Prof. Arima as a RIKEN President (1993-1998)

http://www.riken.jp/~/media/riken/pr/publications/riken88/riken88-photo.pdf

RIKEN RAL Office (1995.4 -)

RIKEN-BNL Spin Physics Collaboration (1995.9 -)

Prof. Akito Arima
7th President of RIKEN
(1993.10—1998.5)

SPring-8 started (1997.3 -)

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RIKEN RAL

Prof. Arima Congratulations for 88th Birthday !

Prof. Akito Arima
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RIKEN-BNL Research Center
(1997.10 -)

RIKEN Brain Science Center (1997.10 -)

55 years ago (1963)
M. Goeppert Mayer's Nobel Lecture
"The Shell Model"

There are essentially two ways in which physicists at present seek to obtain a consistent picture of atomic nucleus. The first, the basic approach, is to study the elementary particles, their properties and mutual interaction. Thus one hopes to obtain a knowledge of the nuclear forces.

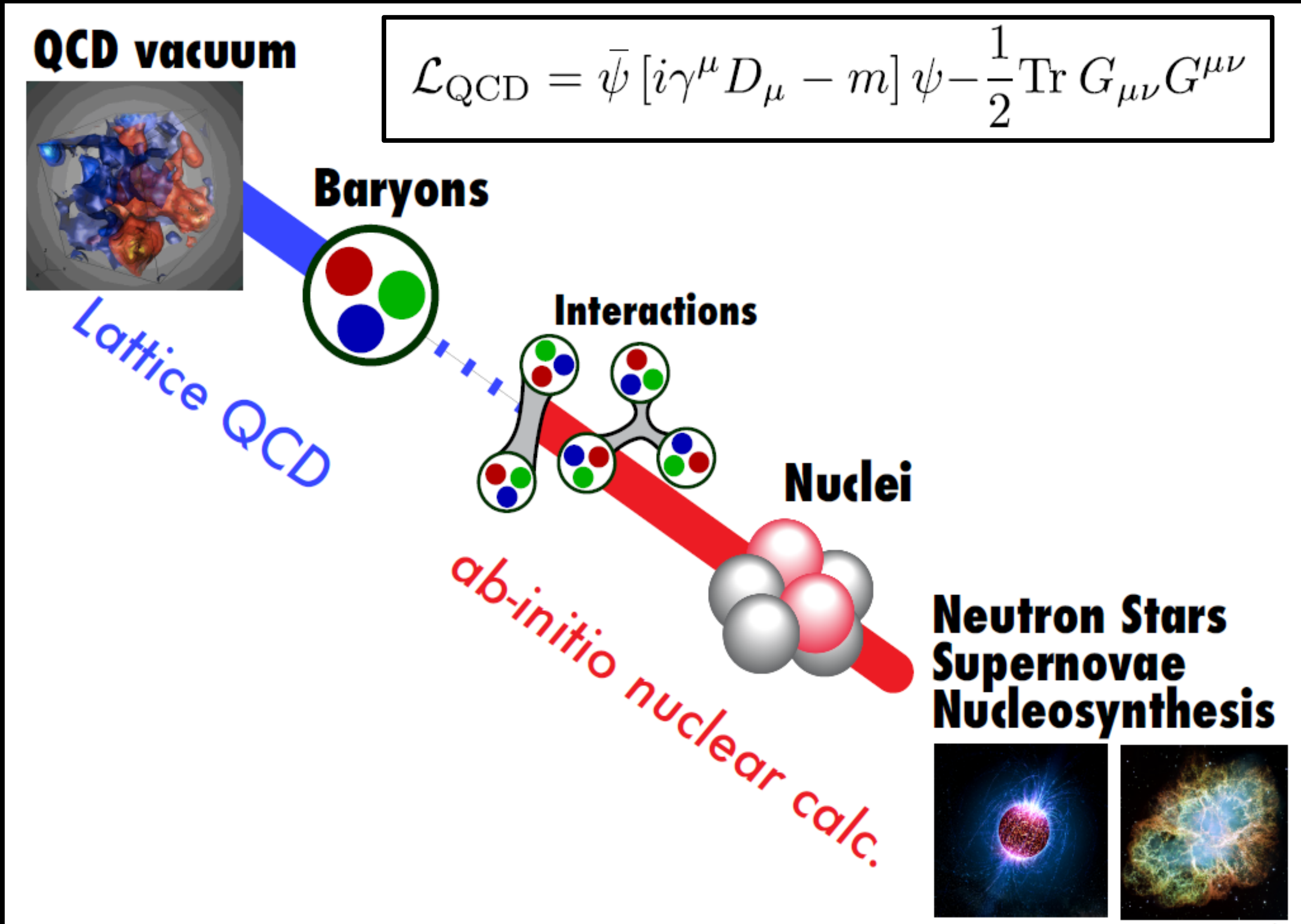
If the forces are known, one should in principle be able to calculate deductively the properties of individual complex nuclei. Only after this has been accomplished can one say that one completely understands nuclear structures.

Considerable progress in this direction has been made in the last few years. The work by Brueckner[1], Bethe[2] and others has developed ways of handling the many-body problem. But our knowledge of the nuclear forces is still far from complete.

The other approach is that of the experimentalist and consists in obtaining by direct experimentation as many data as possible for individual nuclei. One hopes in this way to find regularities and correlations which give a clue to the structure of the nucleus. There are many nuclear models, but I shall speak only of one and leave the others to the next lecture by Professor Jensen.

Baryon-baryon Interactions from Lattice QCD

Tetsuo Hatsuda (iTHEMS, RIKEN)



Baryon-baryon Interactions from Lattice QCD

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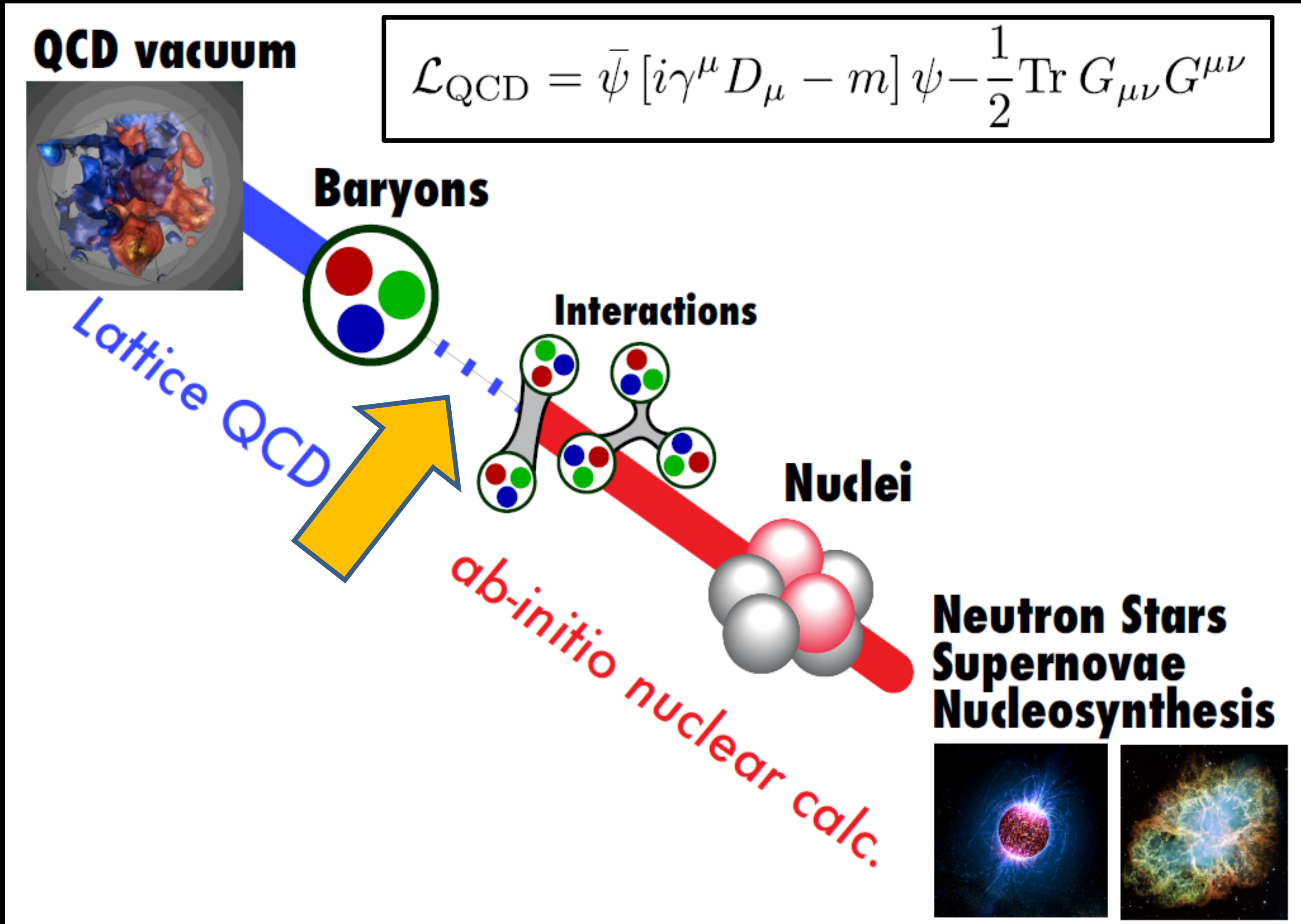


