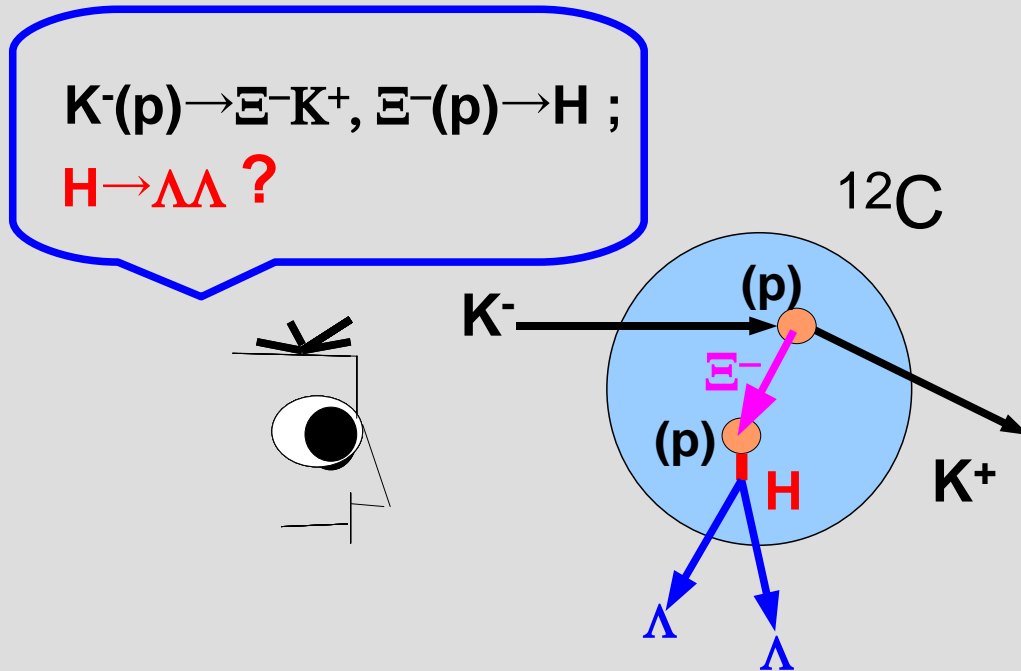


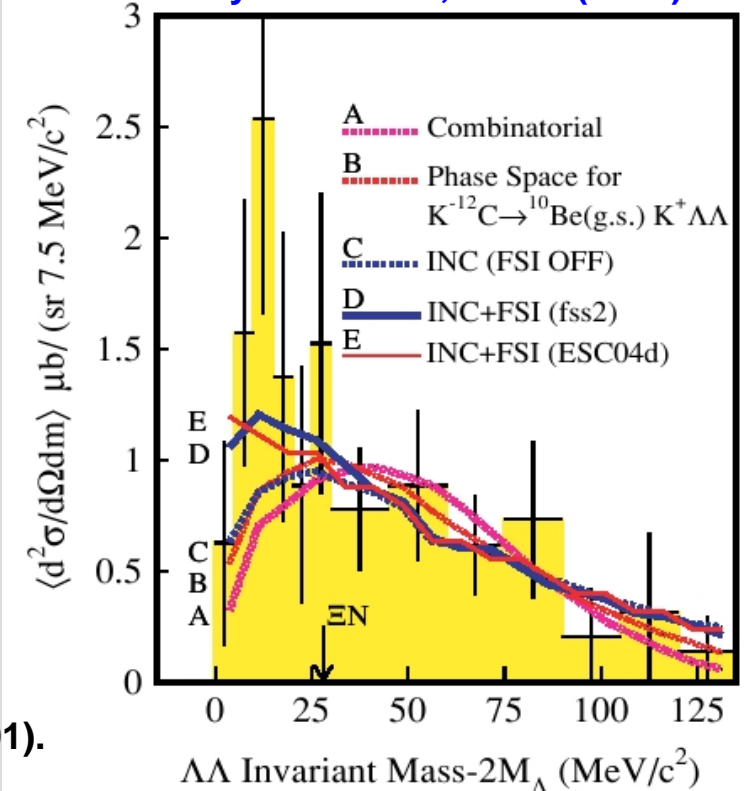
# Extraction of $\Lambda\Lambda$ scattering length

Yoon, Choong-Jae, Seoul Natl Univ.



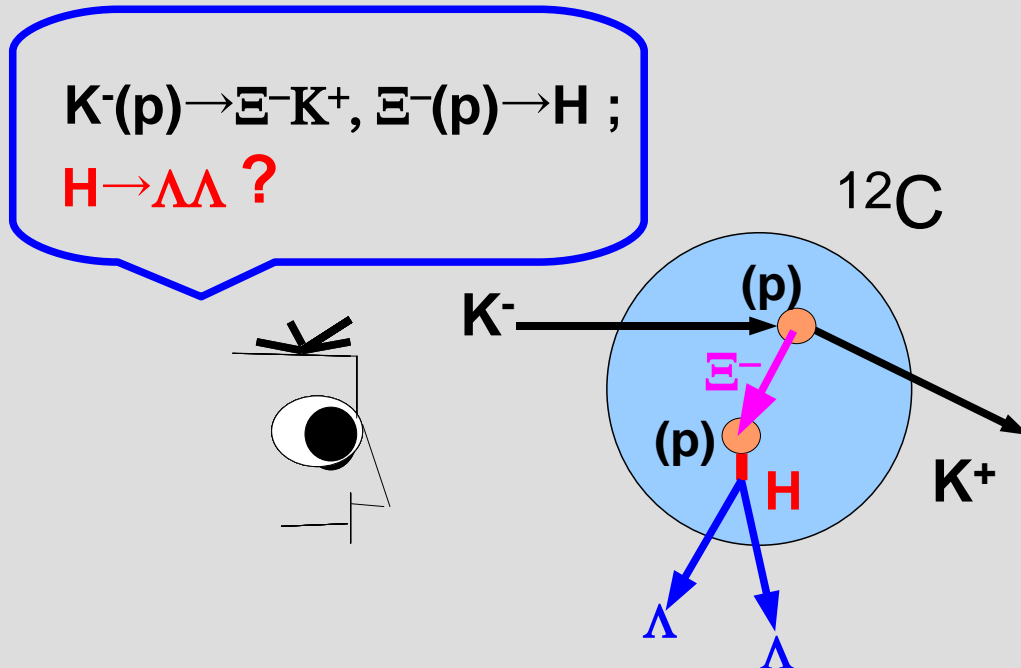
Intranuclear Cascade (INC) model: A BUU type transport model, A. Ohnishi et al., Nucl. Phys. A691, 242c (2001).

C.J. Yoon et al. (KEK-PS E522),  
 Phys Rev C 75, 02201 (2007)



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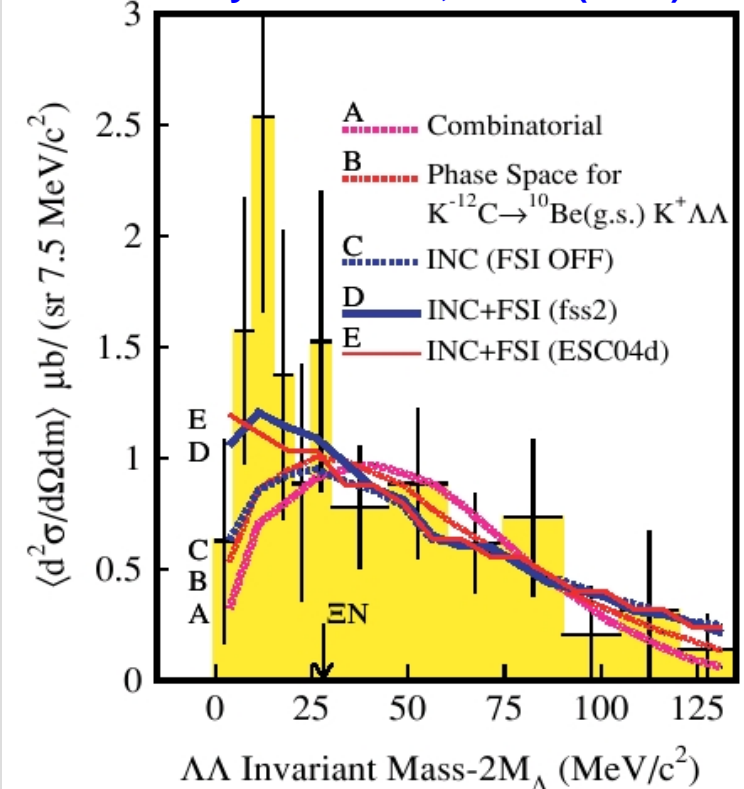
Yoon, Choong-Jae, Seoul Natl Univ.



