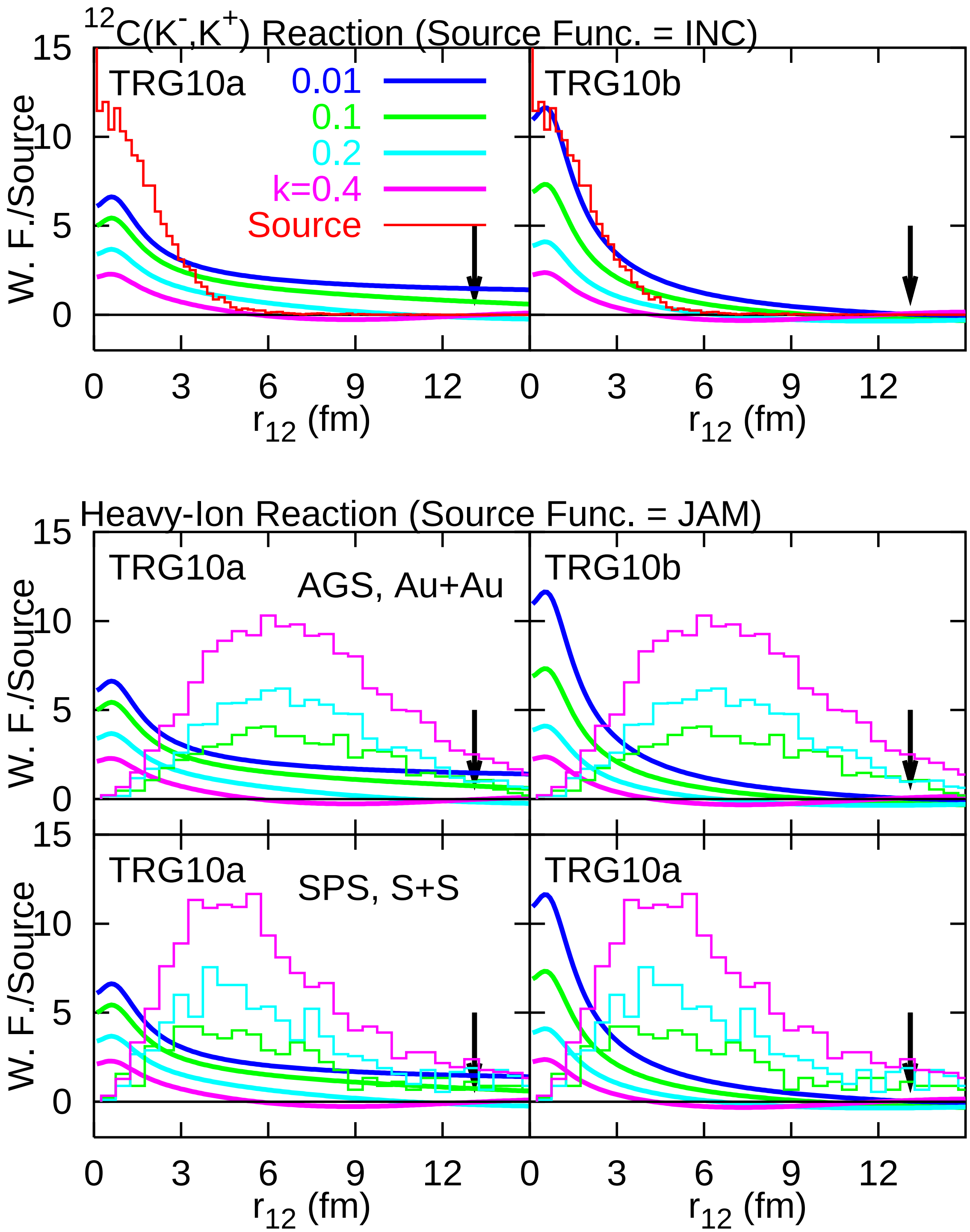
a: **scattering length,** b: **intrinsic range**

→ **Double-well structure:** $a \simeq b \pm \sqrt{F(0)}$



• How to Distinguish Them ?