Quantum Chromodynamics (QCD)

$$\mathcal{L} = -\frac{1}{4} G^a_{\mu\nu} G_a^{\mu\nu} + \bar{q}\gamma^\mu (i\partial_\mu - g t^a A^a_\mu) q - m\bar{q}q$$

$$G^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g f_{abc} A^b_\mu A^c_\nu$$

Quantum Chromodynamics (QCD)

$$\mathcal{L} = -\frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a + \bar{q}\gamma^\mu (i\partial_\mu - g t^a A^a_\mu) q - m\bar{q}q$$

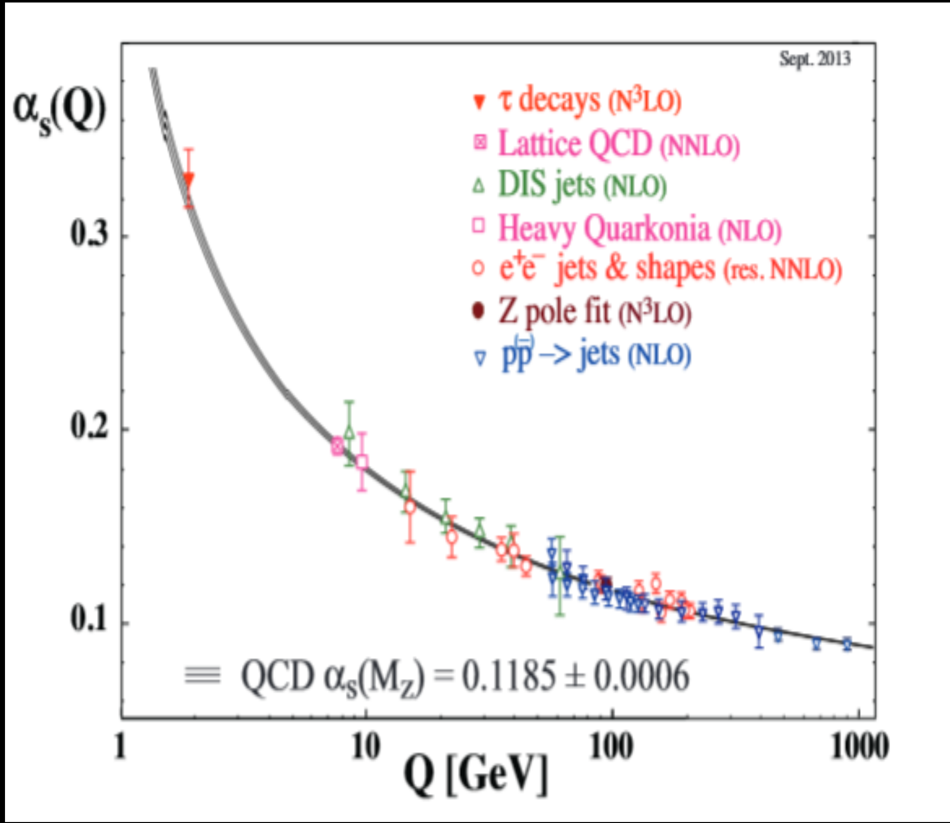
$$G^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g f_{abc} A^b_\mu A^c_\nu$$

Quark masses: m_q

quark masses (from lattice QCD)	**[MeV]** (MS-bar @ 2GeV)
m_u	2.16 (9)(7)
m_d	4.68 (14)(7)
m_s	93.8 (1.5)(1.9)

FLAG Coll.(2015)

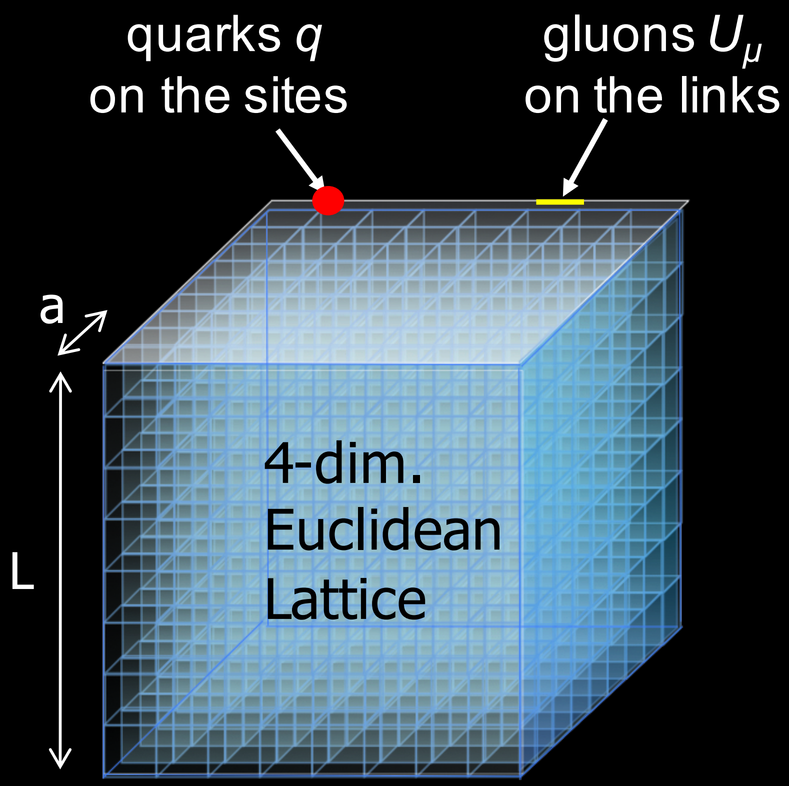
Gauge coupling: $\alpha_s = g^2/4\pi$



PDG (2014)

Lattice QCD (LQCD)

$$Z = \int [dU][dq d\bar{q}] \ \exp\left[- \int d\tau d^3 x \mathcal{L}_{\mathrm{E}} \right]$$

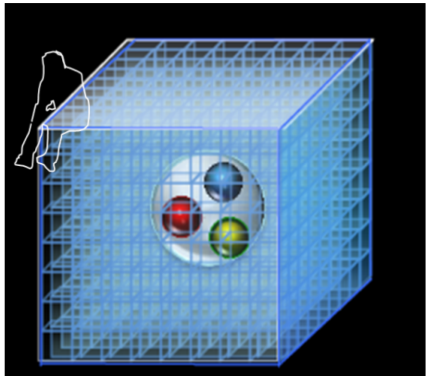


Huge integration variables
~ $10^{9\text{-}10}$ for 96^4 lattice

Importance Sampling
Hybrid MC = MD + Metropolis

Continuum & Thermodynamic Limits
($a \to 0$ & $L \to \infty$)