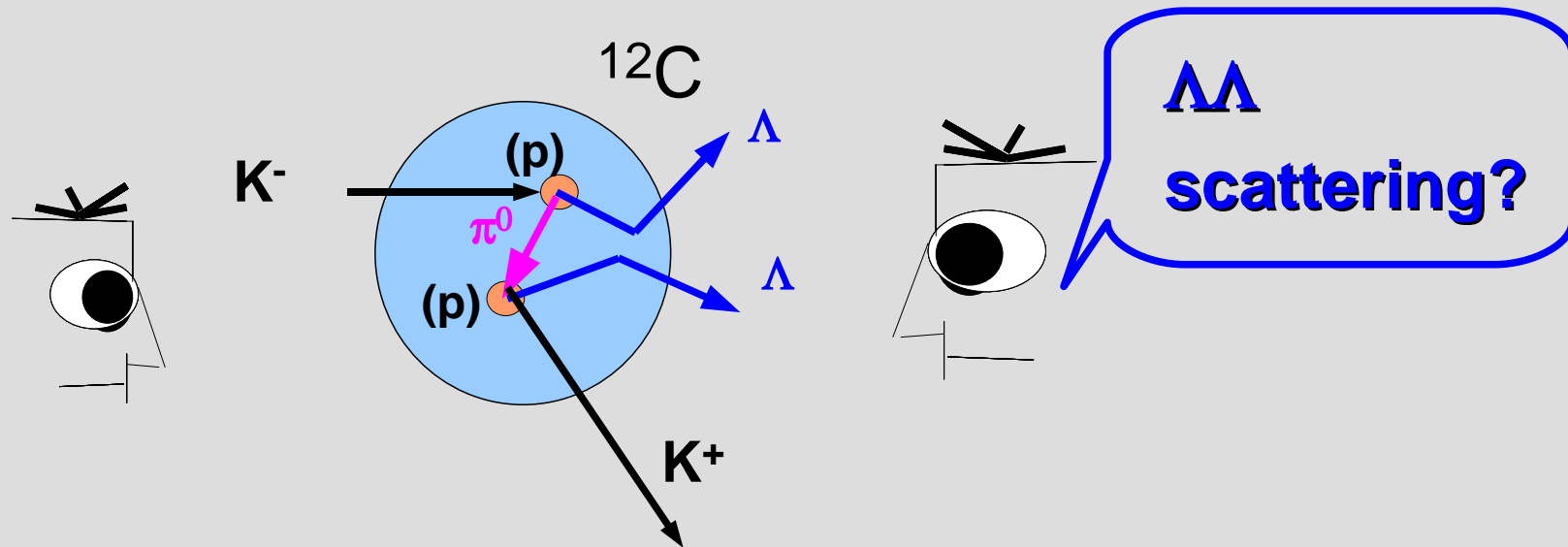
fss2: A potential model developed by Kyoto group.

ESC04d: A model developed by Nijmegen group in 2004.

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# Extraction of $\Lambda\Lambda$ scattering length



C. J. Yoon,<sup>1,\*</sup> H. Akikawa,<sup>1,†</sup> K. Aoki,<sup>1</sup> Y. Fukao,<sup>1,‡</sup> H. Funahashi,<sup>1,§</sup> M. Hayata,<sup>1</sup> K. Imai,<sup>1</sup>  
K. Miwa,<sup>1,¶</sup> H. Okada,<sup>1,‡</sup> N. Saito,<sup>1,†</sup> H. D. Sato,<sup>1</sup> K. Shoji,<sup>1</sup> H. Takahashi,<sup>1,†</sup> K. Taketani,<sup>1</sup>  
J. Asai,<sup>2,‡</sup> M. Kurosawa,<sup>2,‡</sup> M. Ieiri,<sup>3</sup> T. Hayakawa,<sup>4</sup> T. Kishimoto,<sup>4</sup> A. Sato,<sup>4</sup> Y. Shimizu,<sup>4</sup>  
K. Yamamoto,<sup>5</sup> T. Yoshida,<sup>5,\*\*</sup> T. Hibi,<sup>6</sup> K. Nakazawa,<sup>6</sup> J. K. Ahn,<sup>7</sup> B. H. Choi,<sup>7</sup> S. J. Kim,<sup>7</sup>  
S. H. Kim,<sup>8,††</sup> B. D. Park,<sup>8,‡‡</sup> I. G. Park,<sup>8</sup> J. S. Song,<sup>8</sup> C. S. Yoon,<sup>8</sup> K. Tanida,<sup>9,§§</sup> and A. Ohnishi<sup>10,¶¶</sup>

(KEK-PS E522 Collaboration)

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<sup>4</sup>*Department of Physics, Osaka University, Osaka 558-8585, Japan*

<sup>5</sup>*Department of Physics, Osaka City University, Osaka 558-8585, Japan*

<sup>6</sup>*Physics Department, Gifu University, Gifu 501-1193, Japan*

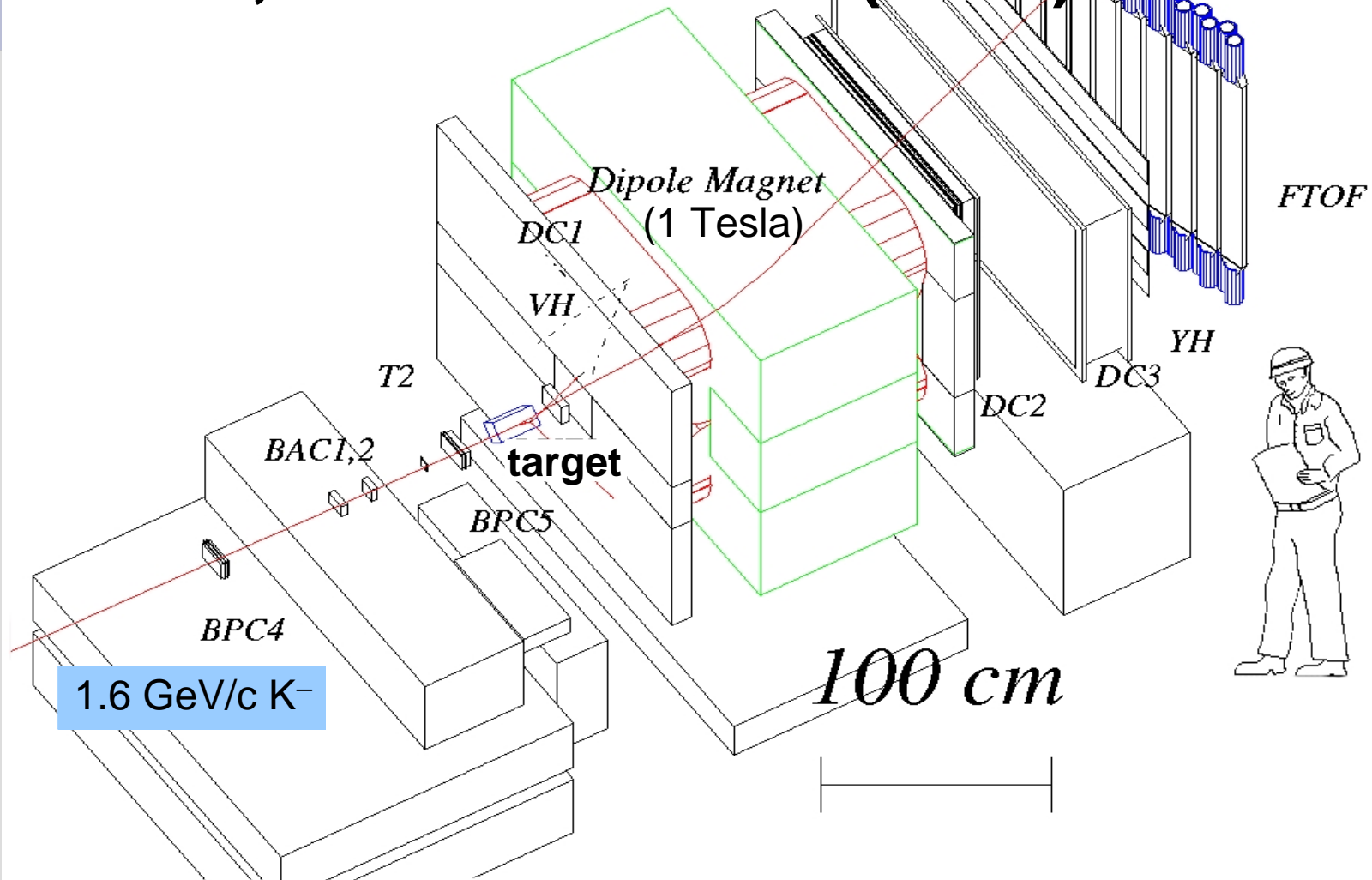
<sup>7</sup>*Department of Physics, Pusan National University, Busan 609-735, Korea*