→ **Use Reactions with Different Source Size, covering the region around Scattering Length.**



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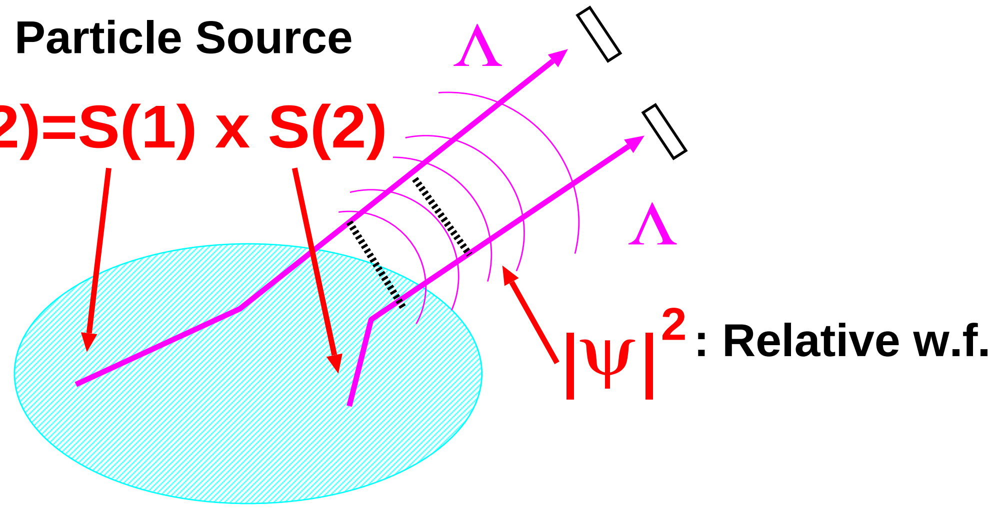
Y.Nara et al., to be submitted.