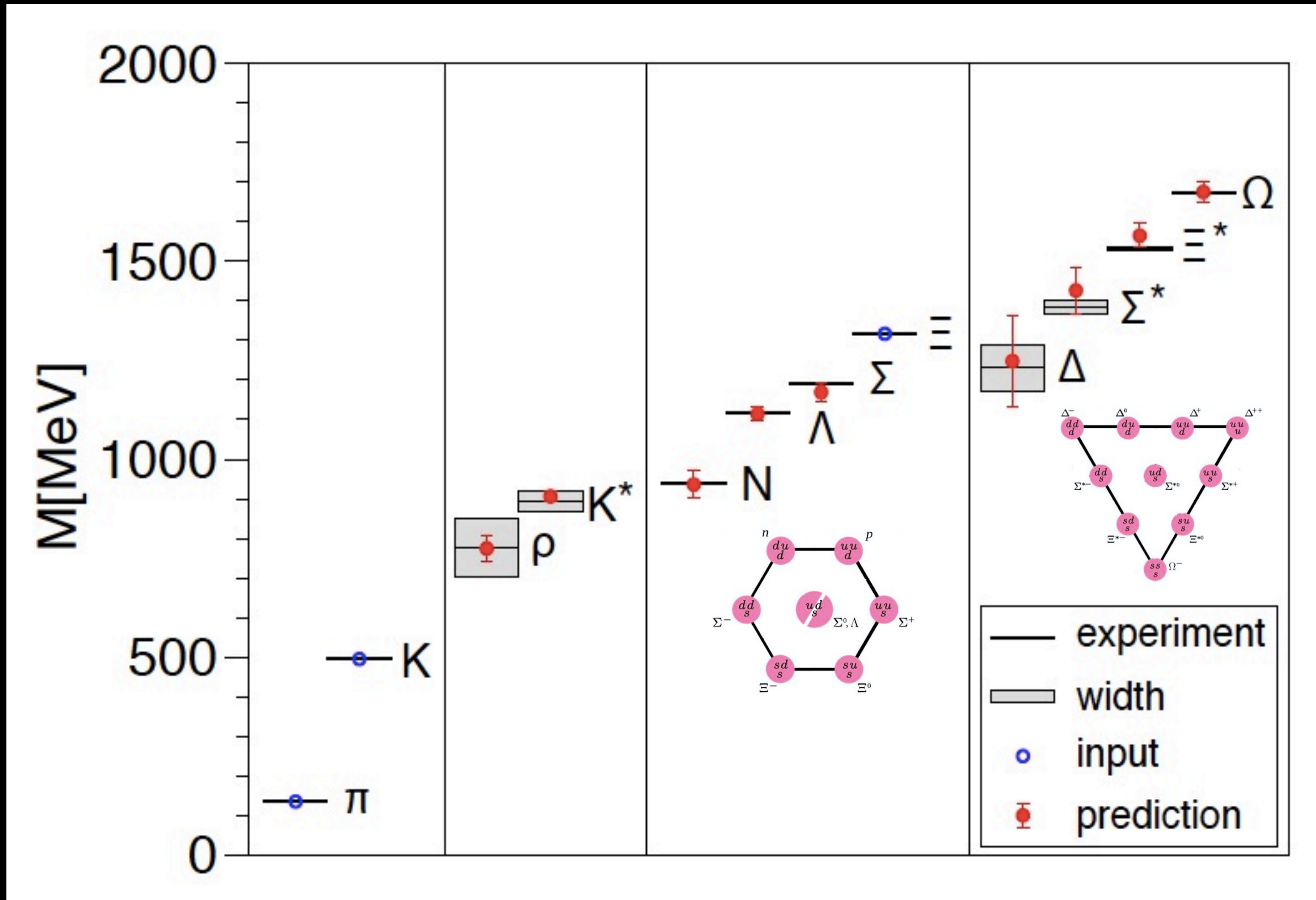
Hadron masses from LQCD



a_{min} = 0.065 fm

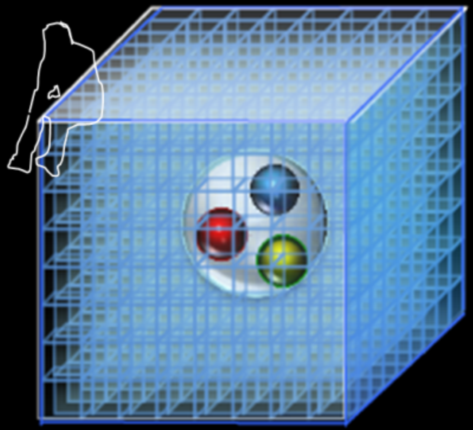
L_{max} = 4.1 fm

$m_{\pi,min}$ =190 MeV



taken from Fodor and Hoelbling, Rev. Mod. Phys. 84 (2012) 449

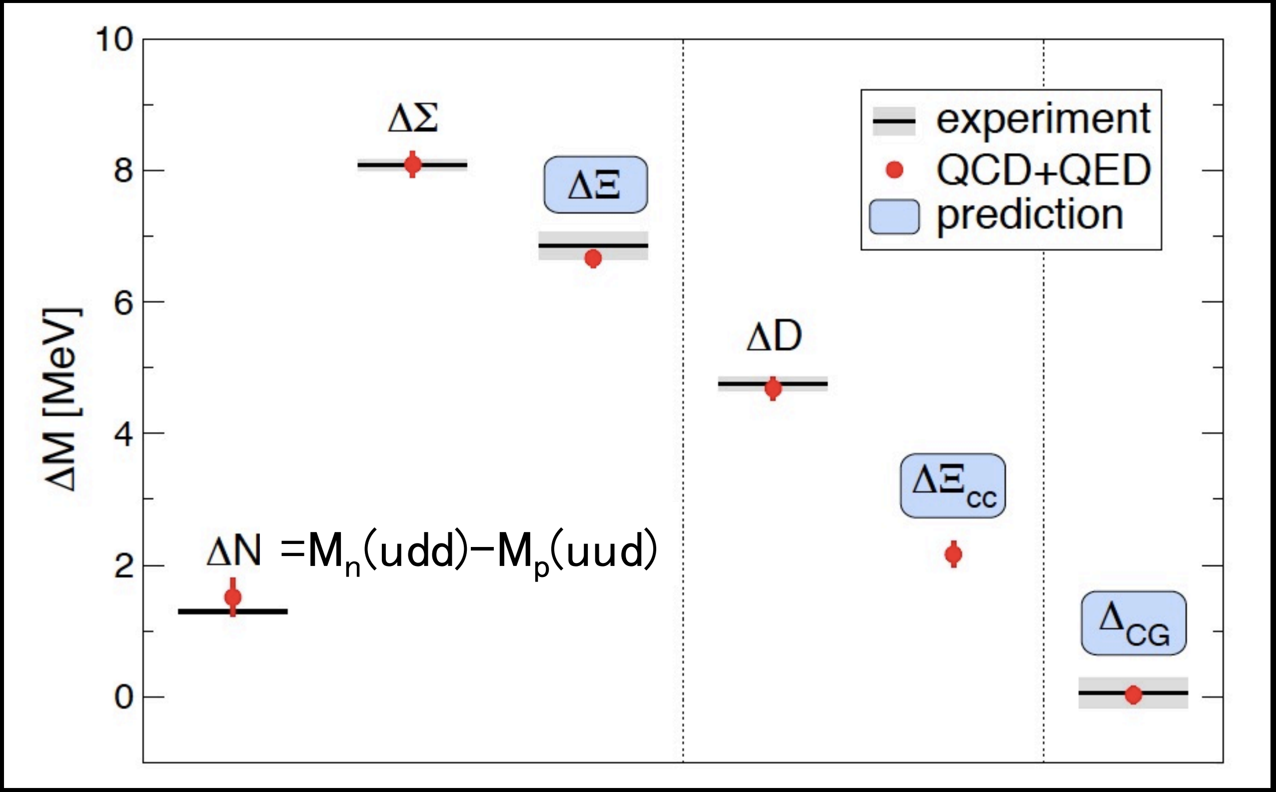
proton-neutron mass difference from LQCD