<sup>8</sup>*Department of Physics and Research Institute of Natural Science, Gyeongsang National University, Jinju 660-701*

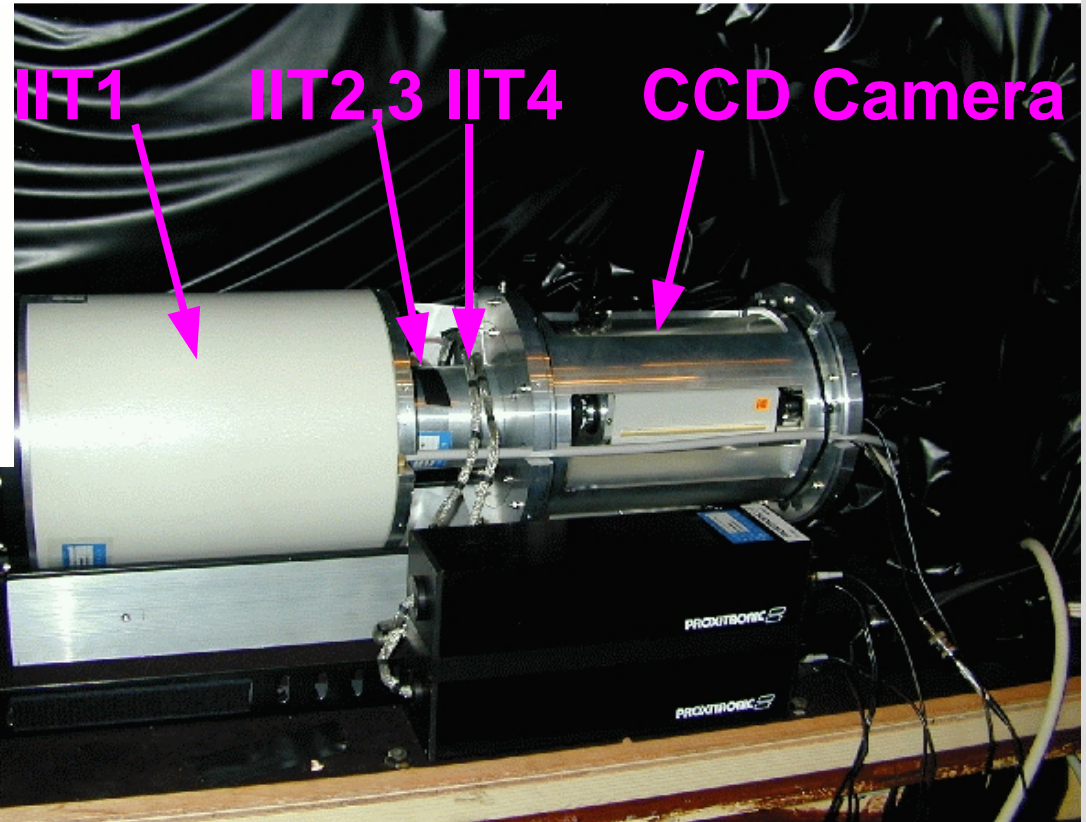
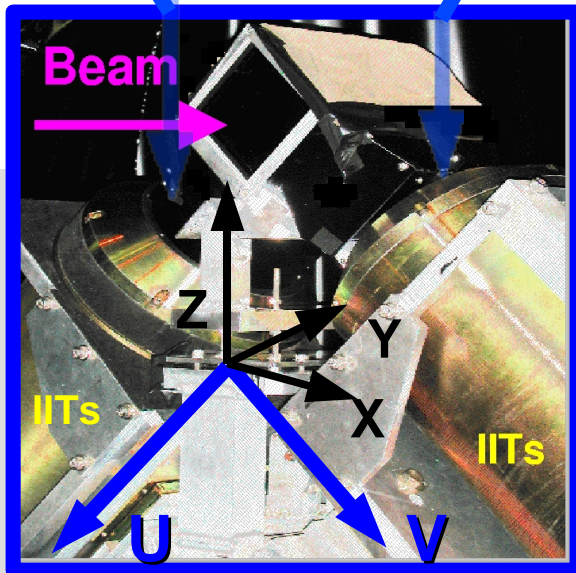
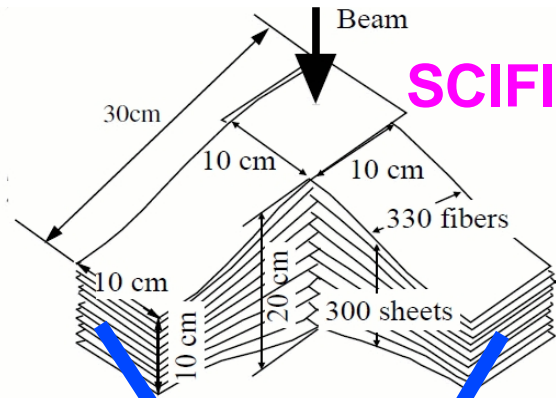
<sup>9</sup>*The Institute of Physical and Chemical Research (RIKEN), Saitama 351-0198, Japan*

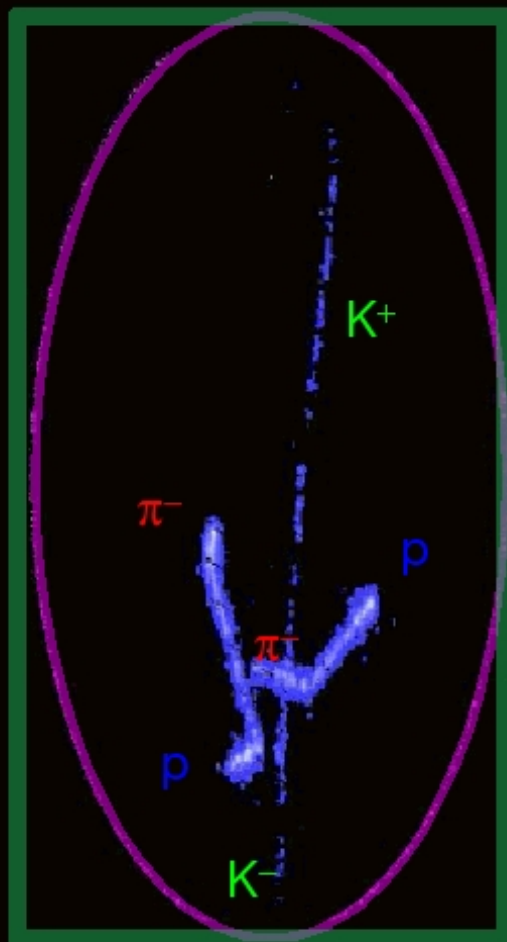
<sup>10</sup>*Department of Physics, Faculty of Science, Hokkaido University, Sapporo 060-0810, Japan*

