TOPICS in LOW-ENERGY QCD with STRANGE QUARKS

Wolfram Weise

ECT* Trento and **T**echnische **U**niversität **M**ünchen

- **Symmetry breaking** patterns in **low-energy QCD**: **chiral SU**(3) **effective field theory**
- **Antikaon-nucleon** interactions and news on $\Lambda(1405)$
- $\mathrm{K^- d}$ **scattering length** and **kaonic deuterium**
- $\mathrm{\bar{K}NN}$ **systems** and search for **quasi-bound state**
- **Hyperon-nucleon interactions** with **strangeness**
  News from **ChEFT** and **Lattice QCD**
- **Strangeness** in **dense baryonic matter**
  New **constraints** from **neutron stars**

BASIC ISSUES

- **Strange quarks** are intermediate between "**light**" and "**heavy**":
  - Interplay between **spontaneous** and **explicit chiral symmetry breaking** in low-energy QCD
- Testing ground: high-precision **antikaon-nucleon** threshold physics
  - **Attractive** low-energy $\bar{\mathrm{K}}\mathrm{N}$ interaction
- Nature and structure of $\Lambda(1405)$ $(\mathrm{B}=1,\ \ \mathrm{S}=-1,\ \ \mathrm{J}^{\mathrm{P}}=1/2^{-})$
  - **Three-quark** valence structure vs. "**molecular**" meson-baryon state ?
- Quest for quasi-bound **antikaon-NN** system(s) ?
- Role of **strangeness** in dense baryonic matter
  - **Kaon condensation** ?
    Strange quark matter, **hyperons** in **neutron stars** ?

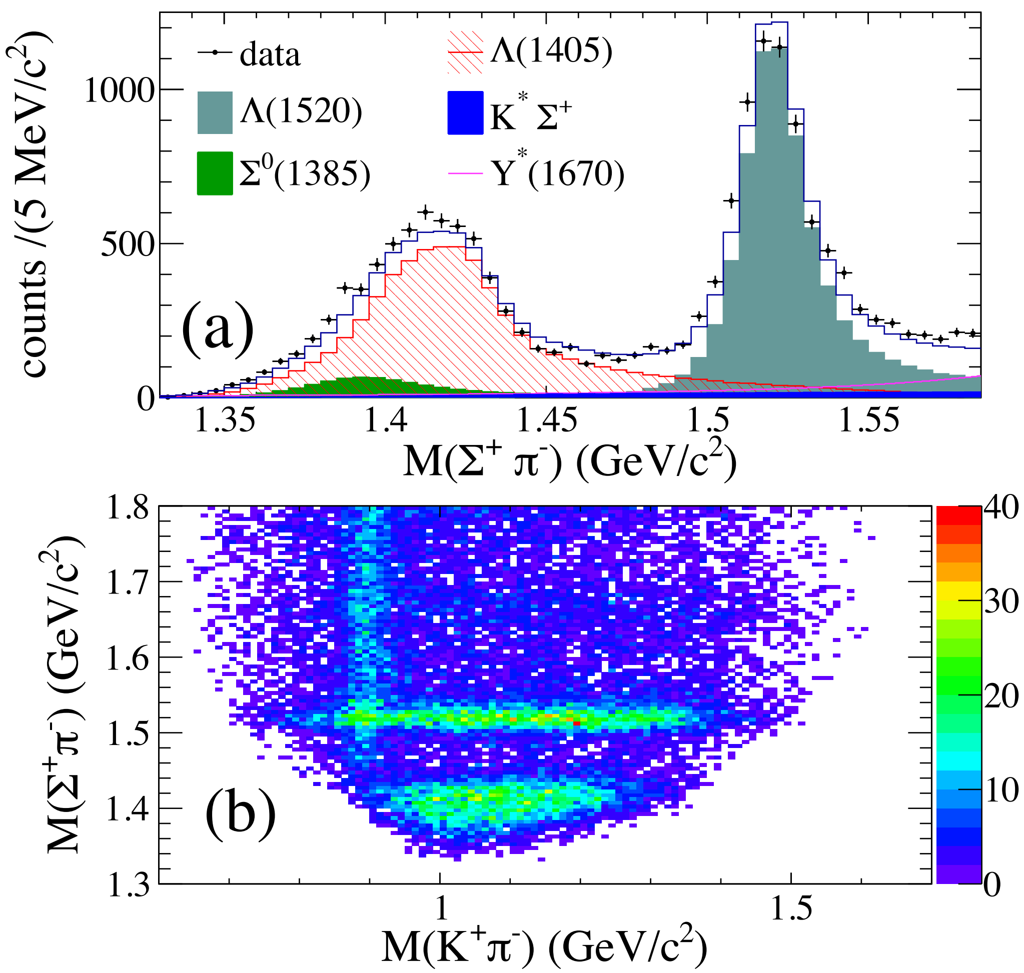
PART I:

$\bar{\mathrm{K}}$N and $\bar{\mathrm{K}}$NN Interactions

ECT*

$\Lambda(1405)$: RECENT NEWS

- $\gamma\, \mathbf{p} \rightarrow \mathbf{K}^{+} \pi^{-} \boldsymbol{\Sigma}^{+}$ @ CLAS / JLab



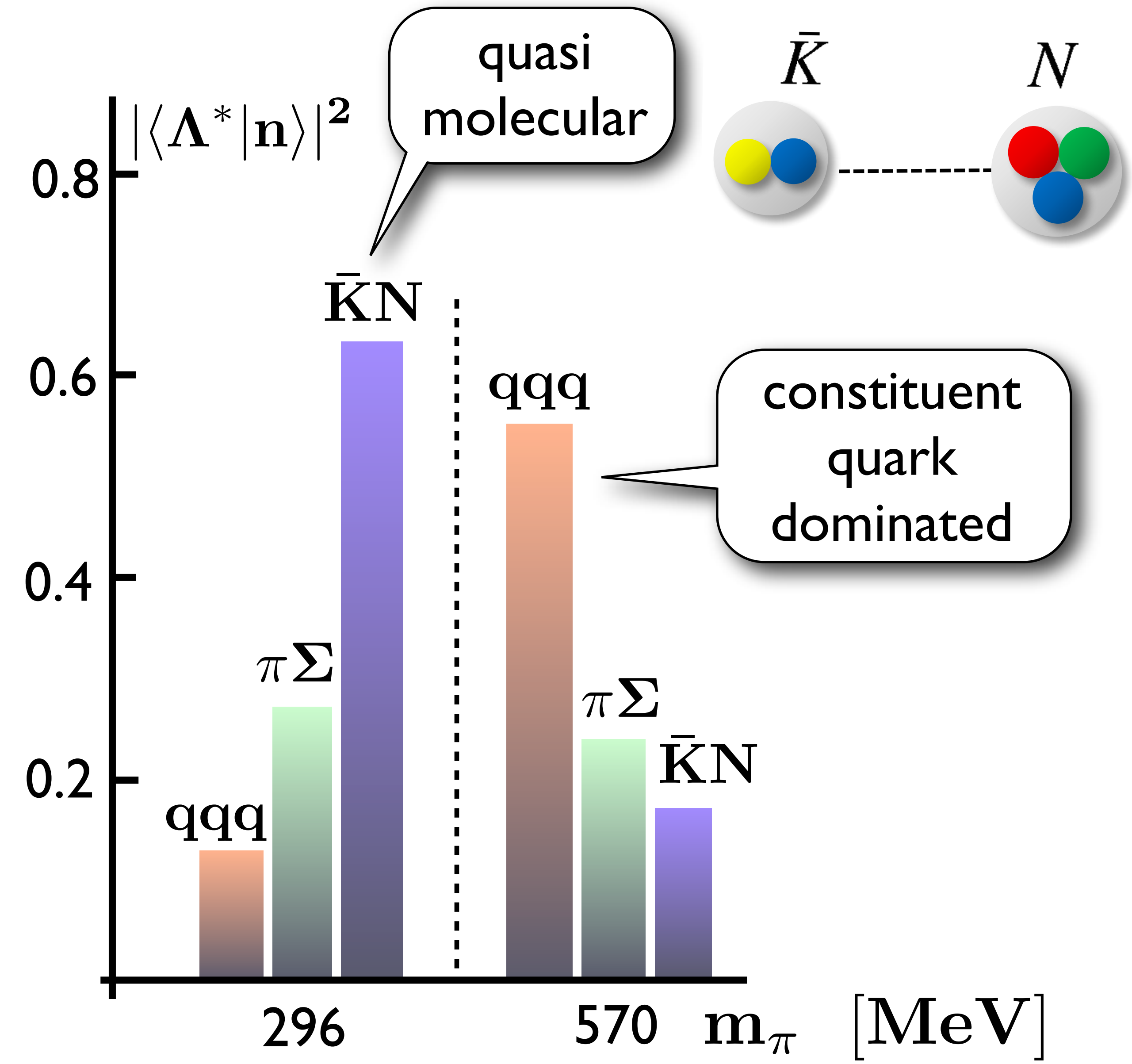
- Detailed analysis of $\Sigma^{+}\pi^{-}$distribution and Σ^{+}polarization confirms

$$\mathbf{J^P} = \frac{\mathbf{1}}{\mathbf{2}}^{-} \text{ of } \Lambda(1405)$$

K. Moriya et al. (CLAS collaboration)
Phys. Rev. Lett. 112 (2014) 068103

- Structure of $\Lambda(1405)$ from Lattice QCD

$$|\Lambda^*\rangle = \mathbf{a}|\mathbf{uds}\rangle + \mathbf{b}|(\mathbf{udu})(\bar{\mathbf{u}}\mathbf{s})\rangle + \ldots$$