a_{min} = 0.054 fm

L_{max} = 8 fm

$m_{\pi,min}$ =190 MeV

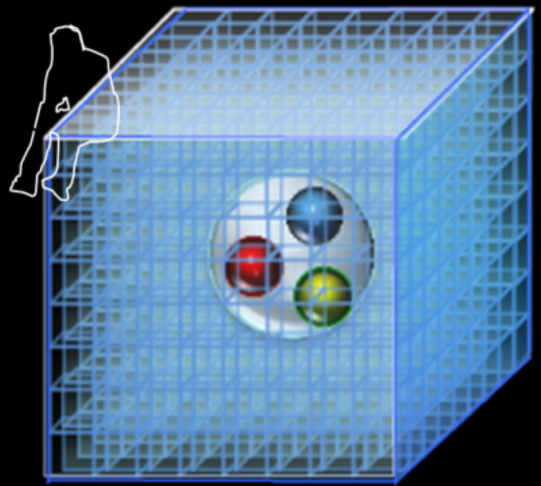


$(M_n - M_p)_{lat}$ = 1.51(16)(23) MeV

$(M_n - M_p)_{exp}$ = 1.29 MeV

BMW Coll., Science 347 (2015) 1452

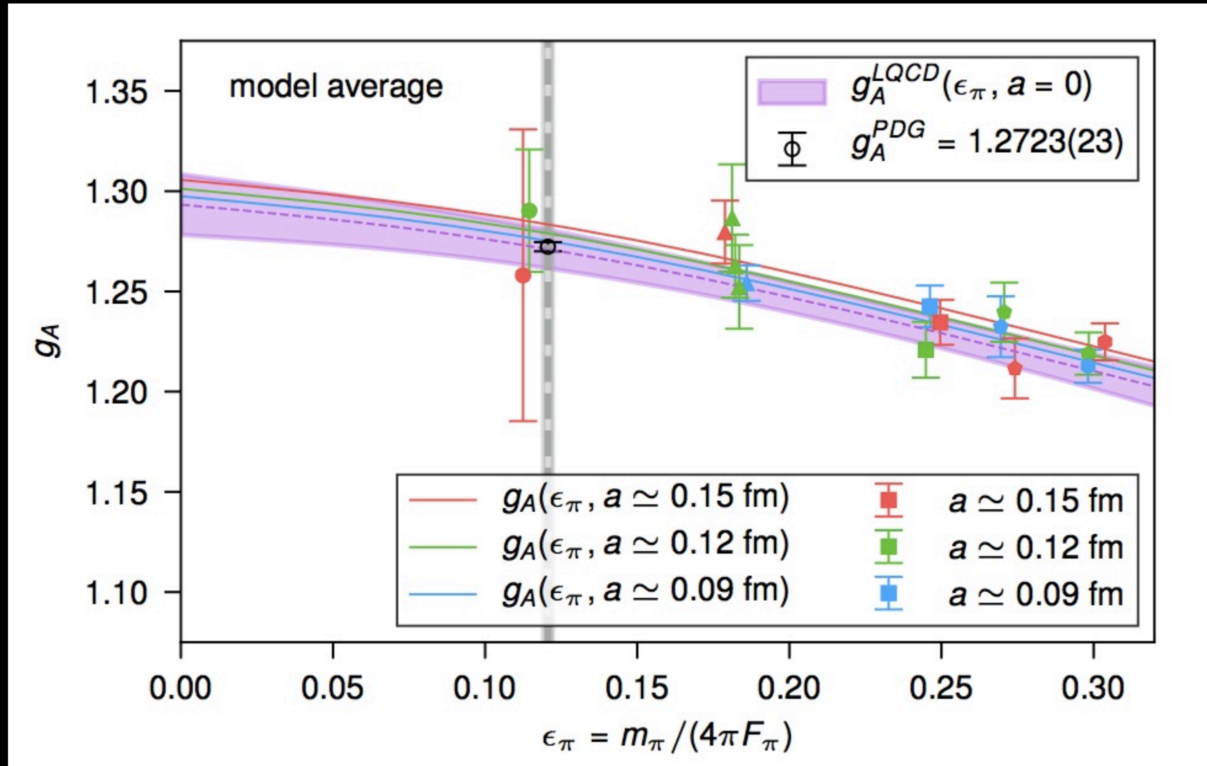
Nucleon axial charge g_A from LQCD



$a_{min} = 0.09$ fm

$L_{max} = 4.8$ fm

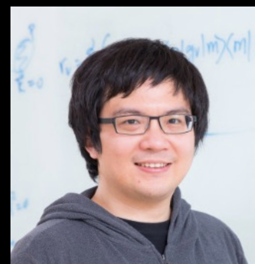
$m_{\pi,min} = 131$ MeV



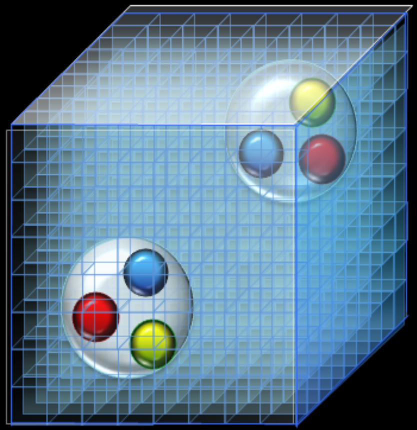
$(g_A)_{lat} = 1.2711(13)$

$(g_A)_{exp} = 1.2723(23)$

Chang et al., Nature 558 (2018) 91



Baryon-baryon Interactions from LQCD



a = 0.085 fm

L = 8.1 fm

m_π = 146 MeV

M_K = 525 MeV

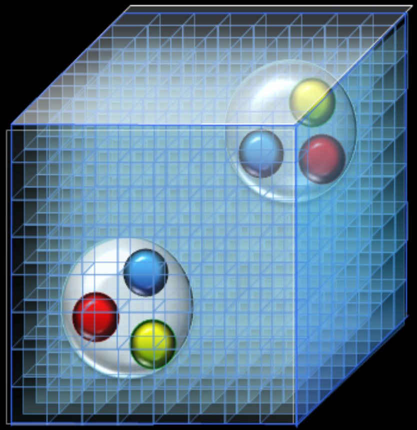
K computer at RIKEN (11 PFlops)

HAL (Hadrons to Atomic nuclei from Lattice) QCD Collaboration

S. Aoki (*YITP*)	**T. Doi** (*RIKEN*)	**F. Etminan** (*Birjand U.*)	**S. Gongyo** (*RIKEN*)	**T. Hatsuda** (*RIKEN*)
Y. Ikeda (*RCNP*)	**T. Inoue** (*Nihon U.*)	**N. Ishii** (*RCNP*)	**T. Iritani** (*RIKEN*)	**D. Kawai** (*YITP*)
T. Miyamoto (*YITP*)	**K. Murano** (*RCNP*)	**H. Nemura** (*RCNP*)	**T. Aoyama** (*YITP*)	**T.M. Doi** (*RIKEN*)

Hadrons to Atomic nuclei HAL from Lattice QCD

Baryon-baryon Interactions from LQCD



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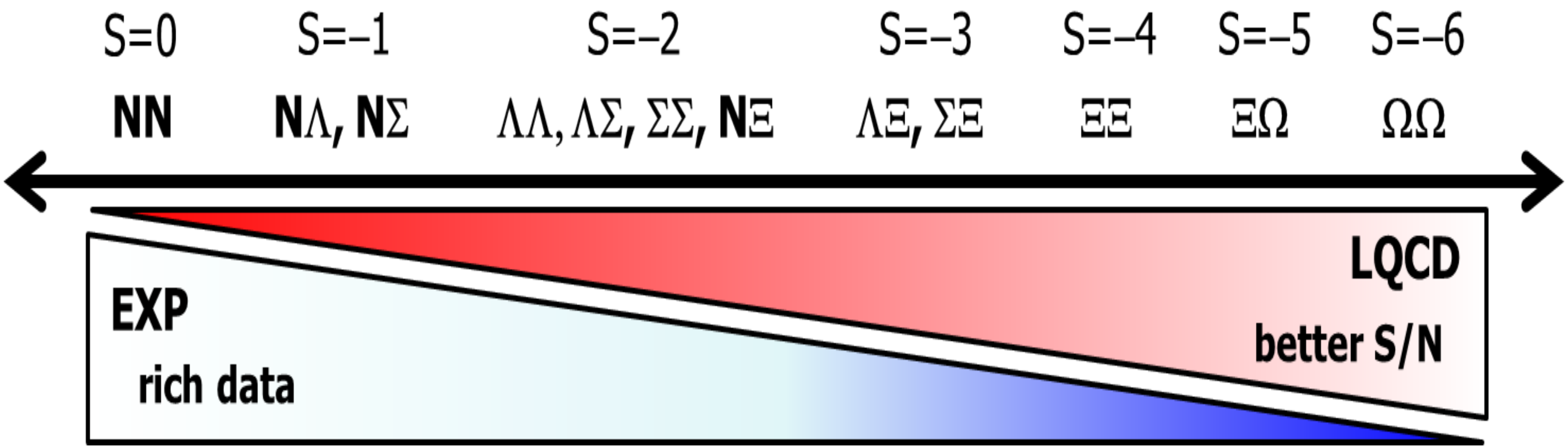
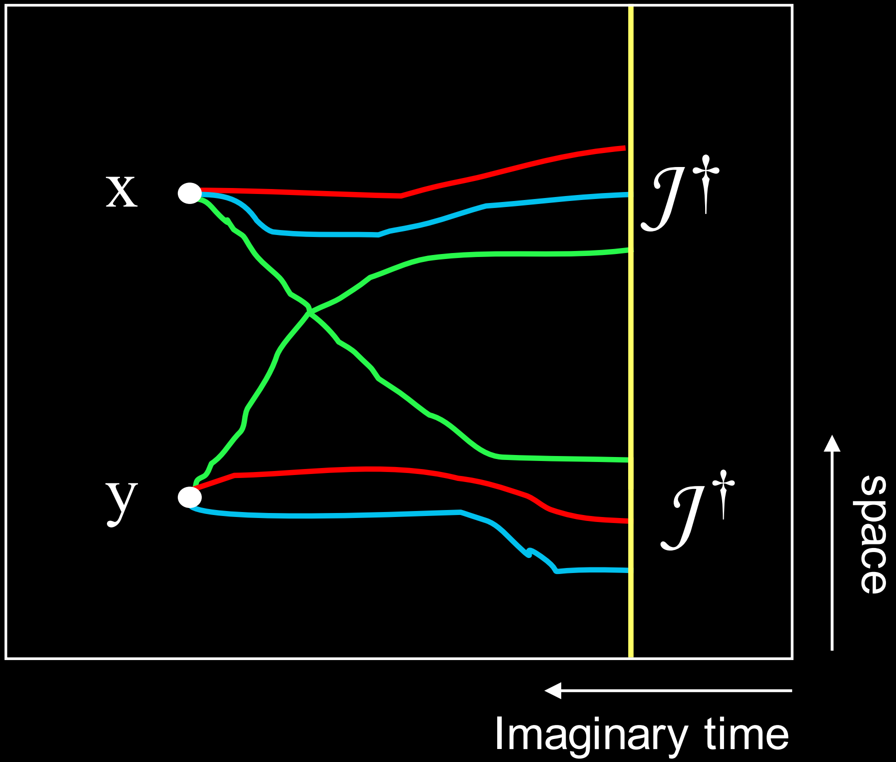


Scattering amplitude in LQCD



$$\langle N_1(\mathbf{x},t)N_2(\mathbf{y},t)\mathcal{J}_1^\dagger(0)\mathcal{J}_2^\dagger(0)\rangle$$
$$= \sum_n \langle 0|N_1(\mathbf{x})N_2(\mathbf{y})|n\rangle a_n e^{-E_n t}$$
$$\xrightarrow{t>t^*} \phi(\mathbf{r},t) = \sum_{n<n^*} b_n \phi_n(\mathbf{r}) e^{-E_n t}$$

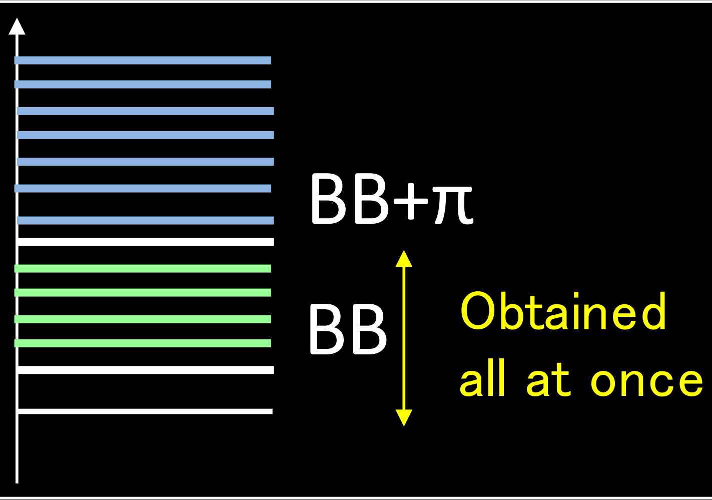
HAL QCD Method

ϕ(r,t) → 2PI kernel (T=U+GUT)