# Experimental Setup at K2, KEK-PS 12 GeV (E522)

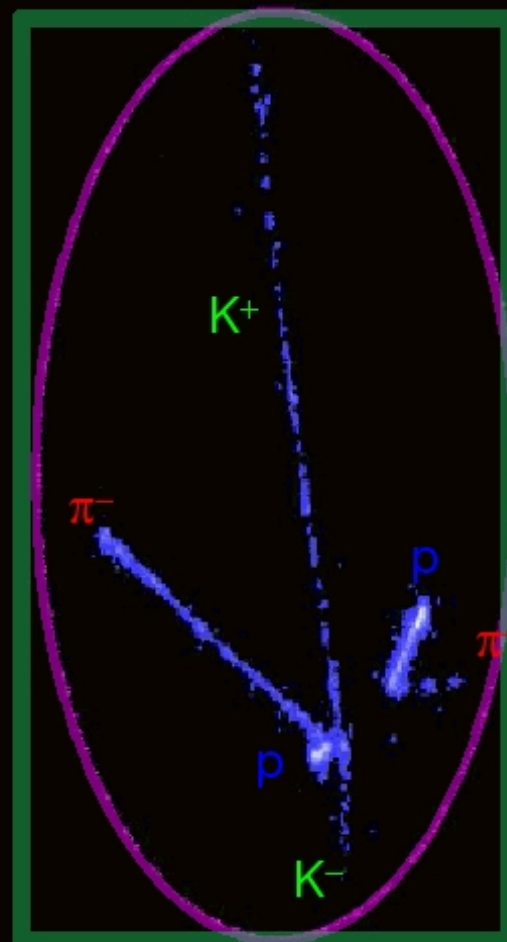


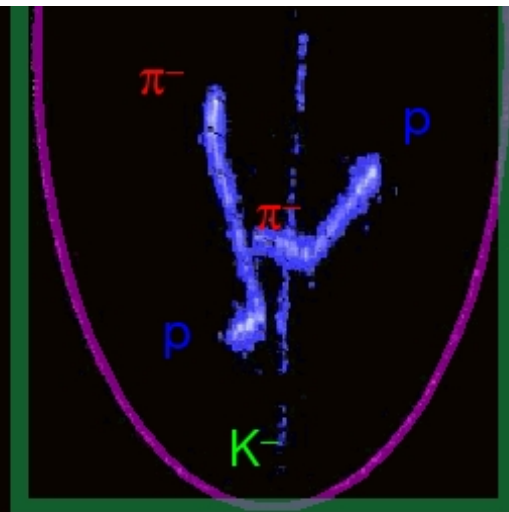
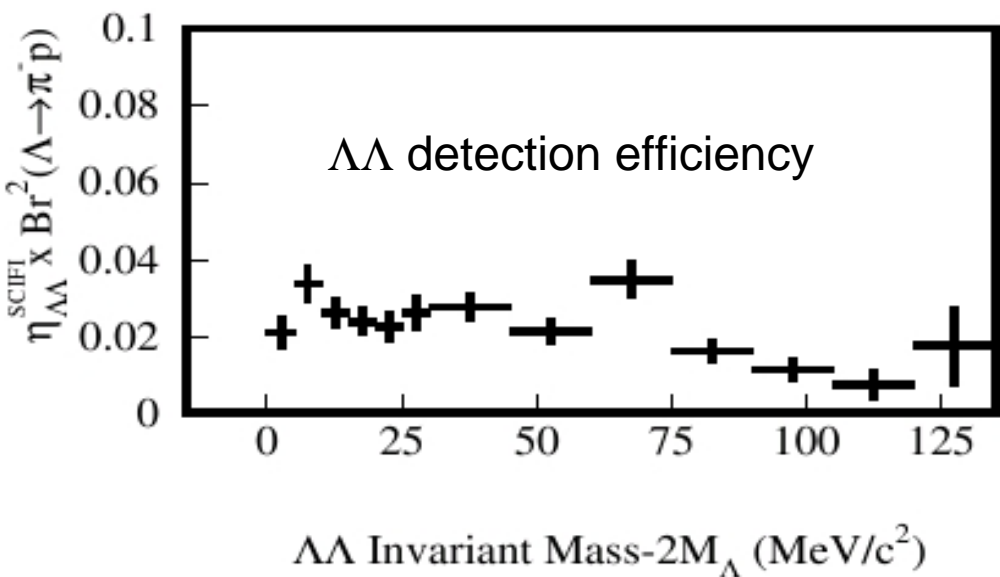
# SCIFI active target, Readout system