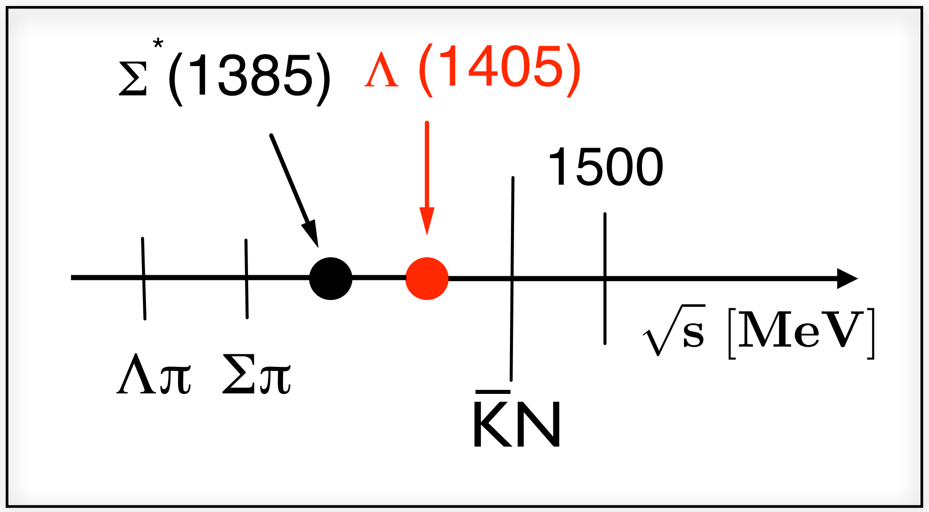
- Quasimolecular $\bar{\mathbf{K}}\mathbf{N}$ structure of $\Lambda(1405)$

J.M.M. Hall et al. (Adelaide group)
(2014)

Low-Energy $\bar{K}N$ Interactions

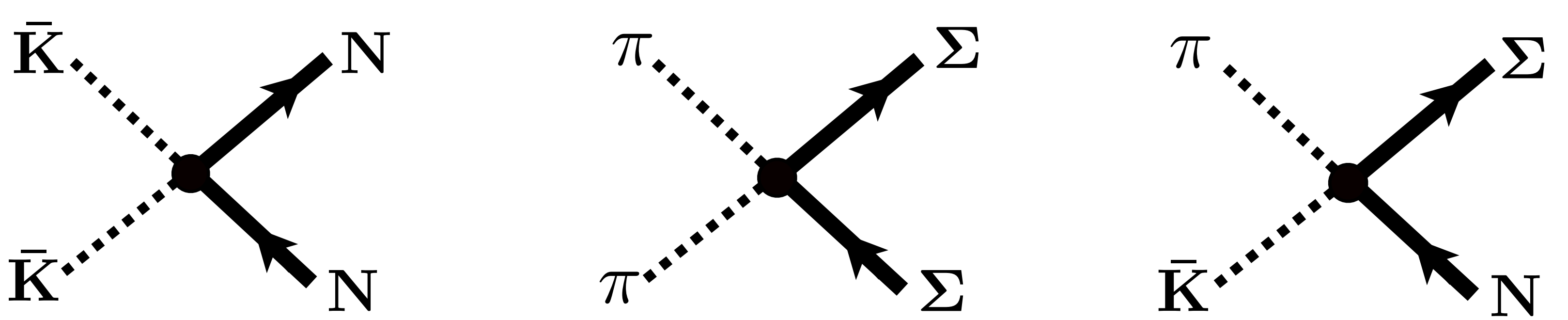
- Framework: **Chiral SU(3) Effective Field Theory** … but :
- Chiral Perturbation Theory **NOT** applicable:
  $\Lambda(1405)$ resonance 27 MeV below K^-p threshold

N. Kaiser, P. Siegel, W.W. (1995)
E. Oset, A. Ramos (1998)

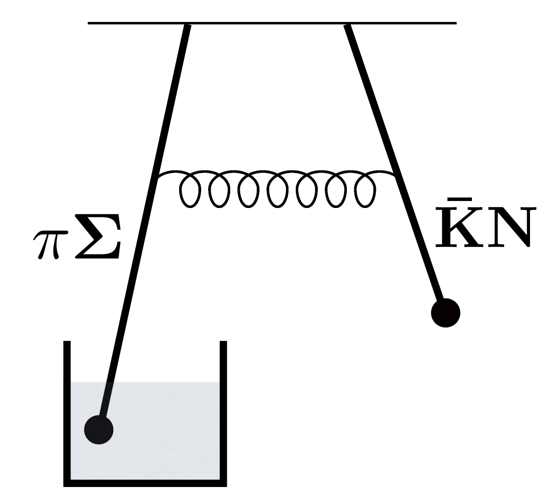


Non-perturbative
Coupled Channels
approach based on
Chiral SU(3) Dynamics

- Leading s-wave I = 0 meson-baryon interactions (Tomozawa-Weinberg)

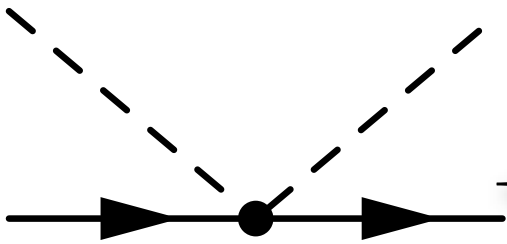


channel coupling



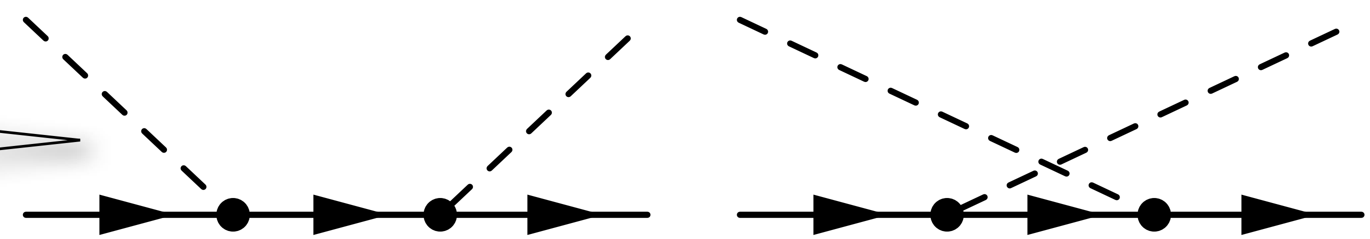
Recent Review:
T. Hyodo, D. Jido
Prog. Part. Nucl. Phys. 67 (2012) 55

CHIRAL SU(3) EFFECTIVE FIELD THEORY COUPLED CHANNELS DYNAMICS:
- NLO hierarchy of driving terms -



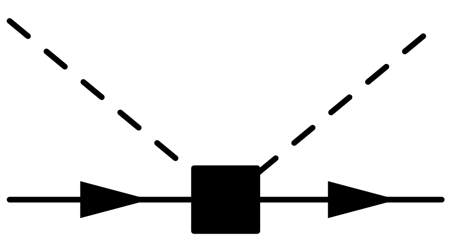
leading order (**W**einberg-**T**omozawa) terms
input: physical pion and kaon decay constants

direct and crossed **Born terms**
input: axial vector constants
D and F from hyperon beta decays



$$g_A = D + F = 1.26$$

$$\mathcal{L}_1^{MB} = \mathrm{Tr}\left(\frac{D}{2}(\bar{B}\gamma^\mu\gamma_5\{u_\mu, B\}) + \frac{F}{2}(\bar{B}\gamma^\mu\gamma_5[u_\mu, B])\right)$$



next-to-leading order (**NLO**) $\mathcal{O}(p^2)$
input: several low-energy constants

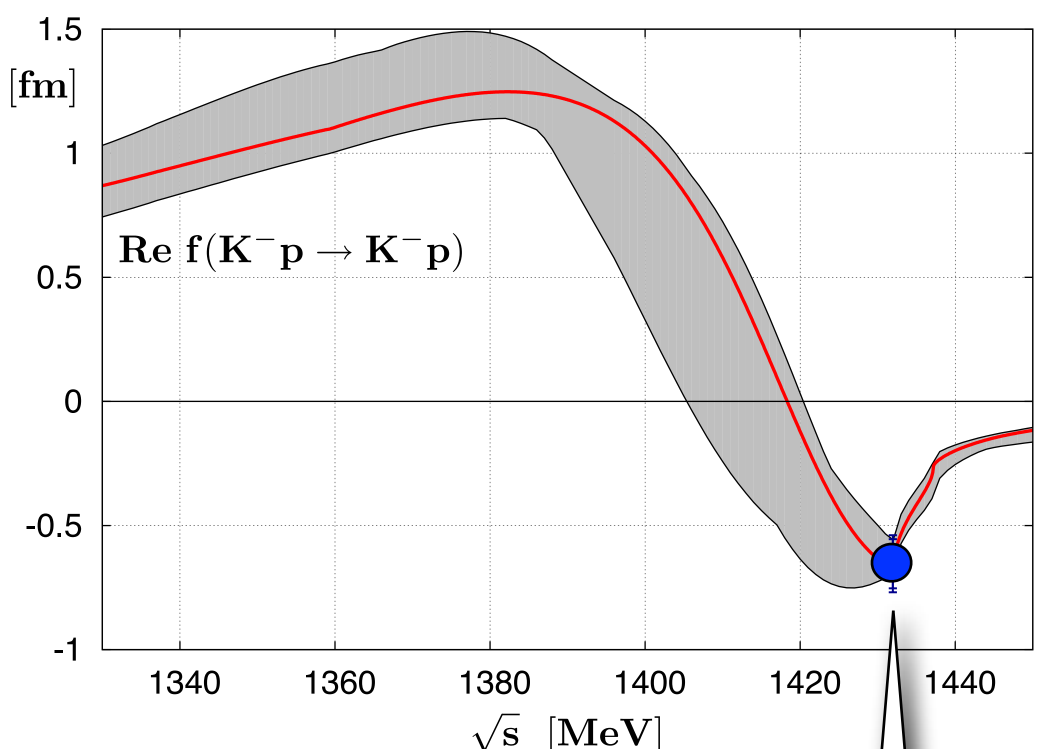
$$\begin{aligned}\mathcal{L}_2^{MB} =& b_D \mathrm{Tr}\big(\bar{B}\{\chi_+, B\}\big) + b_F \mathrm{Tr}\big(\bar{B}[\chi_+, B]\big) + b_0 \mathrm{Tr}(\bar{B}B)\mathrm{Tr}(\chi_+)\\ &+ d_1 \mathrm{Tr}\big(\bar{B}\{u^\mu, [u_\mu, B]\}\big) + d_2 \mathrm{Tr}\big(\bar{B}[u^\mu, [u_\mu, B]]\big)\\ &+ d_3 \mathrm{Tr}(\bar{B}u_\mu)\mathrm{Tr}(u^\mu B) + d_4 \mathrm{Tr}(\bar{B}B)\mathrm{Tr}(u^\mu u_\mu),\end{aligned}$$