Particle Correlation in HIC

Indep. Particle Source

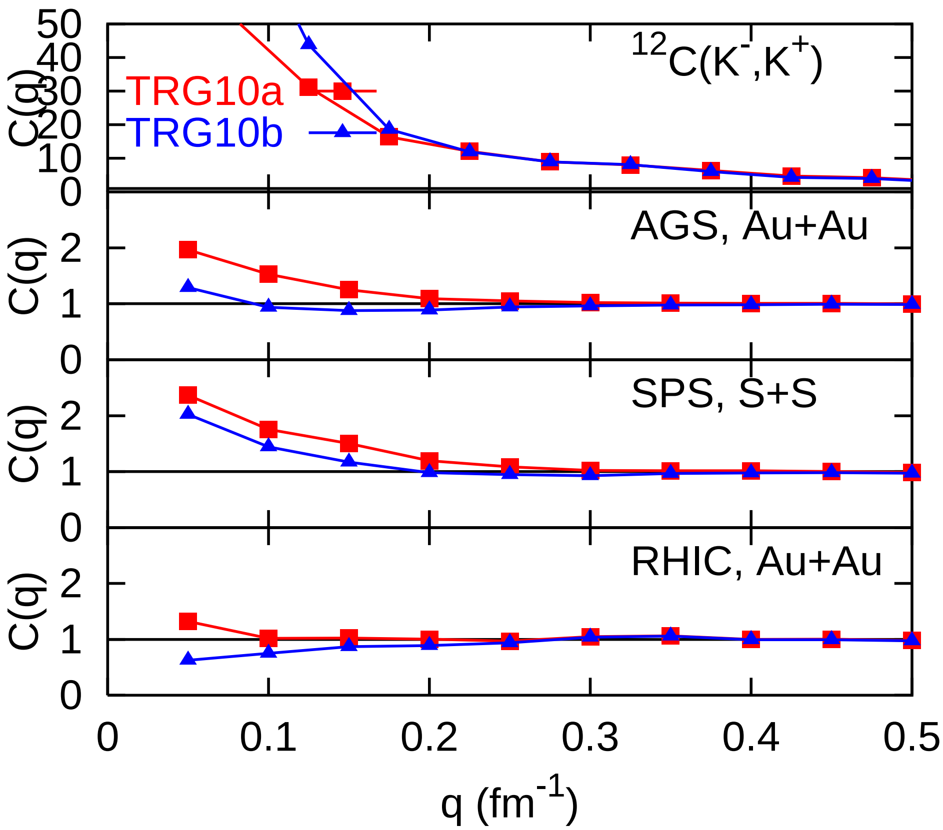
$S(1,2)=S(1) \times S(2)$



$$C(q) = \frac{\int dP\, dx_1 dx_2\, S(p_1,x_1,p_2,x_2)\,|\psi^{(-)}(k,r_{12})|^2}{\int dP\, dx_1 dx_2\, S(p_1,x_1,p_2,x_2)}$$

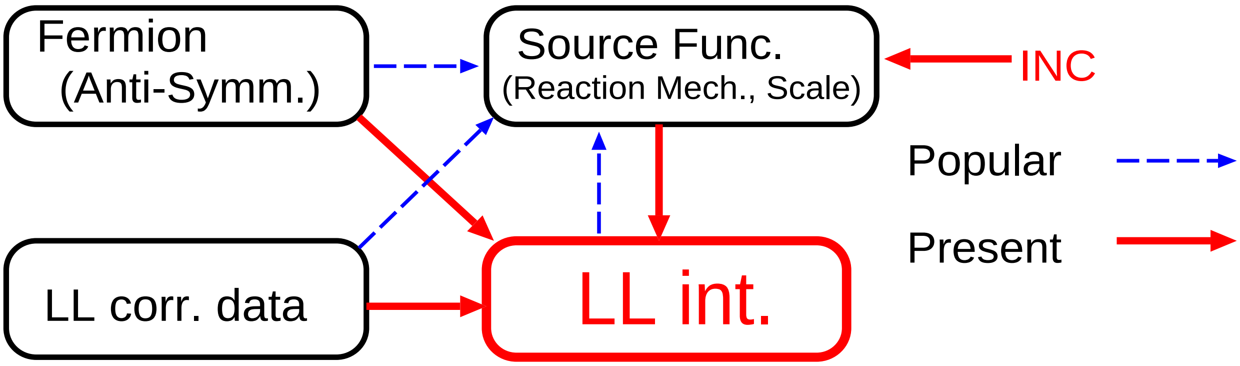
$p_1 = P/2 + q \qquad p_2 = P/2 - q$

ΛΛ Correlation Function



Summary

1. **Source Func. (INC) + Λ-Λ Corr. (Inv. Mass Spec.)**
   $\rightarrow$ Λ-Λ Int.
   (We can use Corr. INVERSELY)



2. **Extracted Λ-Λ Int. at χ^2 Local Min.**

   $\star$ **Best Fit Parameters: No Bound State.**
   $a \simeq -5$ **fm**, $r_{\text{eff}} \simeq 1.8$ **fm**

   $\star$ **Double well structure: We cannot deny Bound S-tate**

$$F(k) \simeq \left(1 - \frac{a}{b}\right)^2 - ck^2 \ ,$$

   $\star$ χ^2**/DOF** $\simeq$ **0.35: Large Error Bar of Data**

3. **Λ-Λ Inv. Mass Spec./Correlation Func.**

   $\star$ (K^-, K^+) **Reaction**
   - **One-Dim. Prod. Mech. + Small Source Size**

   $\rightarrow$ Dyn. Correlated Source
   $\rightarrow$ Large Enh.

   $\star$ **Relativistic Heavy-Ion Collision**
   - **Indep. Prod. Mech. + Large Source Size**

   $\rightarrow$ Corr. Func. is Available through Exp.
   $\rightarrow$ Covers Scat. Length Region of Small B.E.