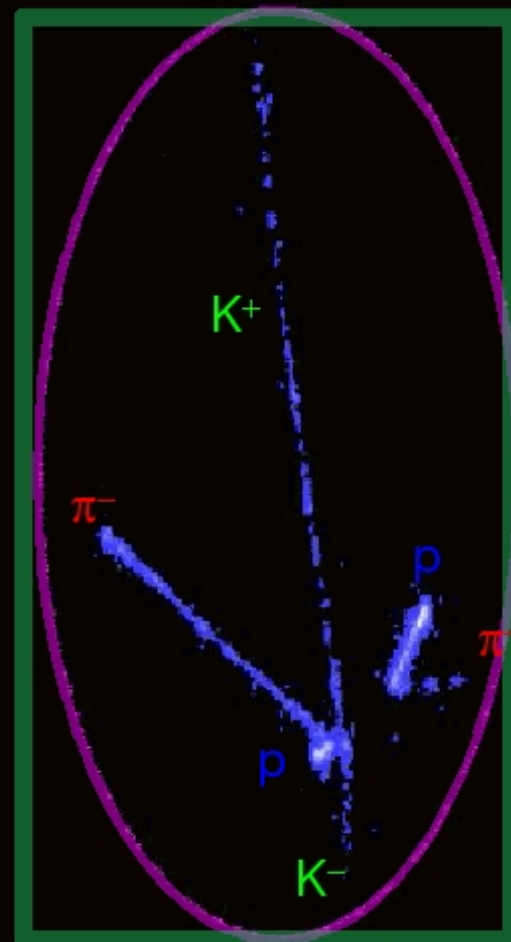


5 cm



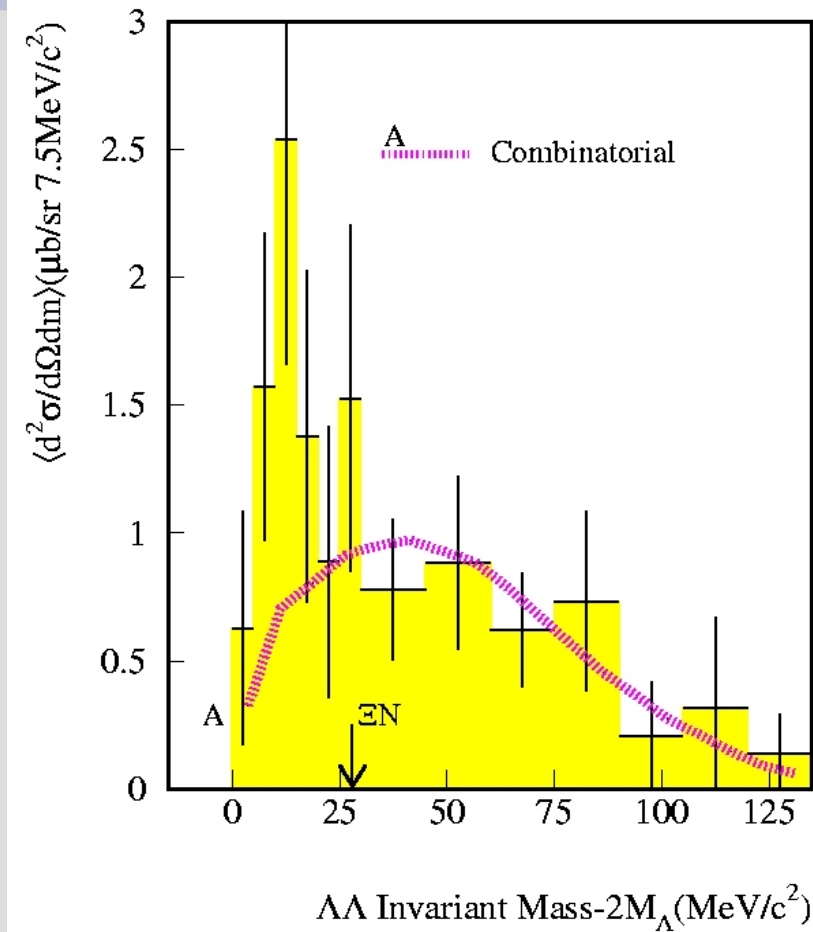


5 cm

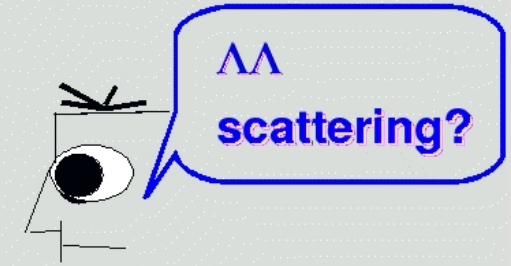
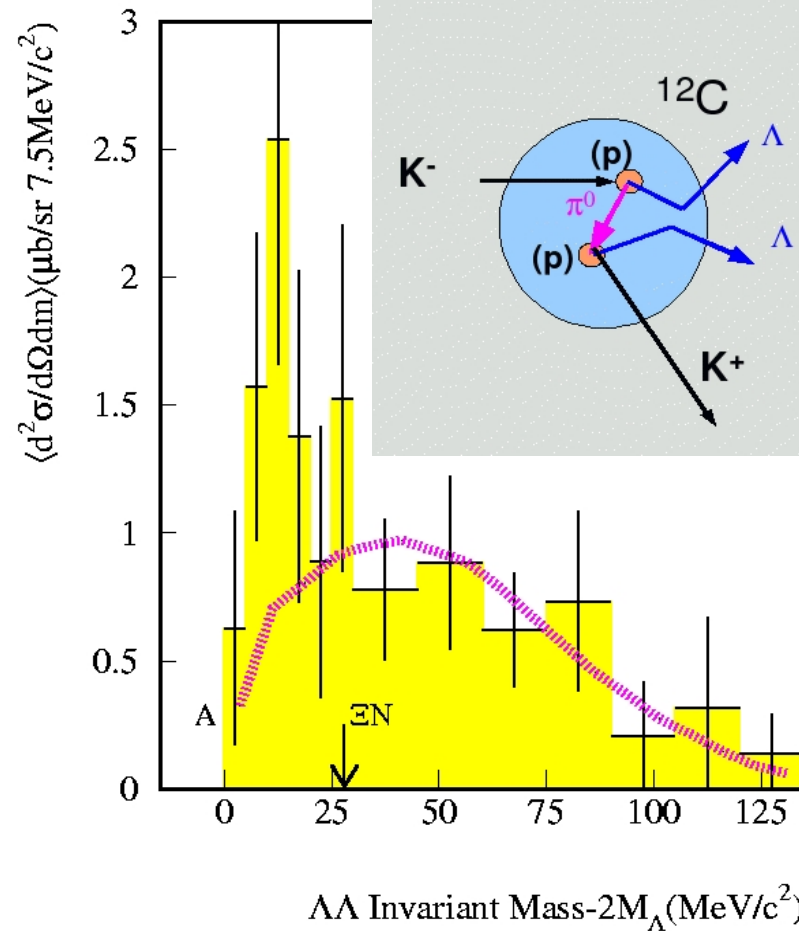




# $\Lambda\Lambda$ FSI+Combinatorial B.G. ?



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# $\Lambda\Lambda$ enhancement factor

$\psi$  (s-wave)  $\sim \sin(kr + \delta)/kr$

$$F = |\sin(kb + \delta)/k|^2$$

Watson (1952)

$$k \cot(\delta) = -1/a + (1/2) rk^2$$

Bethe (1949)

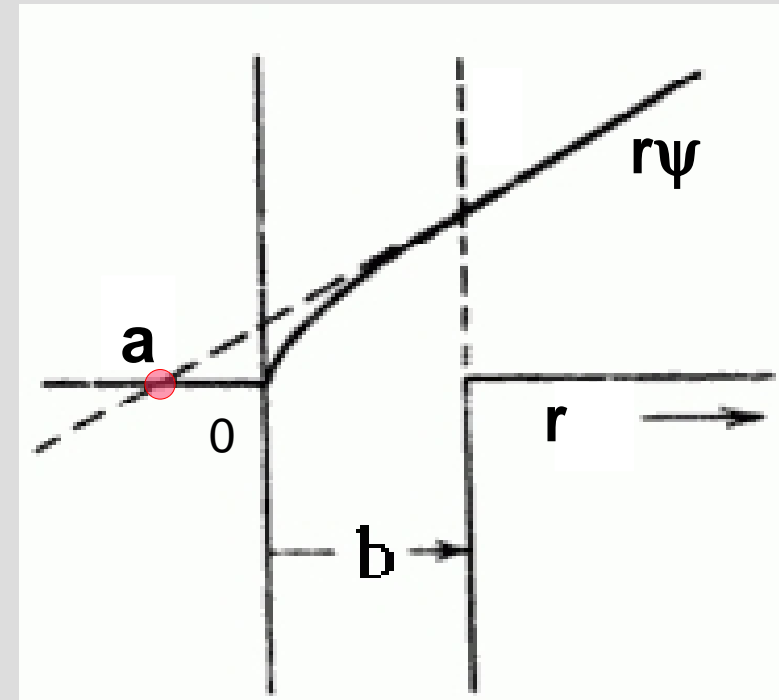
**a** : scattering length,

**r** : effective range,

**$\delta$**  : phase shift,

**b** : intrinsic range,

**k** :  $E_{\Lambda\Lambda} = (\hbar k)^2 / 2\mu$ ,  
 $\mu = m_{\Lambda}^2 / (m_{\Lambda} + m_{\Lambda})$ .



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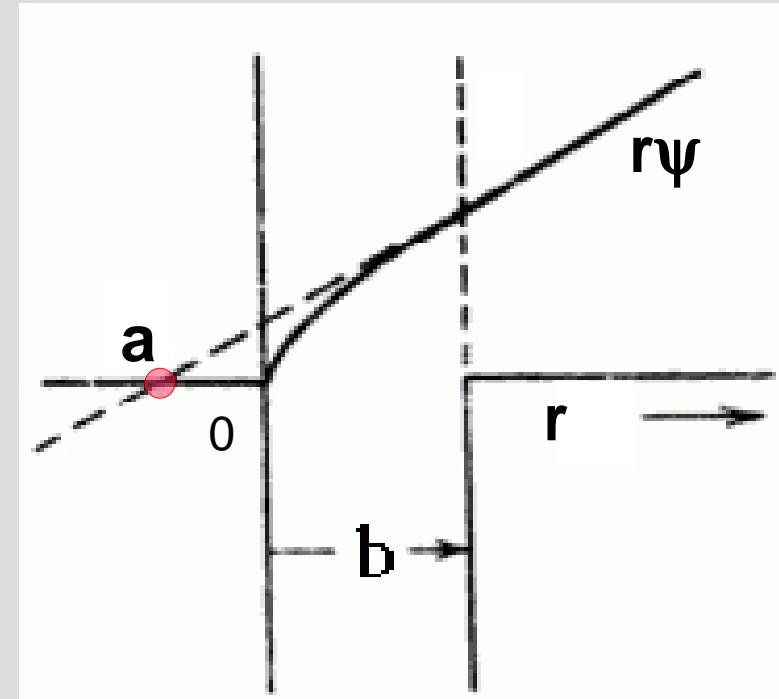
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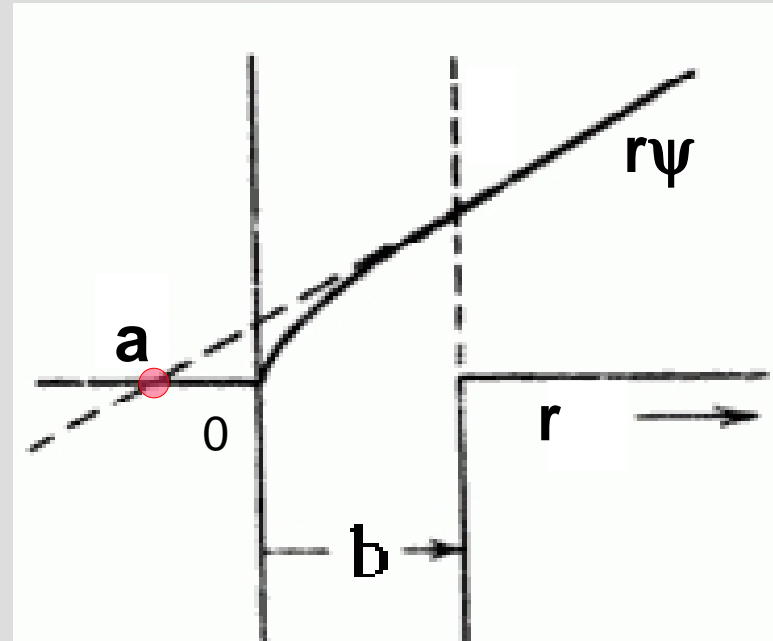
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**$a < 0$ ;**