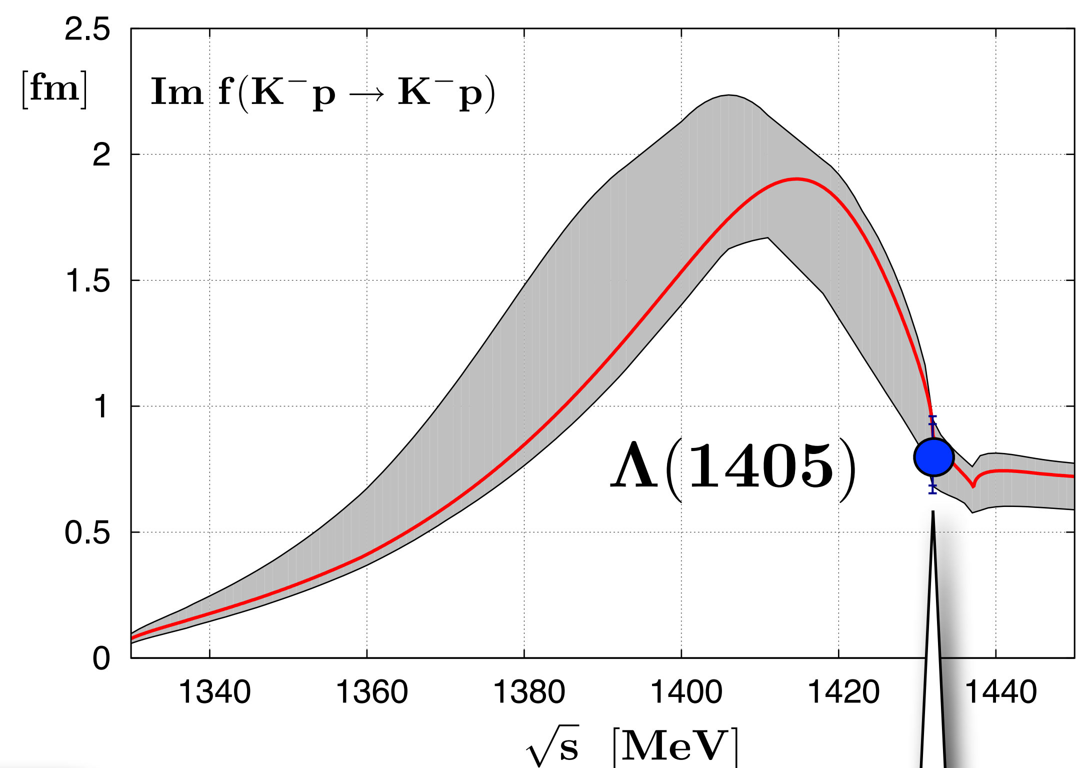
$\mathrm{K^-p}$ SCATTERING AMPLITUDE from CHIRAL SU(3) COUPLED CHANNELS DYNAMICS

$$\mathrm{f(K^-p) = \frac{1}{2}\left[f_{\bar{K}N}(I=0) + f_{\bar{K}N}(I=1)\right]}$$

Y. Ikeda, T. Hyodo, W. W.
PLB 706 (2011) 63
NPA881 (2012) 98

$\mathbf{\Lambda(1405)}$: $\mathbf{\bar{K}N\ (I=0)}$ **quasibound state** embedded in the $\pi\Sigma$ continuum





$\mathrm{Re\ a(K^-p)}$

$\mathrm{Im\ a(K^-p)}$

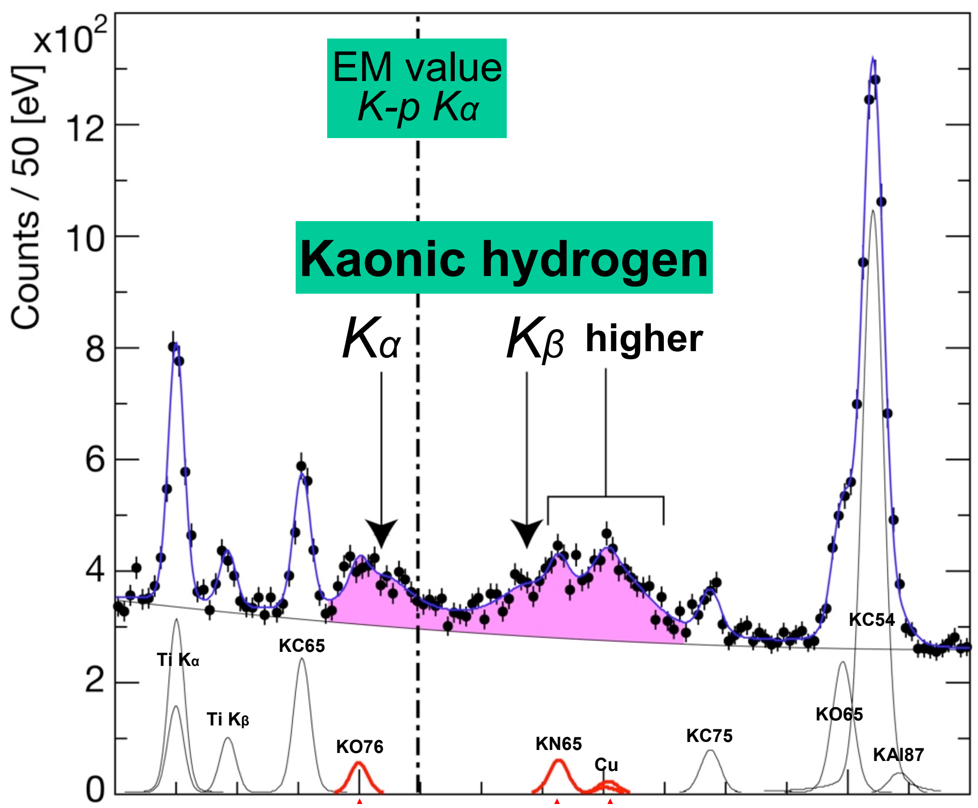
● Complex scattering length (including Coulomb corrections)

$$\mathrm{Re\ a(K^-p) = -0.65 \pm 0.10\ \ fm}$$

$$\mathrm{Im\ a(K^-p) = 0.81 \pm 0.15\ \ fm}$$

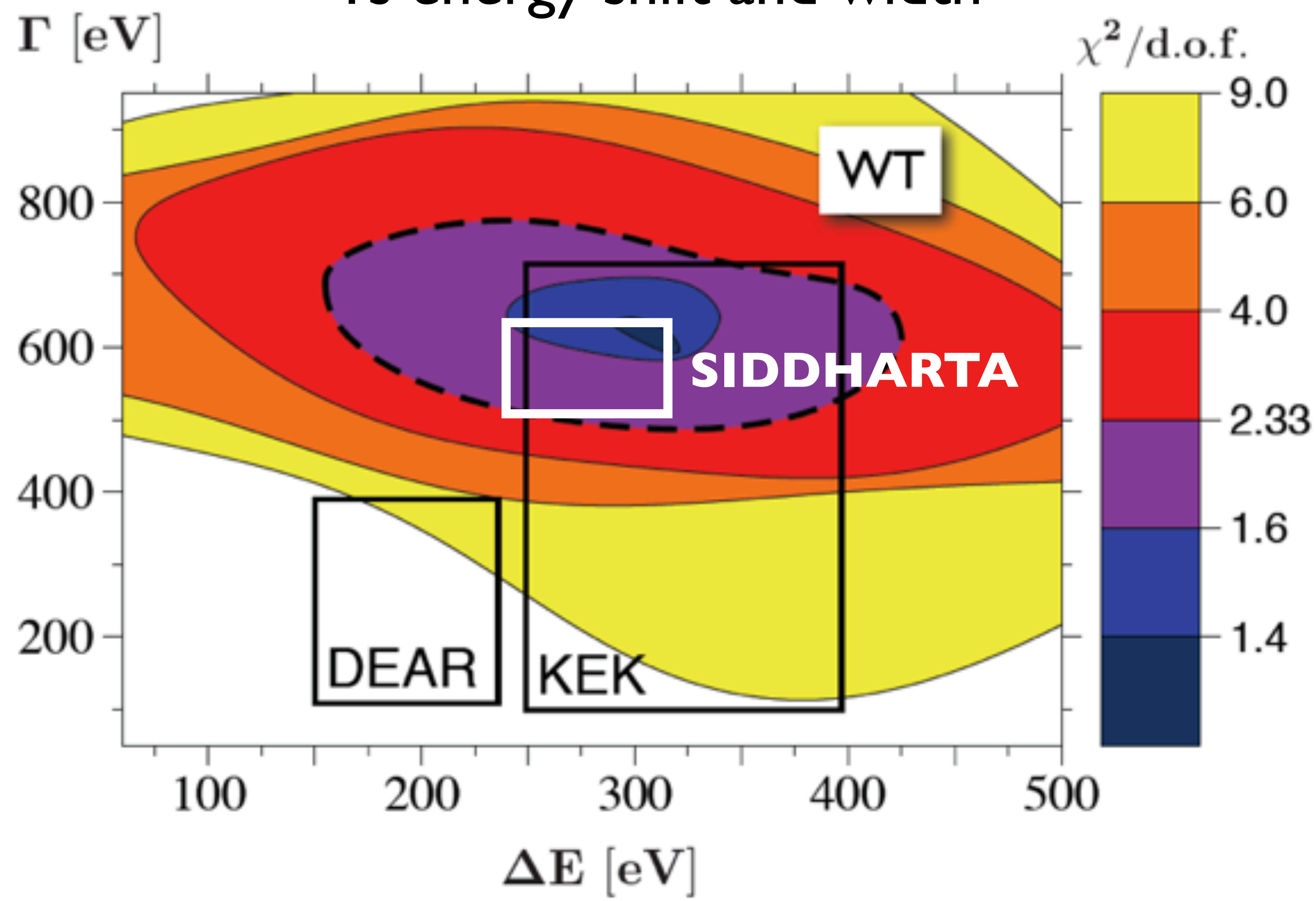
CONSTRAINTS from SIDDHARTA

- **Kaonic hydrogen**
  precision data



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

- **Strong interaction**
  1s energy shift and width



$$\mathbf{\Delta E = 283 \pm 36}\,(stat) \pm \mathbf{6}\,(syst) \quad \mathbf{eV}$$

$$\mathbf{\Gamma = 541 \pm 89}\,(stat) \pm \mathbf{22}\,(syst) \quad \mathbf{eV}$$