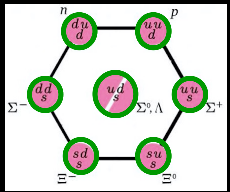
→ phase shift, binding energy

Ishii, Aoki & Hatsuda, PRL 99 (2007) 022001

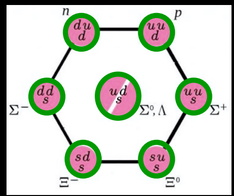
Ishii et al. [HAL QCD Coll.], PLB 712 (2012) 437



Flavor SU(3) Classification of BB system



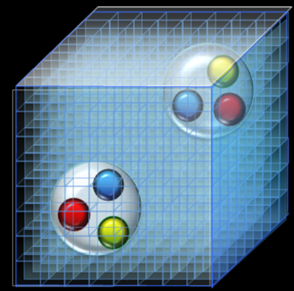
x



$$8 \text{ x } 8 = 27 + 8_s + 1 + 10^* + 10 + 8_a$$

D_{pn} (J=1)

Nuclear Force: $V_C(r)$ and $V_T(r)$



a = 0.085 fm

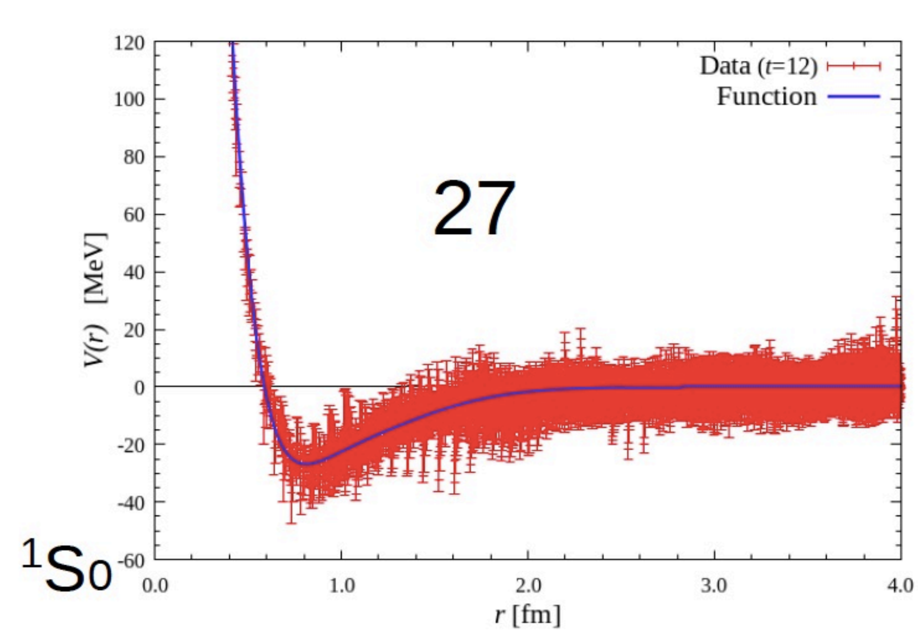
L = 8.1 fm

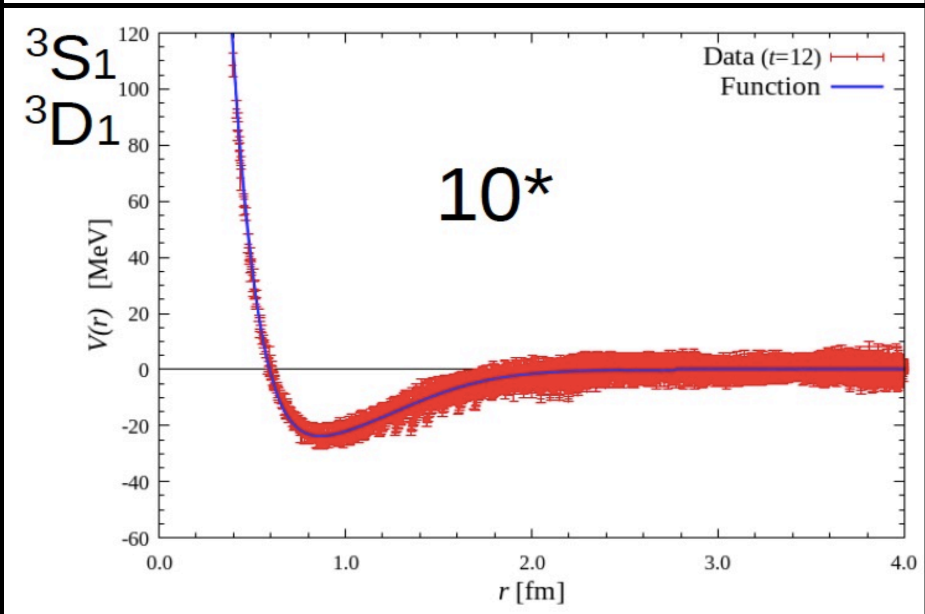
m_π = 146 MeV

M_K = 525 MeV

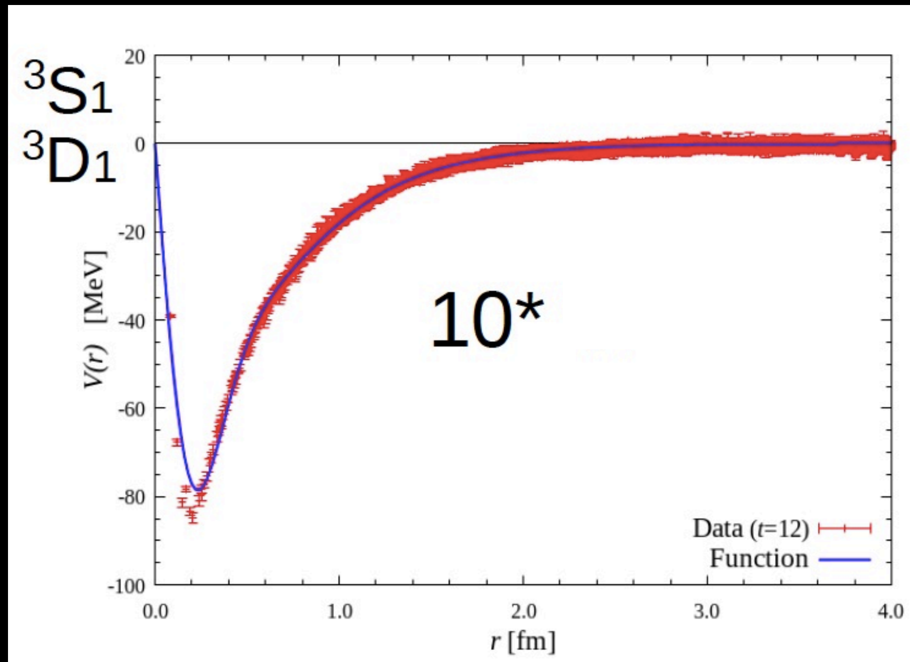
T. Inoue et al.
[HAL QCD Coll.]

Central force



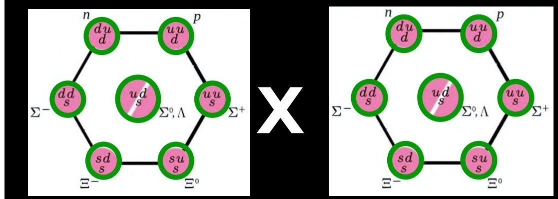


Tensor force



Flavor SU(3) Classification of BB system

c.f. Dyson & Xoung,
PRL 14 (1965)



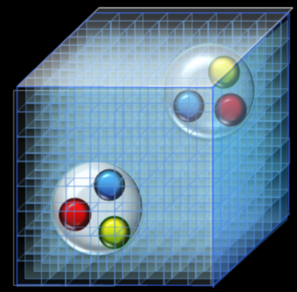
$$8 \times 8 = 27 + 8_s + 1 + 10^* + 10 + 8_a$$

$H_{\Lambda\Lambda-N\Xi-\Lambda\Sigma}$ (J=0) → 1

Jaffe (1977)