**Weakly attractive; but  
there is no bound state.**

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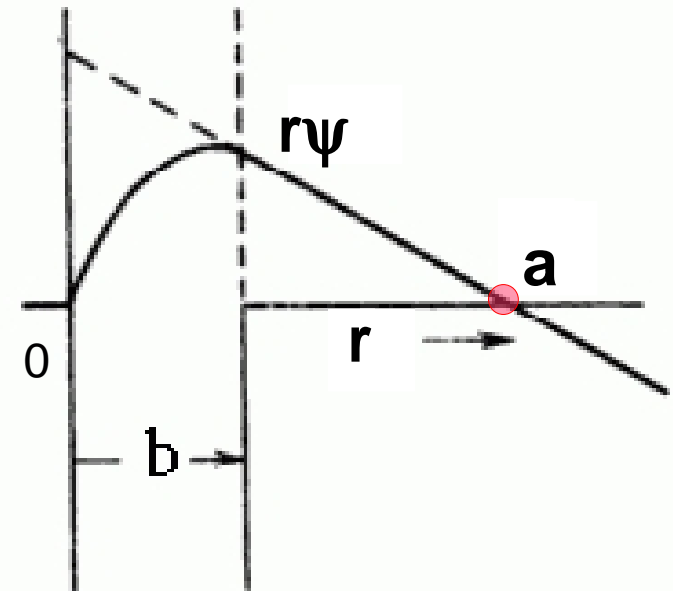
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**a > 0;**  
**repulsive, or a bound state (with strongly attractive potential)**

# How to extract **a** and **r** ?

$$\chi^2 = \sum_i^N (\mathbf{C}_{\text{adj}} \chi F_i(\mathbf{a}, \mathbf{r}; \mathbf{k}) + \text{B.G.}_i - \text{Data}_i)^2 / \sigma_i^2$$

**C<sub>adj</sub>** : Adjusting parameter between M.C. & real data,

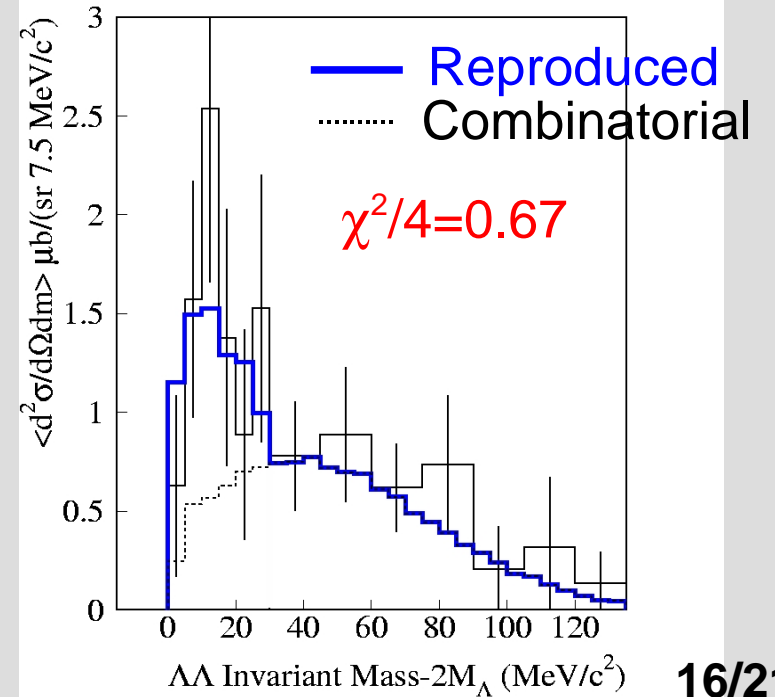
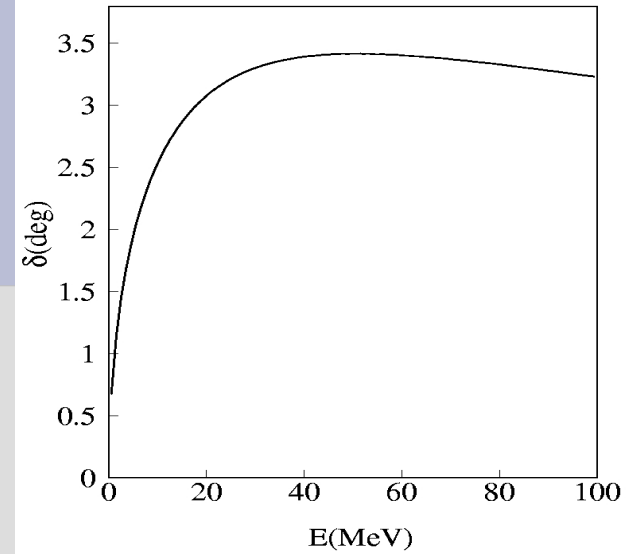
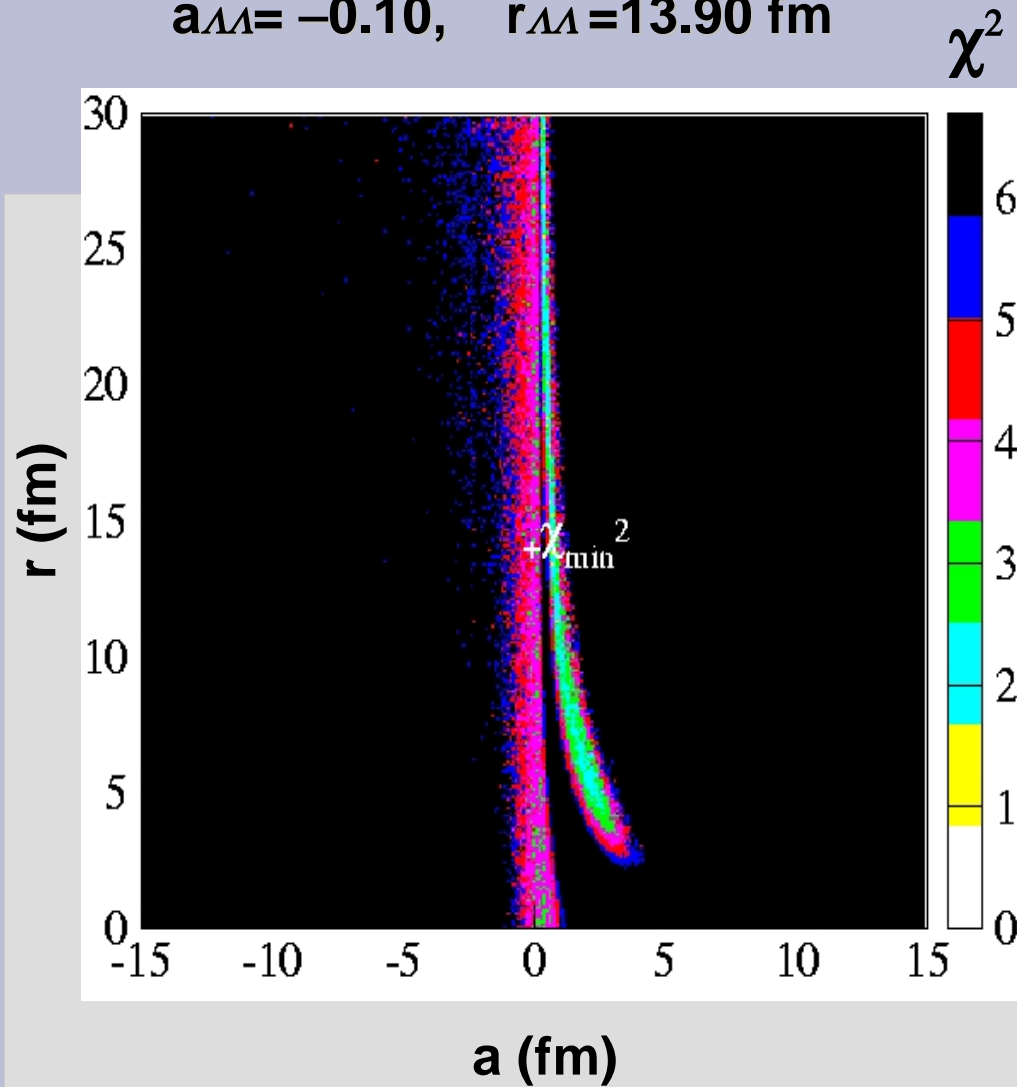
**F(a,r;k)** : Enhancement factor,  $|\sin(kb+\delta)/k|^2$ ,