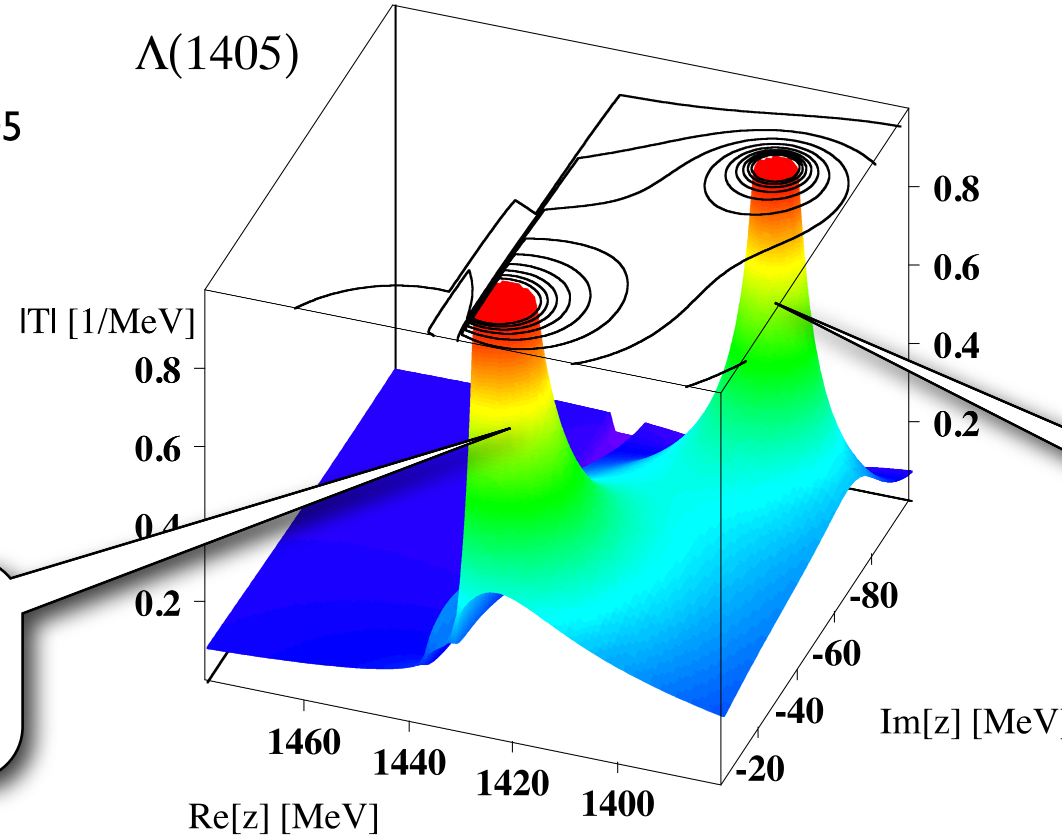
The TWO POLES scenario

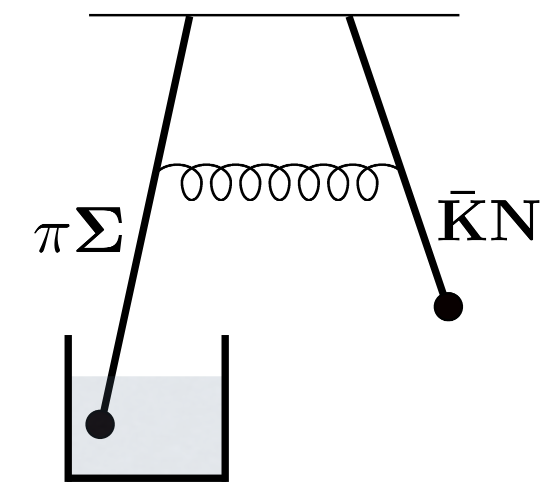
- Characteristic feature of **Chiral SU(3) Dynamics**
  Energy dependent driving interactions

D. Jido et al.
Nucl. Phys. A723 (2003) 205

T. Hyodo, W.W.
Phys. Rev. C 77 (2008) 03524

T. Hyodo, D. Jido
Prog. Part. Nucl. Phys. 67 (2012) 55





- Pole positions from **chiral SU(3) coupled-channels calculation** with **SIDDHARTA** threshold constraints:

$\mathbf{E_1 = 1424 \pm 15\ MeV}$	$\mathbf{E_2 = 1381 \pm 15\ MeV}$
$\mathbf{\Gamma_1 = 52 \pm 10\ MeV}$	$\mathbf{\Gamma_2 = 162 \pm 15\ MeV}$

Y. Ikeda, T. Hyodo, W.W. :
Nucl. Phys. A 881 (2012) 98

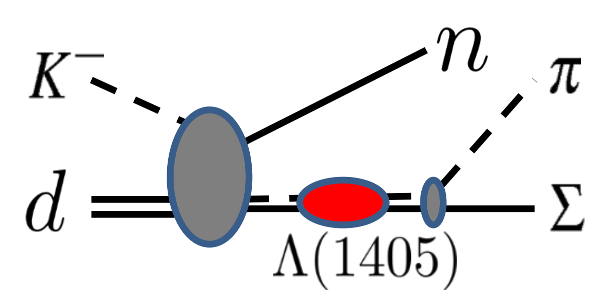
- Note: phenomenological potential approach is qualitatively different:
  energy-**independent** interaction, **single** $\Lambda(1405)$ pole

Scenarios:
TWO-POLES ENERGY-DEPENDENT
vs.
SINGLE-POLE ENERGY-INDEPENDENT

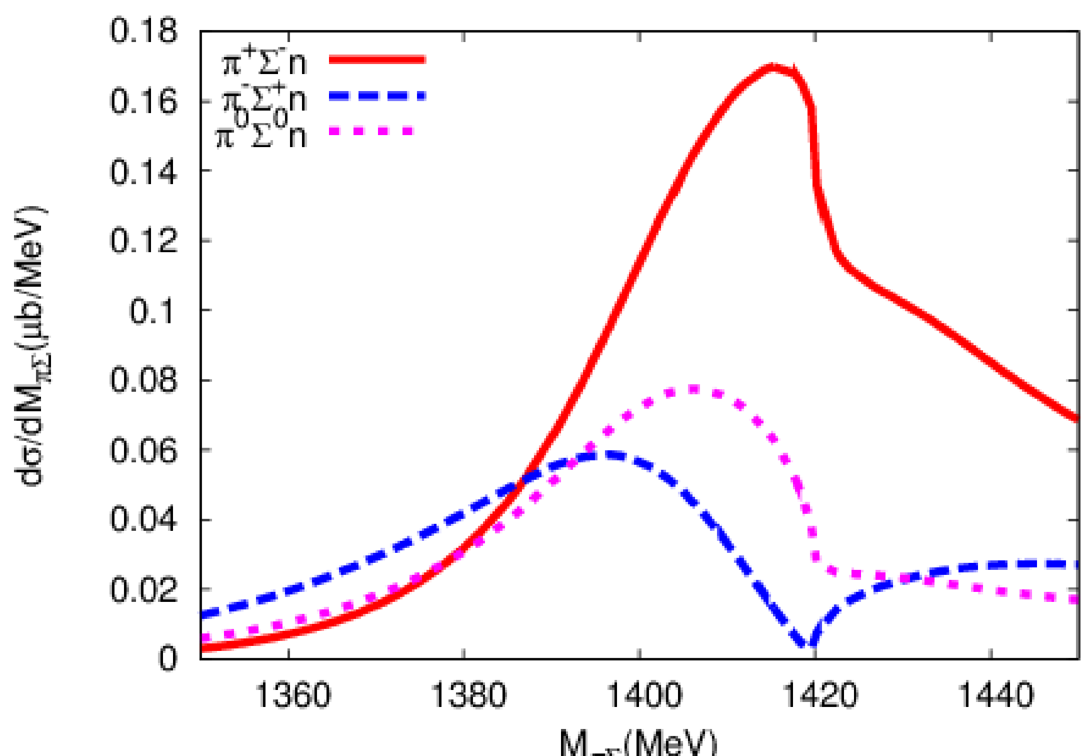
- Three-body coupled channels (Faddeev) calculations