D_{pn} (J=1) → 10^*

S=-2 BB interactions : $V_C(r)$



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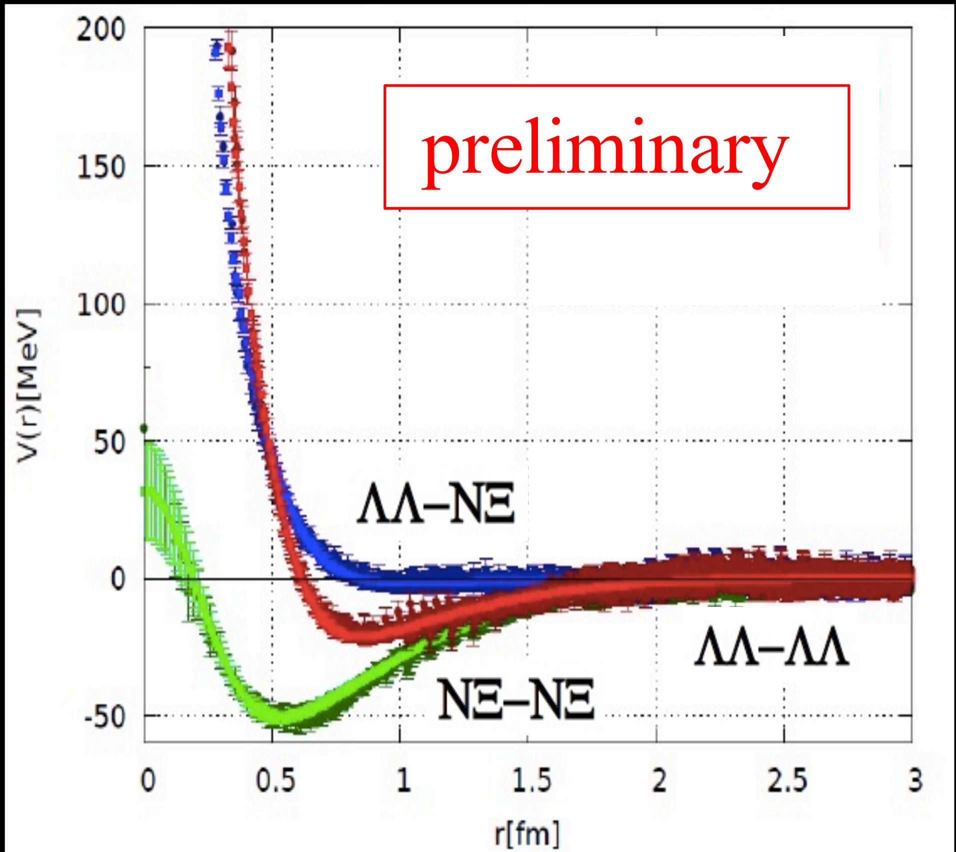
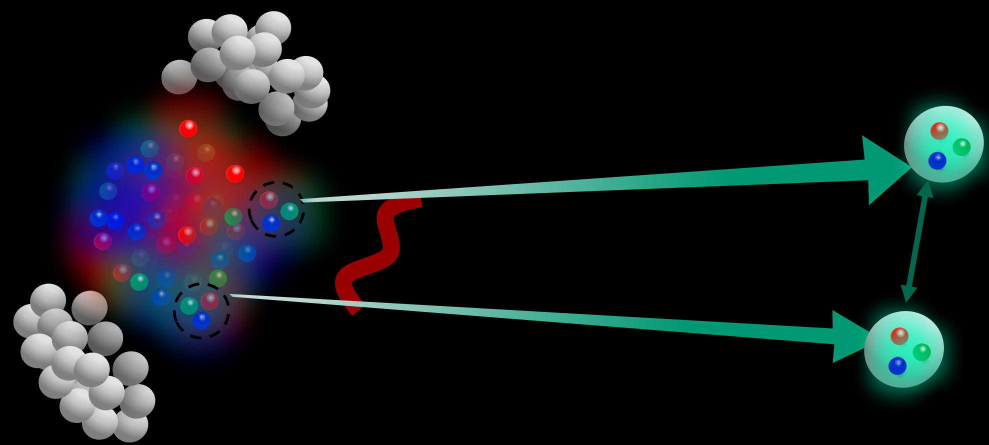
$L = 8.1$ fm
$m_\pi = 146$ MeV
$M_K = 525$ MeV

K. Sasaki et al. [HAL QCD Coll.]



ALICE Coll., arXiv:1805.12455



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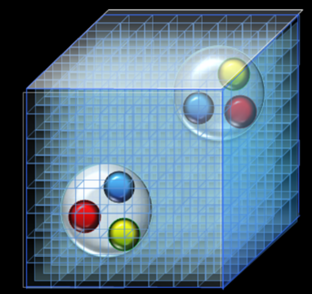

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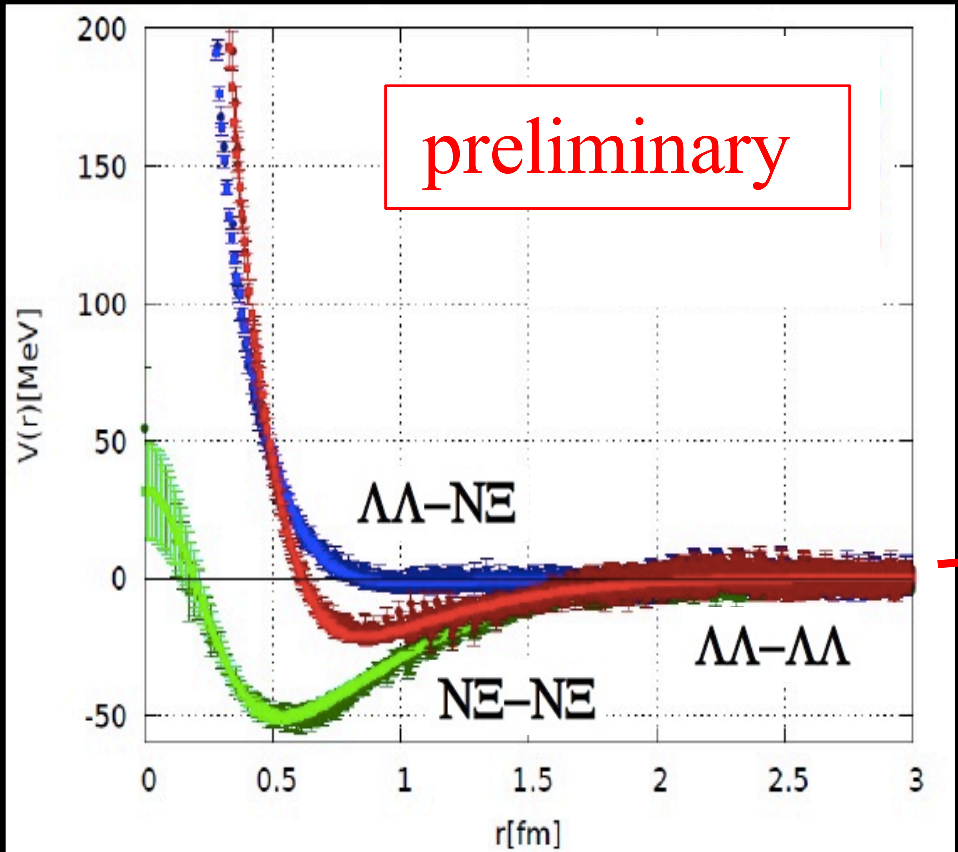
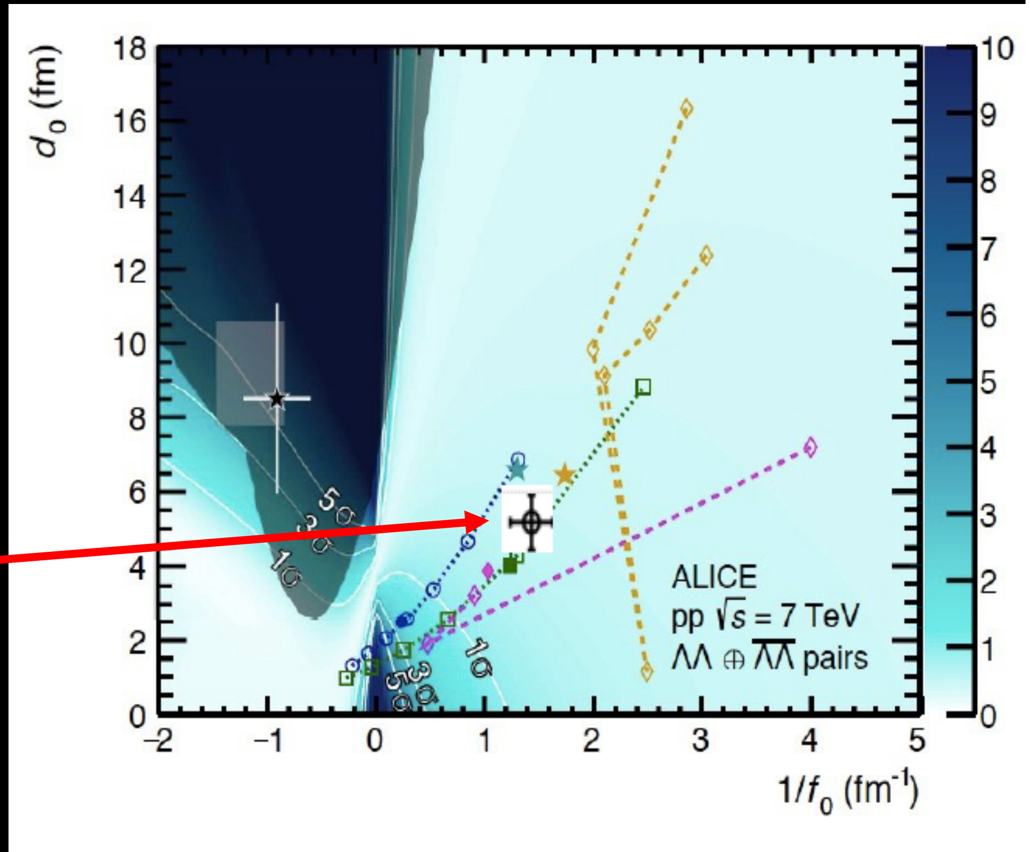


ALICE Coll., arXiv:1805.12455



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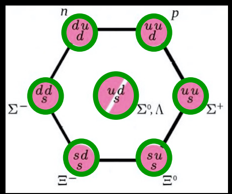
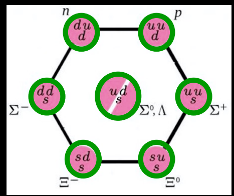
c.f. Dyson & Xoung, PRL 14 (1965)

 x 

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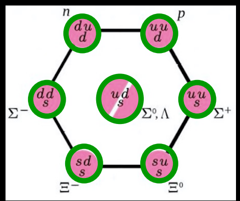
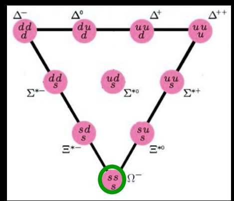
Jaffe (1977)