**B.G** : Background taken from combinatorial b.g.,

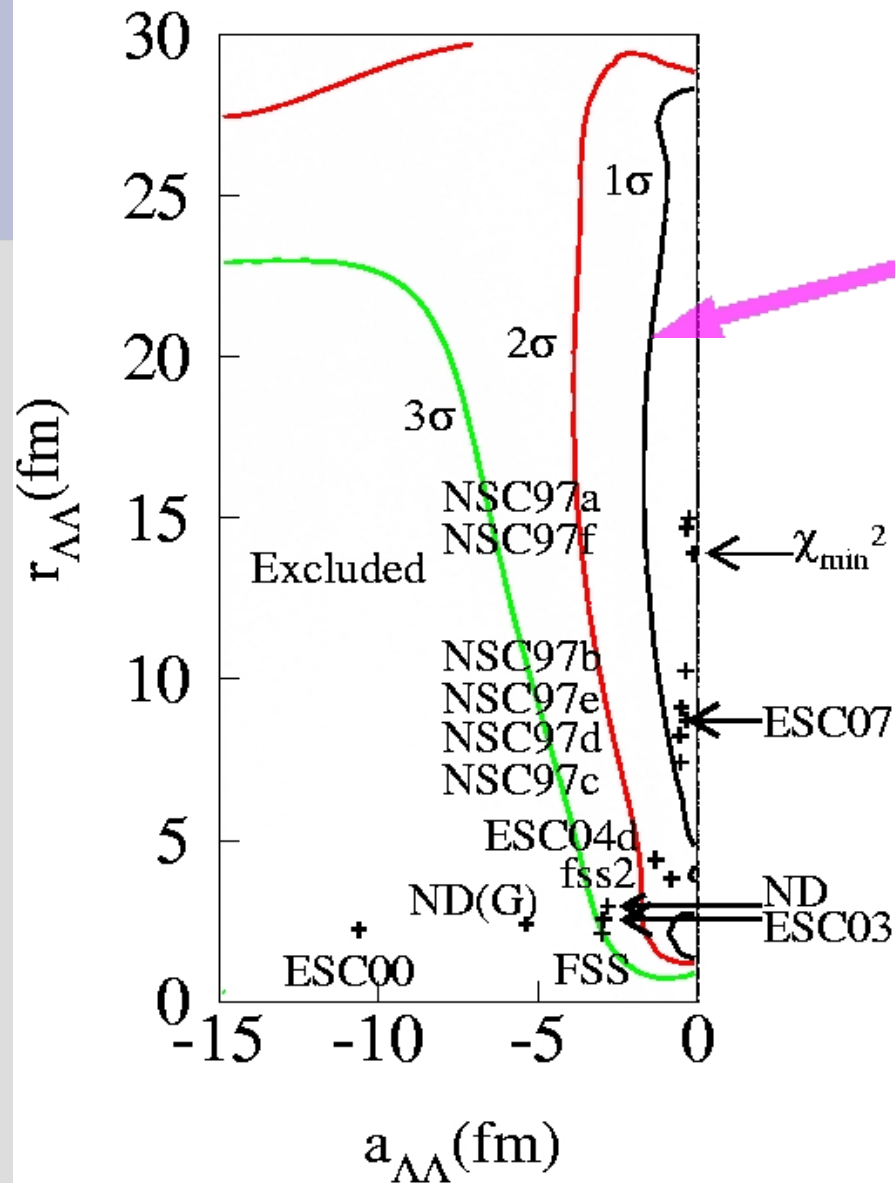
**Data** :  $\Lambda\Lambda$  invariant masses,

**$\sigma_i$**  : Uncertainty at i-th bin.

$a_{\Lambda\Lambda} = -0.10, \quad r_{\Lambda\Lambda} = 13.90 \text{ fm}$





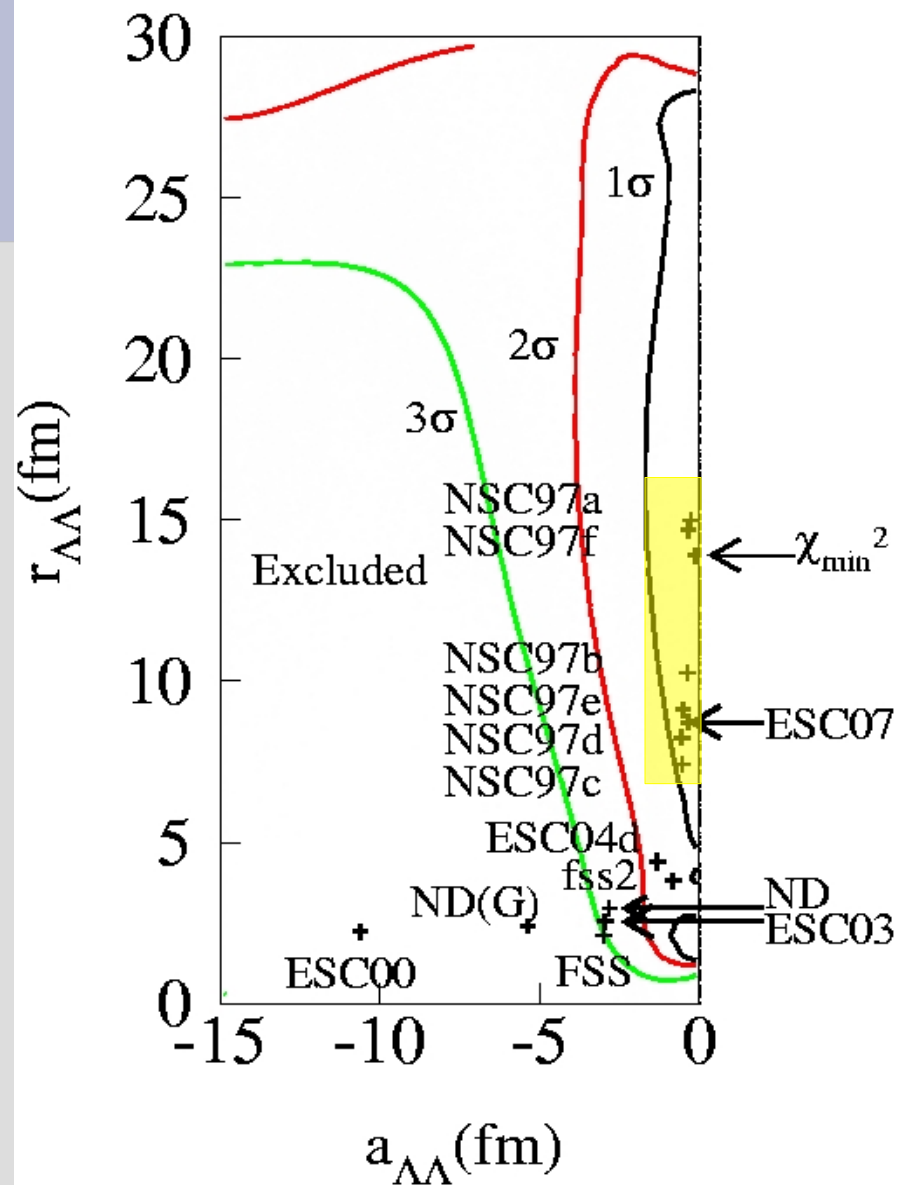


- $a_{\Lambda\Lambda} = -0.10^{+0.37}_{-1.56} \pm 0.28,$   
 $r_{\Lambda\Lambda} = 13.90^{+14.35}_{-9.13} \pm 10.53 \text{ fm.}$