$\pi\Sigma$ invariant mass distribution

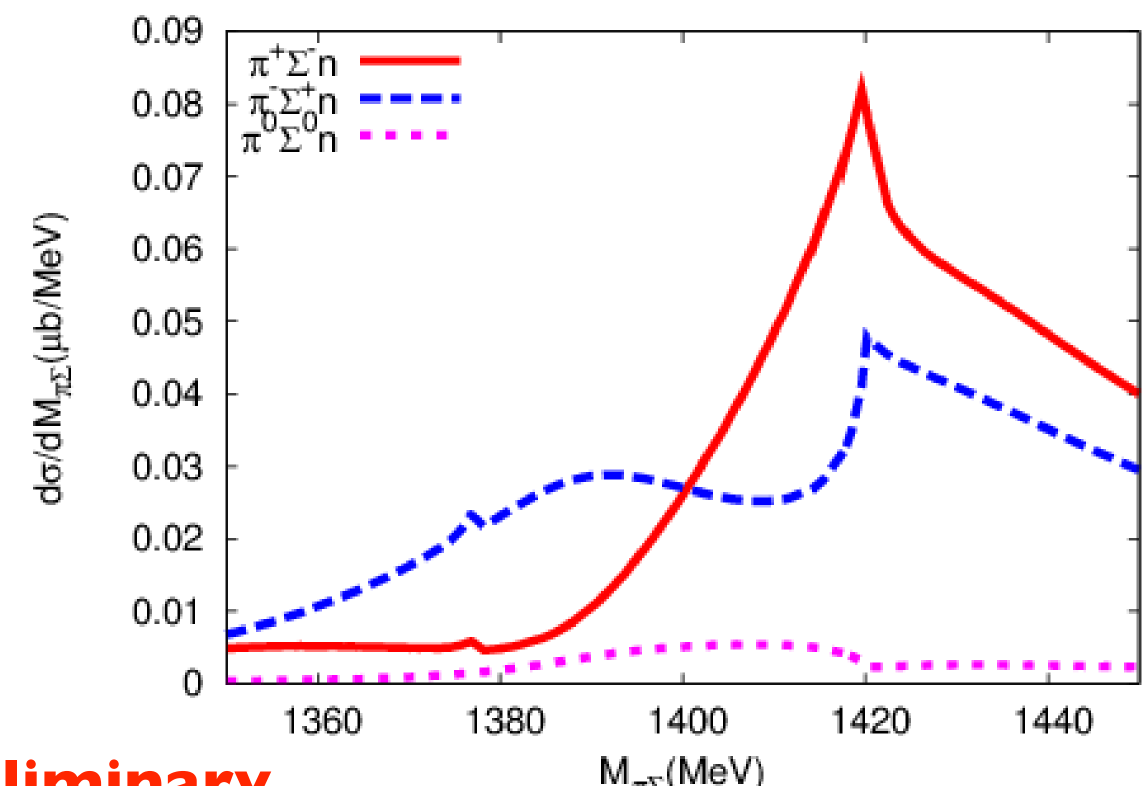
$p_{\bar{K}}^{lab} = 700\mathrm{MeV}$



E-dep. (two-pole, 1420)



E-indep. (one-pole, 1405)



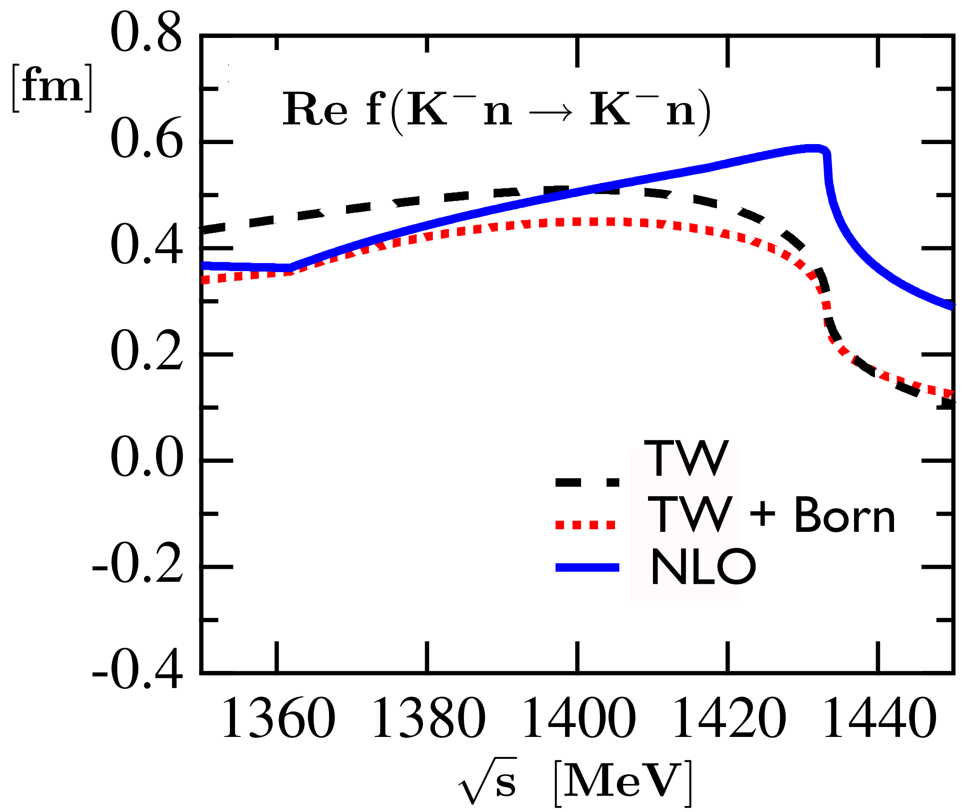
preliminary

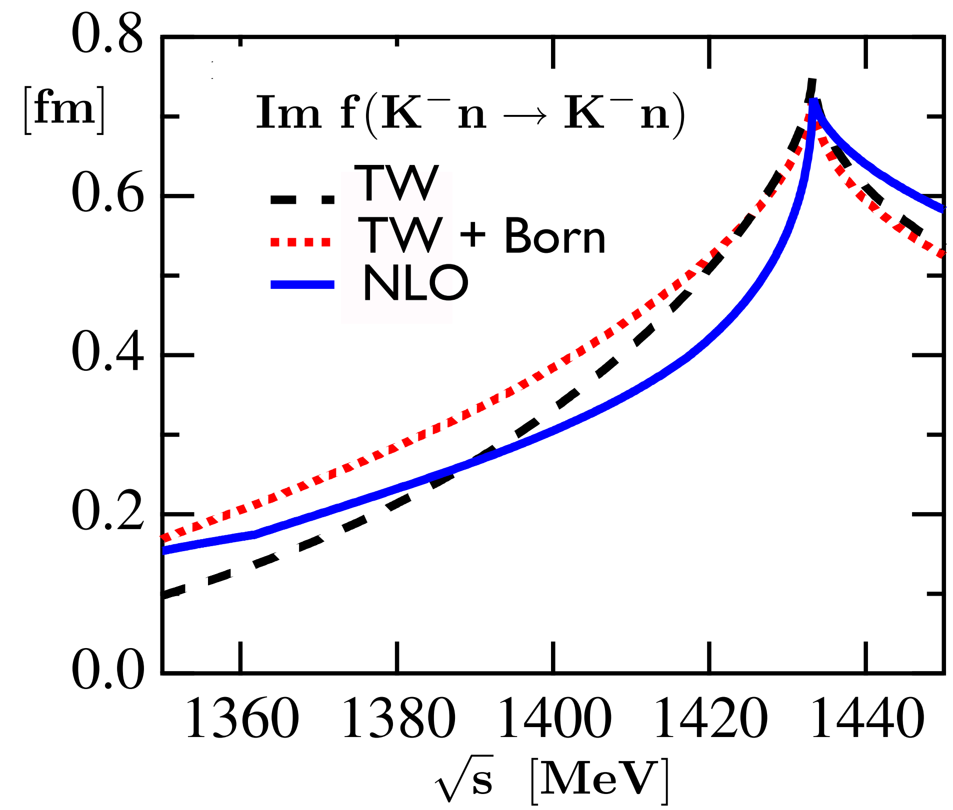
Shota Ohnishi, Y. Ikeda, T. Hyodo, E. Hiyama, W.W. (2014)

CHIRAL SU(3) COUPLED CHANNELS DYNAMICS

- Predicted **antikaon-neutron** amplitudes at and below threshold

Y. Ikeda, T. Hyodo, W. Weise : Phys. Lett. B 706 (2011) 63 , Nucl. Phys. A 881 (2012) 98





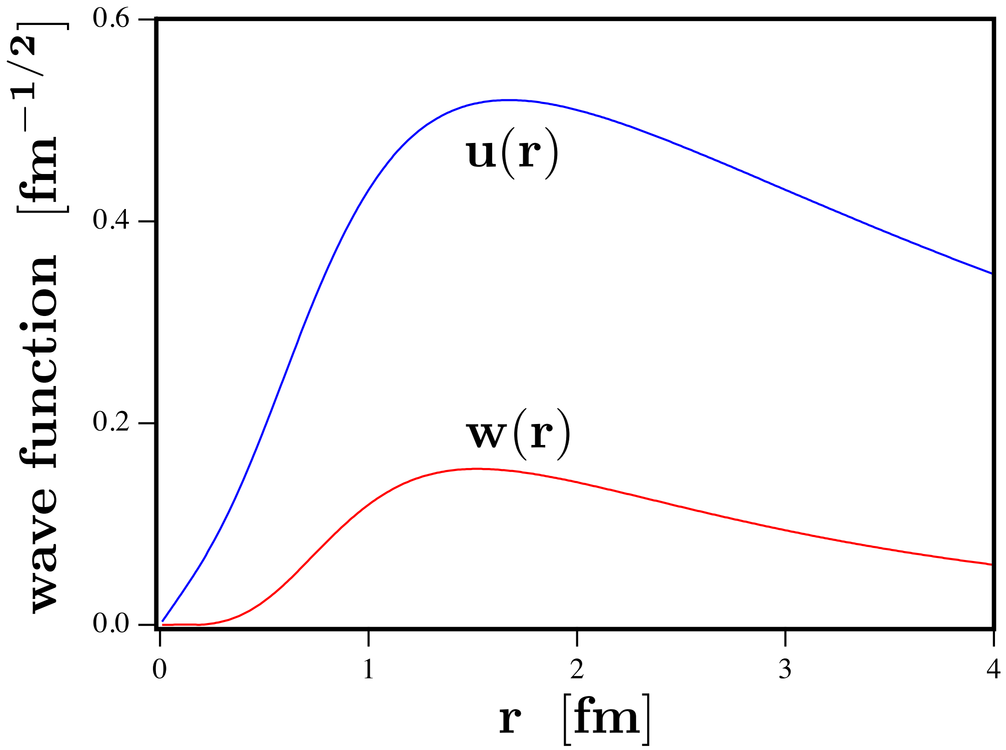
$$\mathbf{a(K^-n) = 0.57^{+0.04}_{-0.21} + i\,0.72^{+0.26}_{-0.41}\ \ fm}$$