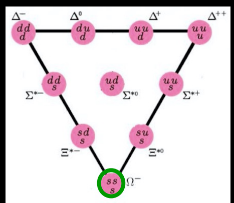
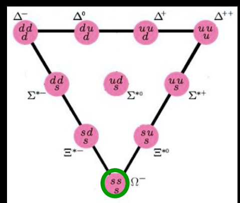
D_{pn} (J=1) → 10^*

 x 

$$8 \times 10 = 35 + 8 + 10 + 27$$

$N\Omega$ (J=2) → 8

Goldman et al (1987)

 x 

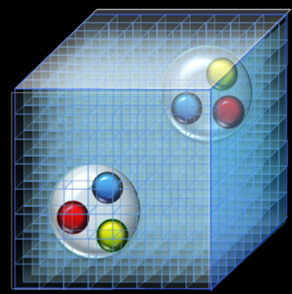
$$10 \times 10 = 28 + 27 + 35 + 10^*$$

$\Omega\Omega$(J=0) → 28

Zhang et al (1997)

S=-6 BB interaction $V_C(r)$

Gongyo et al. [HAL QCD Coll.],
Phys. Rev. Lett. 120 (2018) 212001

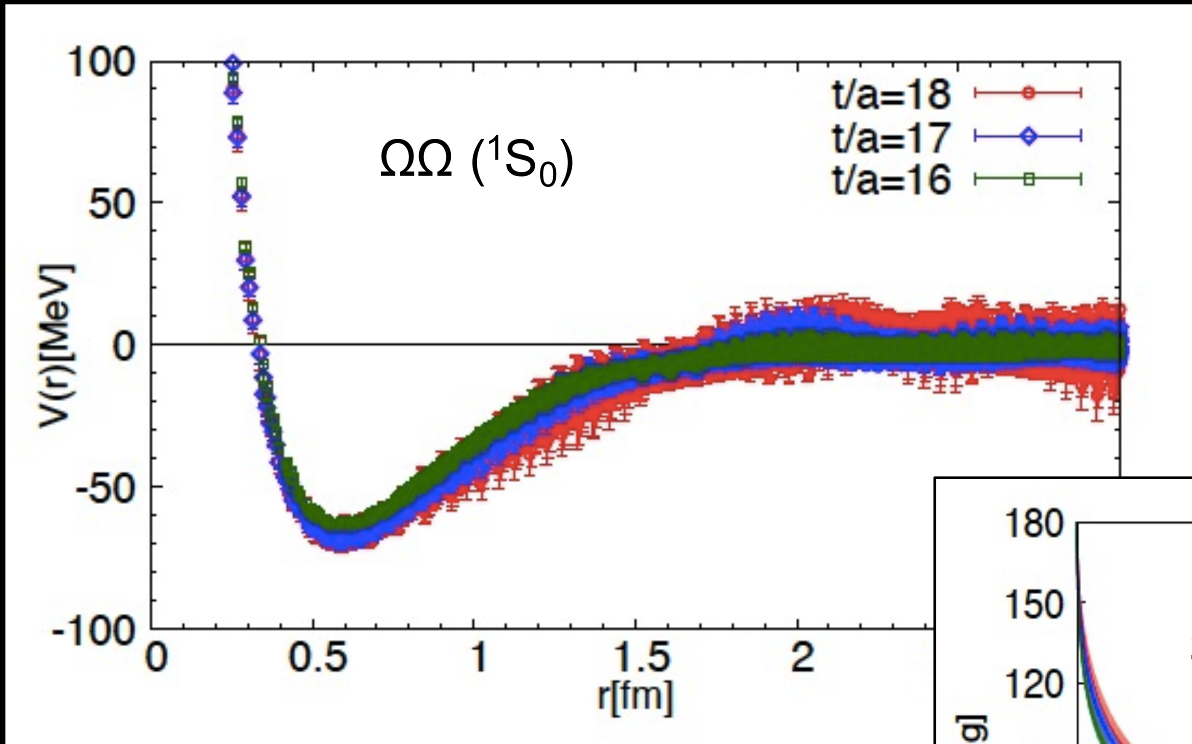


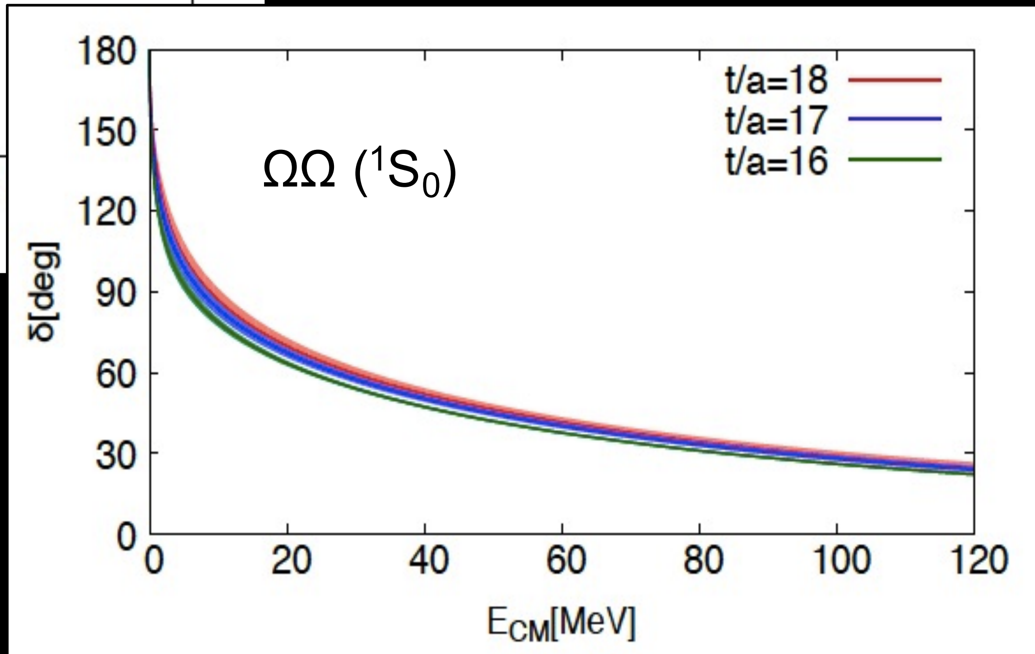
a = 0.085 fm

L = 8.1 fm

m_π = 146 MeV

M_K = 525 MeV

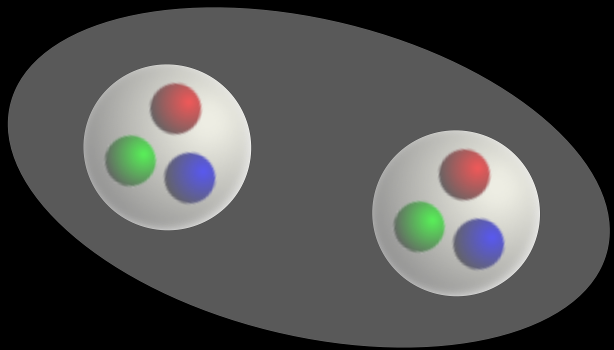




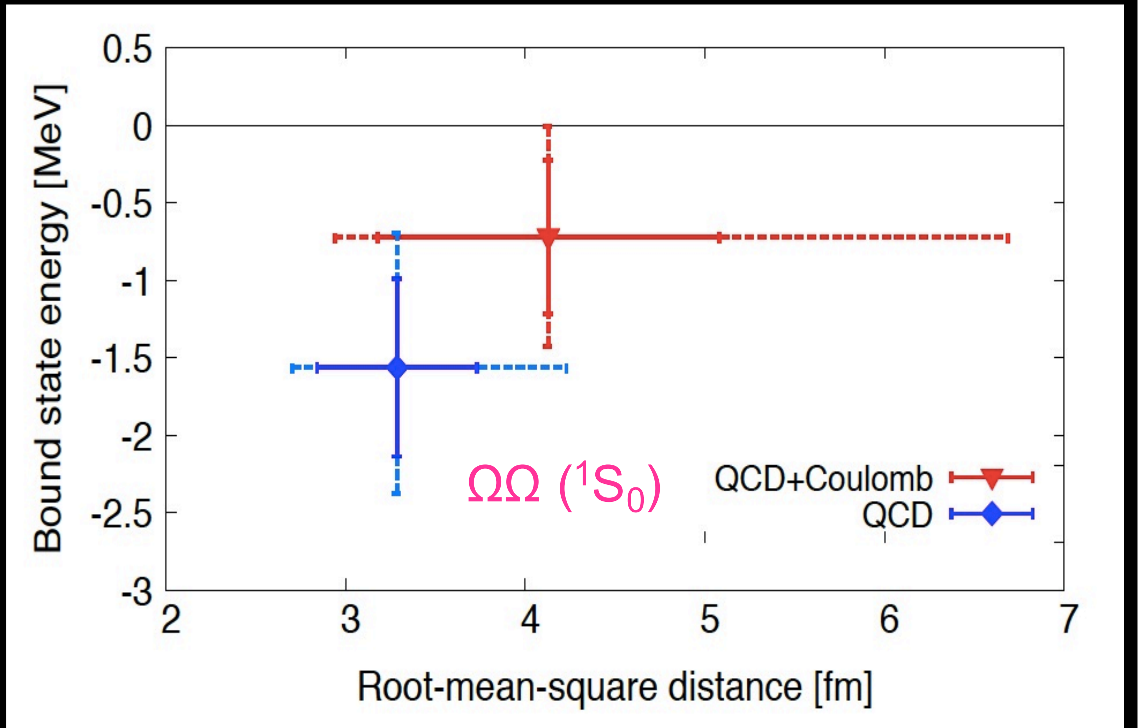
New “stable” dibaryon?