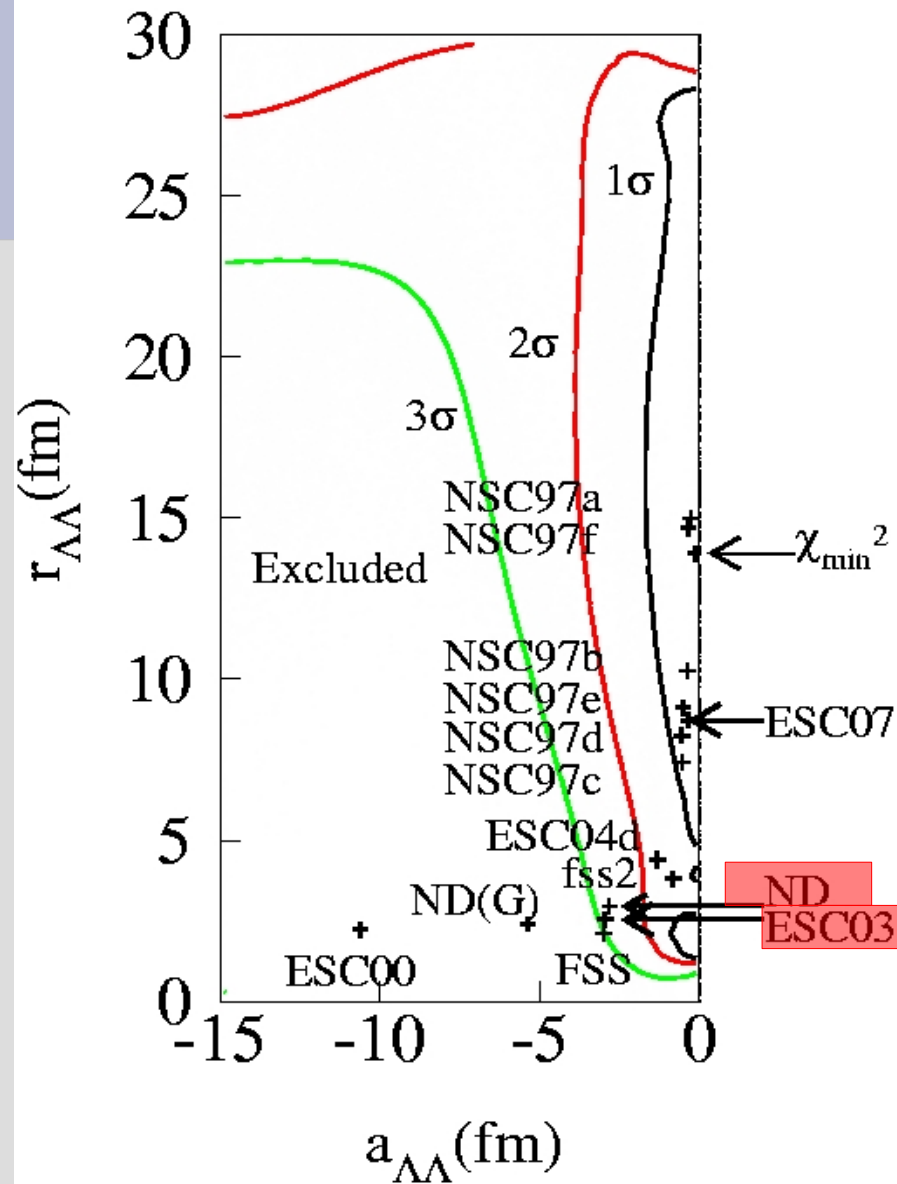
Systematic uncertainties were determined by considering

- change of  $b$ ; 2 – 2.5 fm, and bin size in  $a$ - $r$  plane ; 0.04, 9.48 fm.
- uncertainty arise from smoothing procedure of contour plot, ; 0.28 fm.
- uncertainty arise from different analysis methods, ; 0.1, 4.6 fm.

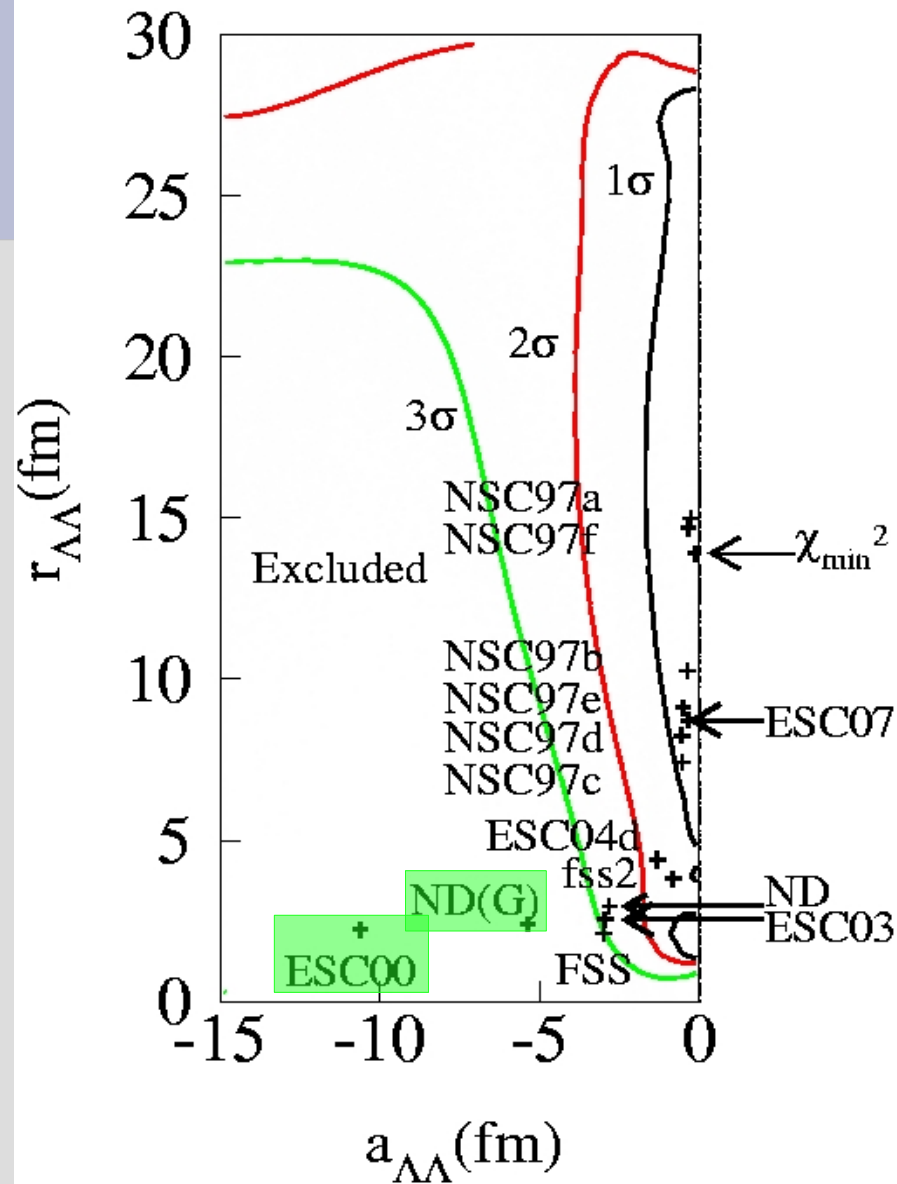
$$k \cot \delta = -\frac{1}{a_{\Lambda\Lambda}} + \frac{1}{2} r_{\Lambda\Lambda} k^2 - P r_{\Lambda\Lambda}^3 k^4,$$



Model	$a_{\Lambda\Lambda}$ (fm)	$r_{\Lambda\Lambda}$ (fm)
Nijmegen hard-core		
ND	$-2.81^{\dagger\dagger}$	2.95
ND(G-matrix)	$-5.37^{\dagger\dagger\dagger}$	2.40
Nijmegen soft-core		
NSC97a	-0.27	15.00
NSC97b	-0.38	10.24
NSC97c	-0.53	7.43
NSC97d	-0.53	8.24
NSC97e	-0.50	9.11
NSC97f	-0.35	14.68
Nijmegen extended soft-core		
ESC00	$-10.60^{\dagger\dagger\dagger}$	2.23
ESC03	$-2.94^{\dagger\dagger}$	2.53
ESC04a	$-1.15^{\dagger}$	4.48
ESC04b	$-1.25^{\dagger}$	4.45
ESC04c	$-1.08^{\dagger}$	4.46
ESC04d	$-1.32^{\dagger}$	4.40
ESC07	$-0.34$	8.73
Kyoto-Niigata		
FSS	$-3.01^{\dagger\dagger\dagger}$	2.14
fss2	$-0.81^{\dagger}$	3.80



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# Summary and conclusion

- We have determined  $\Lambda\Lambda$  scattering parameters in  $^{12}\text{C}(\text{K}^-, \text{K}^+\Lambda\Lambda)$  reaction by using scintillating fiber active target.
- The obtained value,  $a_{\Lambda\Lambda} = -0.10_{-1.56}^{+0.37} \pm 0.28$  fm,  $r_{\Lambda\Lambda} = 13.9_{-9.13}^{+14.35} \pm 10.53$  fm, is most consistent with the values predicted by using the Nijmegen soft core models, NSC97's, and the extended soft core model, ESC07.
- However, the Nijmegen hard core model ND (G-matrix), the extended soft core model ESC00 predictions are out of three standard deviations from the determined scattering parameters.