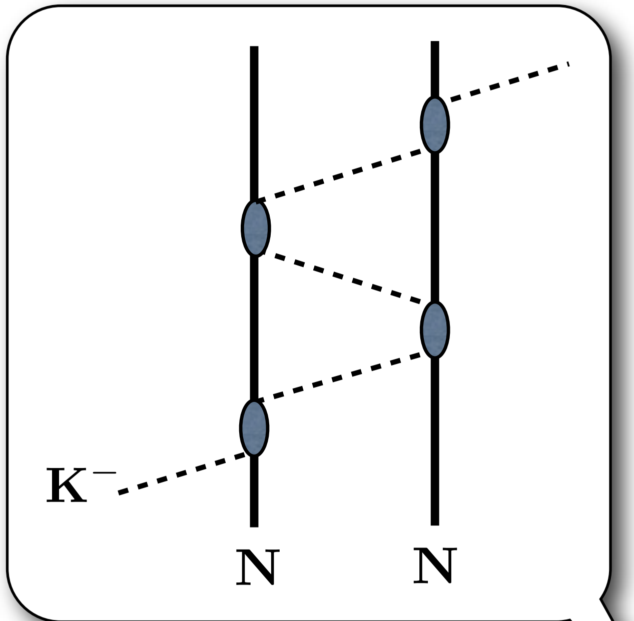
- **Needed**: accurate constraints from **antikaon-deuteron** threshold measurements
  - **complete** information for both isospin $\mathbf{I=0}$ and $\mathbf{I=1}$ $\mathbf{\bar{K}N}$ channels
  - plus potentially important information about **K-NN absorption**

ANTIKAON - DEUTERON THRESHOLD PHYSICS
$\mathrm{K^-d}$ SCATTERING LENGTH and KAONIC DEUTERIUM

- Three-body calculation using Chiral SU(3) Coupled Channels approach

$$\mathbf{\bar{K}NN} \leftrightarrow \pi\mathbf{YN}$$





- Importance of charge exchange: $\mathbf{K^-pn} \leftrightarrow \mathbf{\bar{K}^0nn}$

S.S. Kamalov, E. Oset, A. Ramos
Nucl. Phys. A 690 (2001) 494

$$\mathbf{a(K^-d)} = \left(\mathbf{1} + \frac{\mathbf{m_K}}{\mathbf{M_d}}\right)^{\mathbf{-1}} \int_{\mathbf{0}}^{\infty} \mathbf{dr}\left[\mathbf{u^2(r)} + \mathbf{w^2(r)}\right] \mathbf{A(r)}$$

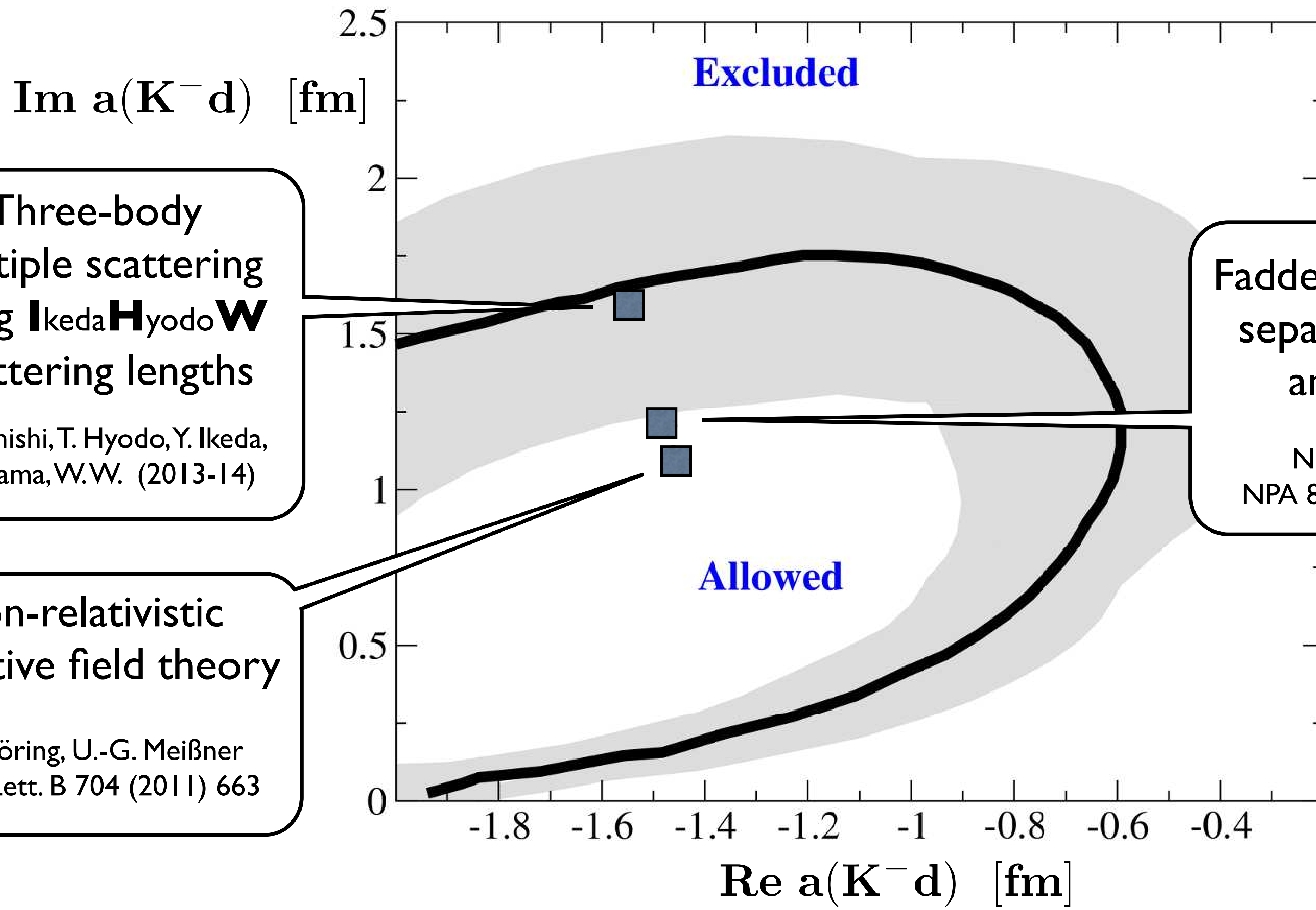
- Recent result constrained by SIDDHARTA $\mathbf{K^-p}$ input:

$$\mathbf{a(K^-d)} = (\mathbf{-1.55} + \mathbf{i\,1.66})\ \mathbf{fm} \qquad (\pm\mathbf{10\%})$$

S. Ohnishi, Y. Ikeda, T. Hyodo, E. Hiyama, W.W. (2014)

ANTIKAON - DEUTERON SCATTERING LENGTH

- Recent calculations using SIDDHARTA - constrained input



Three-body multiple scattering using **I**keda**H**yodo**W** scattering lengths

S. Ohnishi, T. Hyodo, Y. Ikeda, E. Hiyama, W.W. (2013-14)

Non-relativistic effective field theory

M. Döring, U.-G. Meißner Phys. Lett. B 704 (2011) 663

Faddeev calculation separable "chiral" amplitudes

N.V. Shevchenko NPA 890-891 (2012) 50

- Sources of (10 - 20 %) uncertainties:

  - "Fixed scatterer" approximation
  - $K^- n$ amplitude
  - $K^- d \rightarrow YN$ absorption

A. Gal, Int. J. Mod. Phys. A 22 (2007) 226

KAONIC DEUTERIUM
STRONG INTERACTION ENERGY SHIFT & WIDTH

- **Exp. Proposals**: SIDDHARTA-2 and J-PARC
- **Theory**: using $\mathbf{K^-d}$ scattering length based on 3-body Chiral SU(3) dynamics

Complex potential

$$\mathbf{U} = -\frac{2\pi}{\mu}\,\mathbf{A_{KNN}}\,\rho_\mathbf{d}$$

$\mathbf{K^-NN}$ 3-body amplitude

deuteron density distribution

Energy shift and width (1s)

$$\mathbf{\Delta E} - \frac{\mathbf{i}}{\mathbf{2}}\mathbf{\Gamma} = \frac{\langle\mathbf{\Phi}|\mathbf{U}|\mathbf{\Psi}\rangle}{\langle\mathbf{\Phi}|\mathbf{\Psi}\rangle}$$

kaonic deuterium Coulomb wavefunction

kaonic deuterium Coulomb + **strong** wavefunction

$$\mathbf{\Delta E = (958 \pm 50)\,eV} \qquad \mathbf{\Gamma = (906 \pm 70)\,eV}$$

S. Ohnishi, T. Hyodo, Y. Ikeda, E. Hiyama, W.W. (2014)

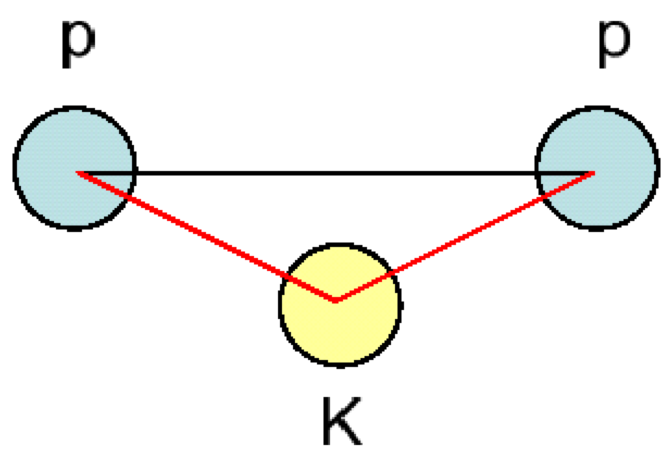
including finite-size Coulomb, vacuum polarization and binding corrections