$$a_0^{(\Omega\Omega)} = 4.6(6)(^{+1.2}_{-0.5}) \quad \text{fm},$$
$$r_{\text{eff}}^{(\Omega\Omega)} = 1.27(3)(^{+0.06}_{-0.03}) \quad \text{fm}.$$

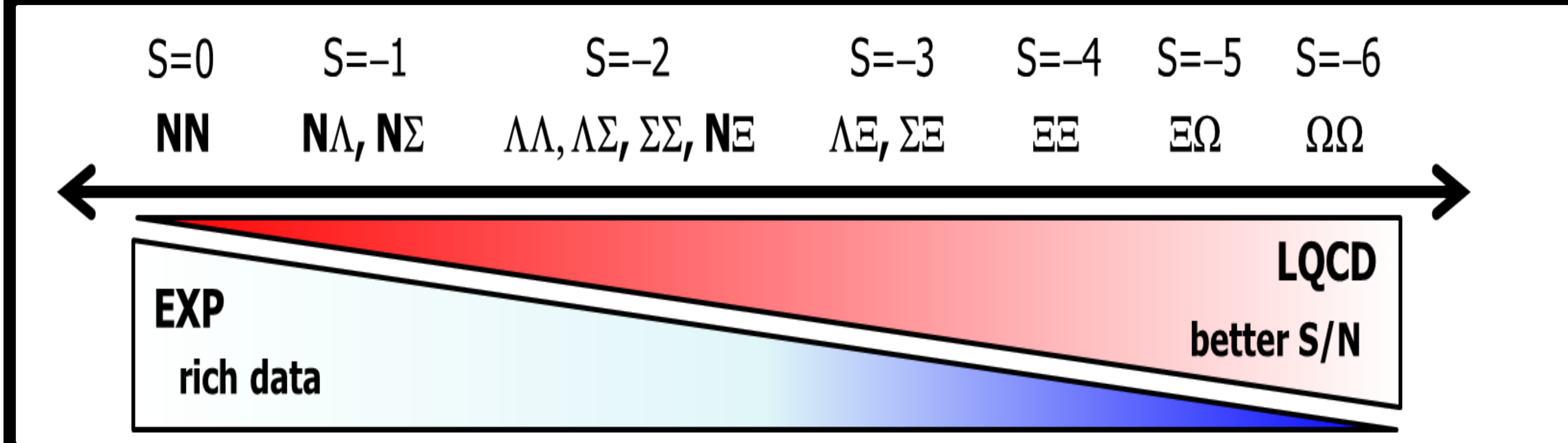
Gongyo et al. [HAL QCD Coll.],
Phys. Rev. Lett. 120 (2018) 212001



Deuteron (1931, Urey)
Di−Omega ΩΩ ?



Summary

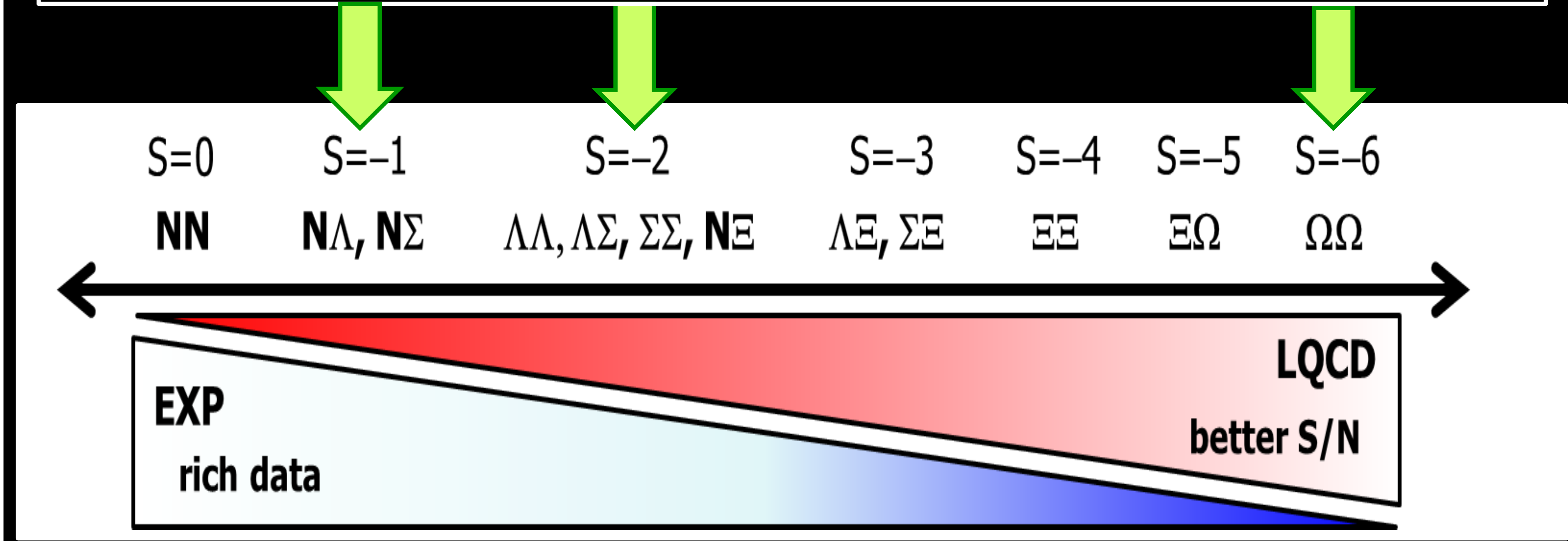

S=0
S=−1
S=−2
S=−3
S=−4
S=−5
S=−6
NN
NΛ, NΣ
ΛΛ, ΛΣ, ΣΣ, NΞ
ΛΞ, ΣΞ
ΞΞ
ΞΩ
ΩΩ
LQCD
better S/N
EXP
rich data

Summary

Hadrons to Atomic nuclei HAL from Lattice QCD

BB interactions from LQCD

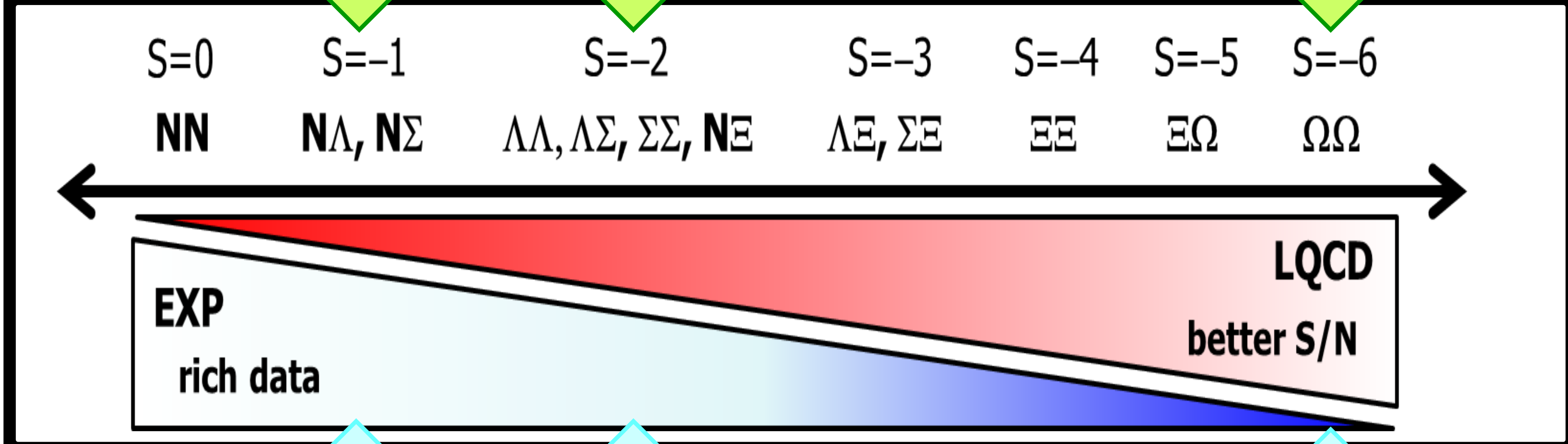
Prediction by HAL QCD Coll. (L=8.1fm, m_π=146 MeV, m_K= 525 MeV)



Summary

BB interactions from LQCD

Prediction by HAL QCD Coll. (L=8.1fm, m_π=146 MeV, m_K= 525 MeV)



Hypernuclear levels
FSI at RHIC, LHC

FSI in
Future HIC

Prof. Arima as a RIKEN President (1993-1998)

http://www.riken.jp/~/media/riken/pr/publications/riken88/riken88-photo.pdf

RIKEN RAL

Prof. Arima Congratulations for 88th Birthday !

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