- Comparison with improved Deser formula:

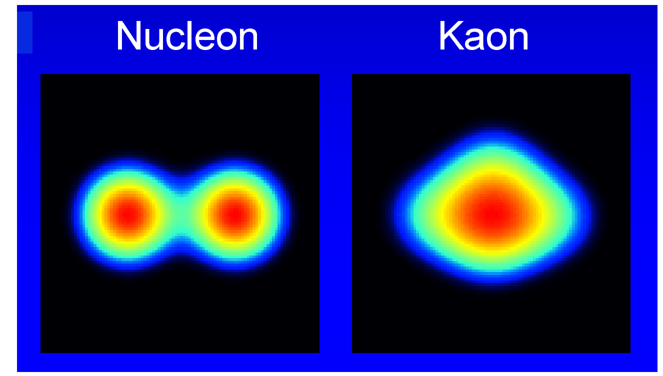
U.-G. Meißner, U. Raha, A. Rusetsky Eur. Phys. J. C 35 (2004) 349

$$\mathbf{\Delta E} - \frac{\mathbf{i}}{\mathbf{2}}\mathbf{\Gamma} = -\frac{\mathbf{2}\mu^\mathbf{2}\alpha^\mathbf{3}\,\mathbf{a(K^-d)}}{\mathbf{1} - \mathbf{2}\mu\alpha(\mathbf{1} - \ln\alpha)\,\mathbf{a(K^-d)}} \qquad \left(\mathbf{\Delta E},\ \frac{\mathbf{\Gamma}}{\mathbf{2}}\right) = \mathbf{(870,\ 593)\,eV}$$

UPDATE on QUASIBOUND K^-pp



3-Body (Faddeev) calculations



Variational calculations

- . . . now consistently using amplitudes from **Chiral SU(3) coupled-channels** dynamics including **energy dependence** in subthreshold extrapolations
- Calculated **binding energy** and **width** (in MeV) of the $\mathrm{K^-pp}$ system

modest binding
large width

	[1]	[2]	[3]
B	16	17–23	9–16
Γ	41	40–70	34–46

remarkable degree of consistency

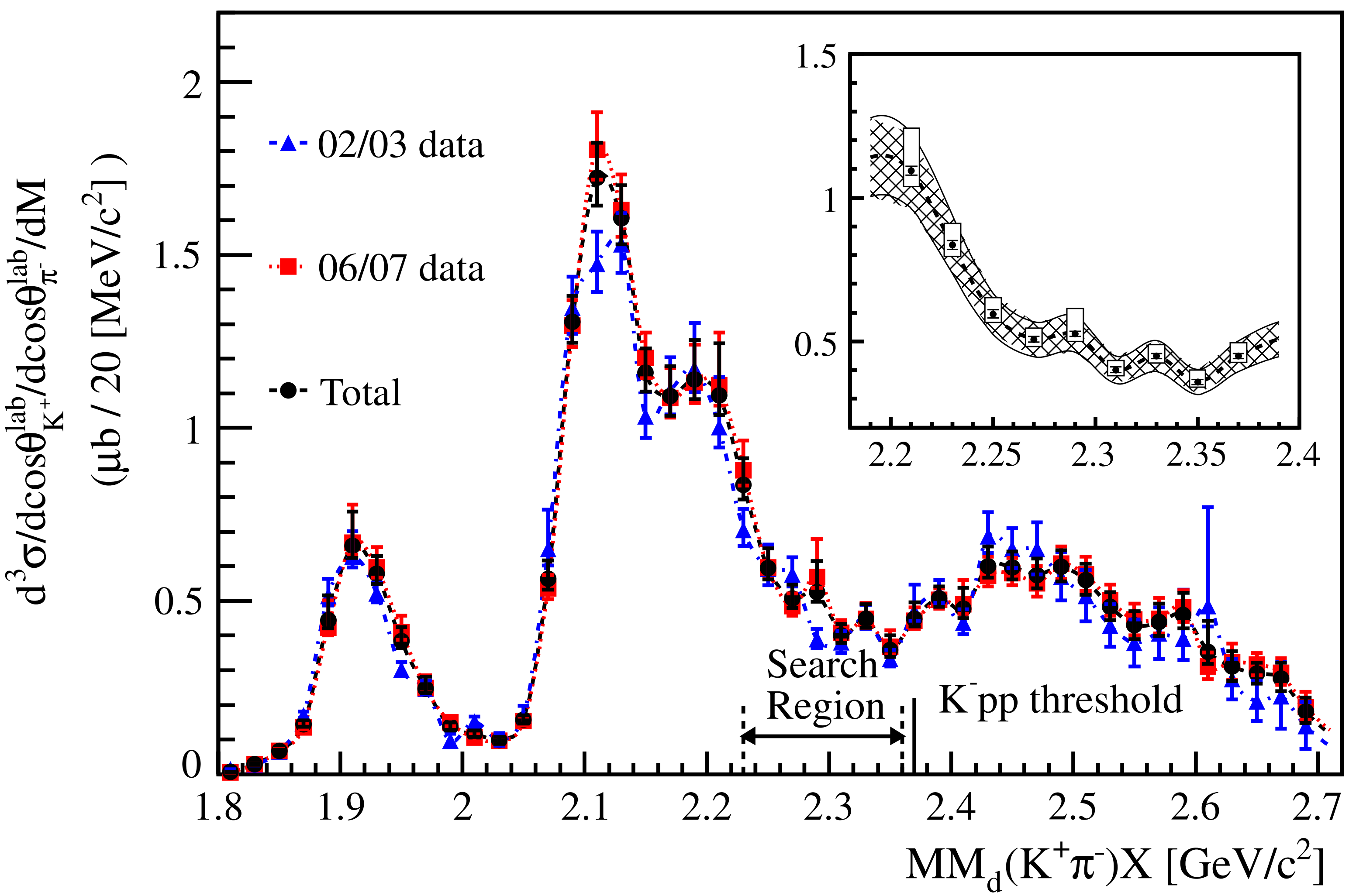
[1] Variational (hyperspherical harmonics): N. Barnea, A. Gal, E.Z. Livets ; Phys. Lett. B 712 (2012) 132

[2] Variational (Gaussian trial wave functions): A. Doté, T. Hyodo, W.W. ; Phys. Rev. C 79 (2009) 014003

[3] Faddeev: Y. Ikeda, H. Kamano, T. Sato ; Prog. Theor. Phys. 124 (2010) 533

New Searches for QUASIBOUND K^-pp
- part I -

- $\gamma\, \mathrm{d} \rightarrow \mathrm{K}^+ \pi^- \mathrm{X}$ at LEPS / SPRING-8



A.O. Tokiyasu et al.
(LEPS collaboration)
Phys. Lett. B 728 (2014) 616

- **No significant signal** found in the search region of interest

- **Upper limits** (0.1 - 0.7 μb) estimated for differential cross section of quasibound state production

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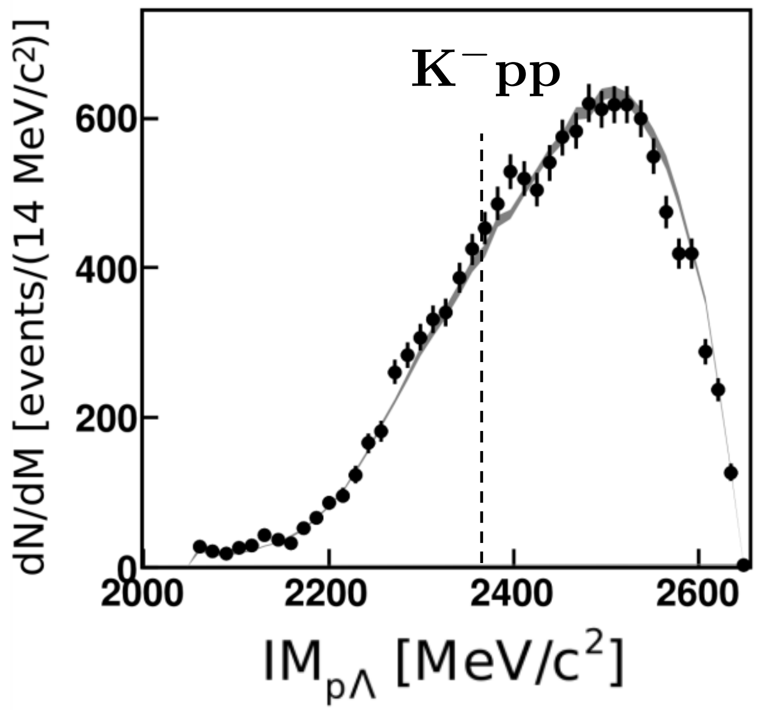
New Searches for QUASIBOUND K^-pp
- part II -

- $p + p \xrightarrow{3.5GeV} p + K^+ + \Lambda$

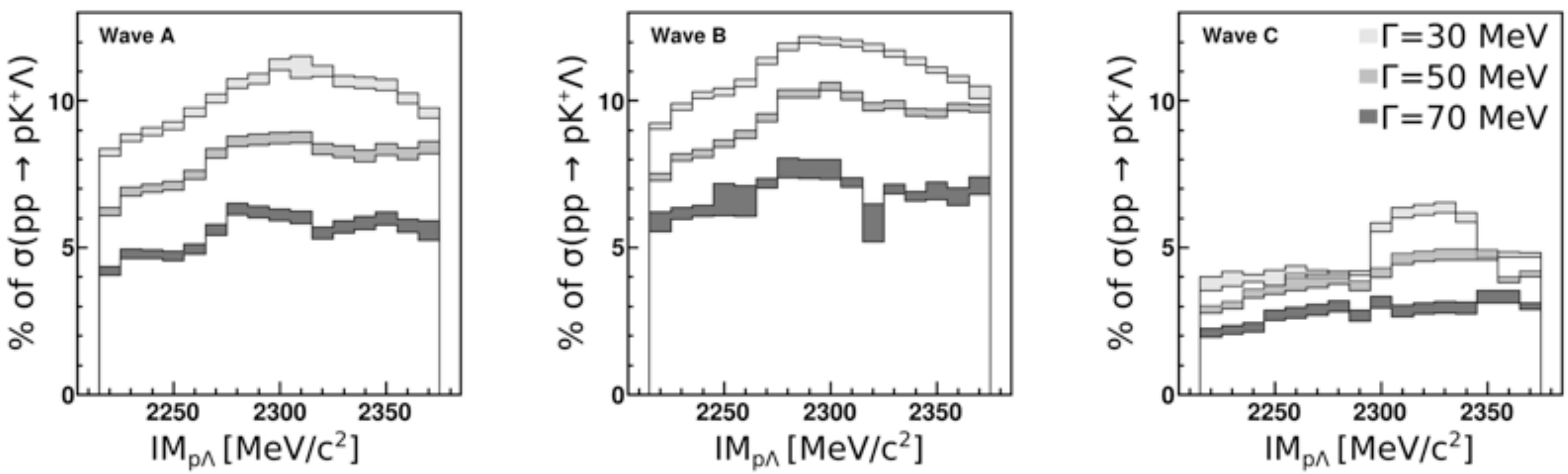
HADES

E. Epple et al.
(HADES collaboration)



Systematic
partial wave analysis
using series of
N* resonances

- **No significant signal** found in the search region of interest



- **Upper limit** for cross section of $p\,p \rightarrow K^+$ "K^-pp" quasibound state production

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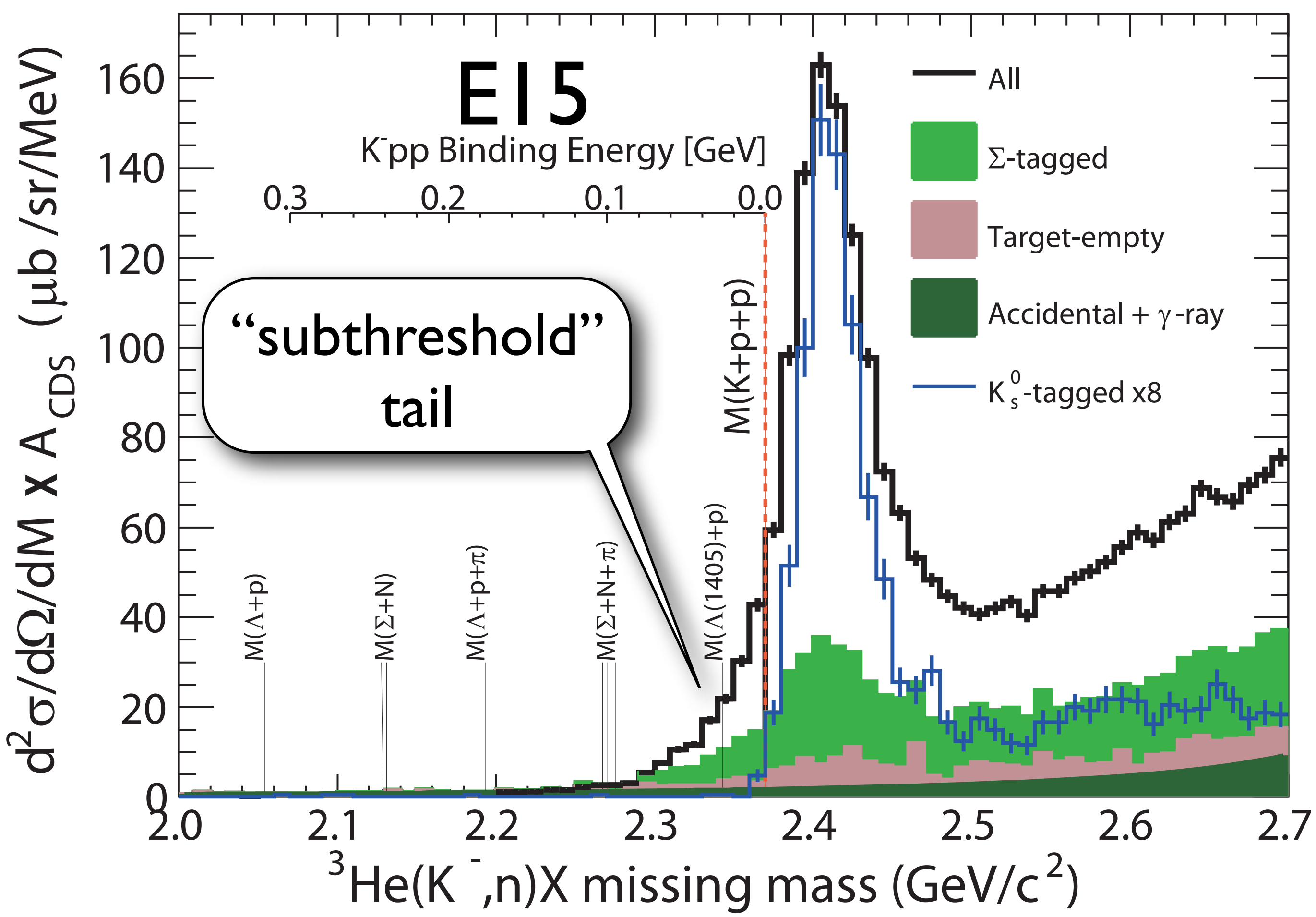
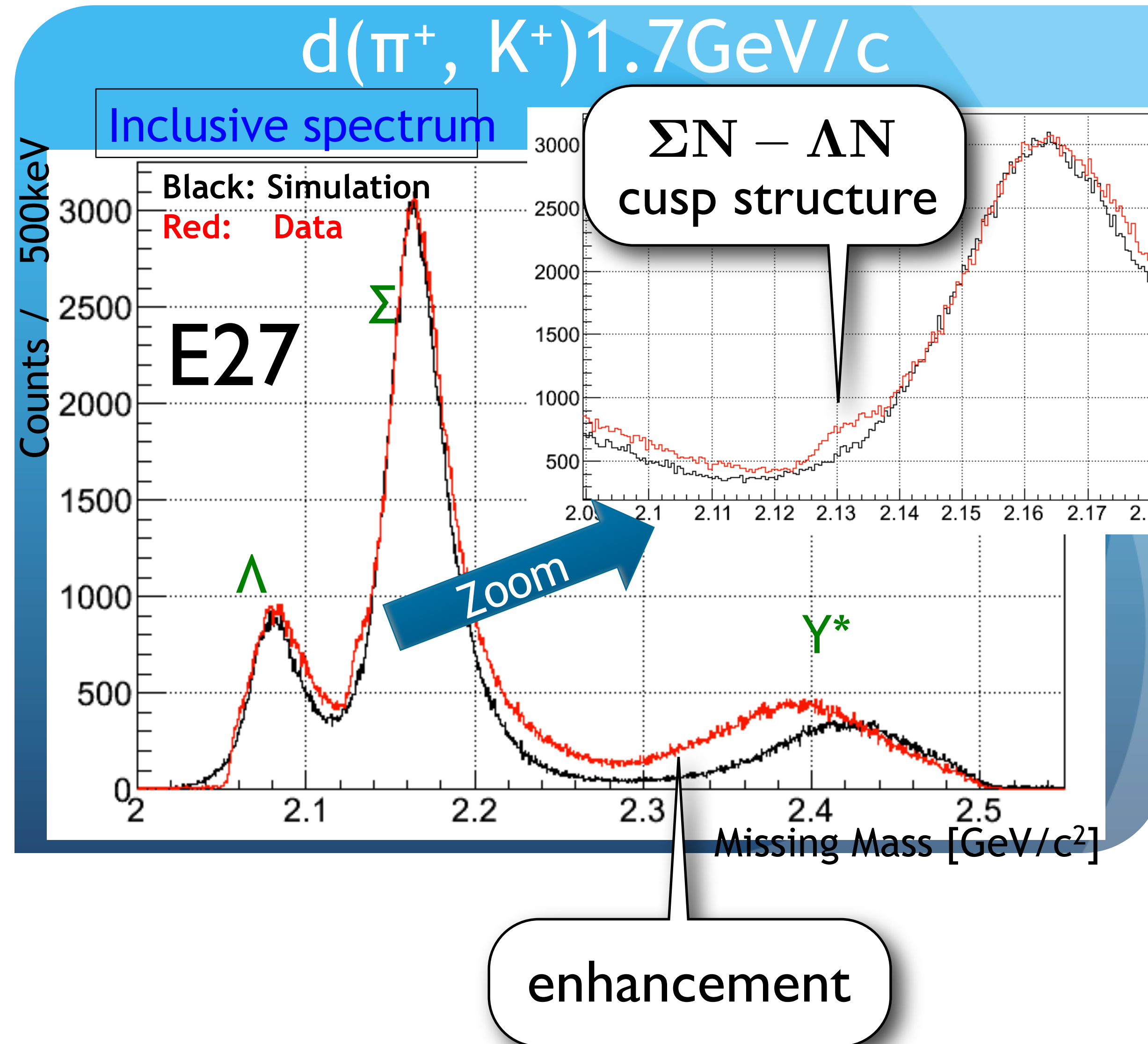
New Searches for QUASIBOUND K$^-$pp
- part III -

- **Experiments** at **J-PARC**
(in progress)

$$\mathbf{K^- + {}^3He \rightarrow n + X}$$



$$\pi^+ + \mathbf{d} \rightarrow \mathbf{K}^+ + \mathbf{X}$$



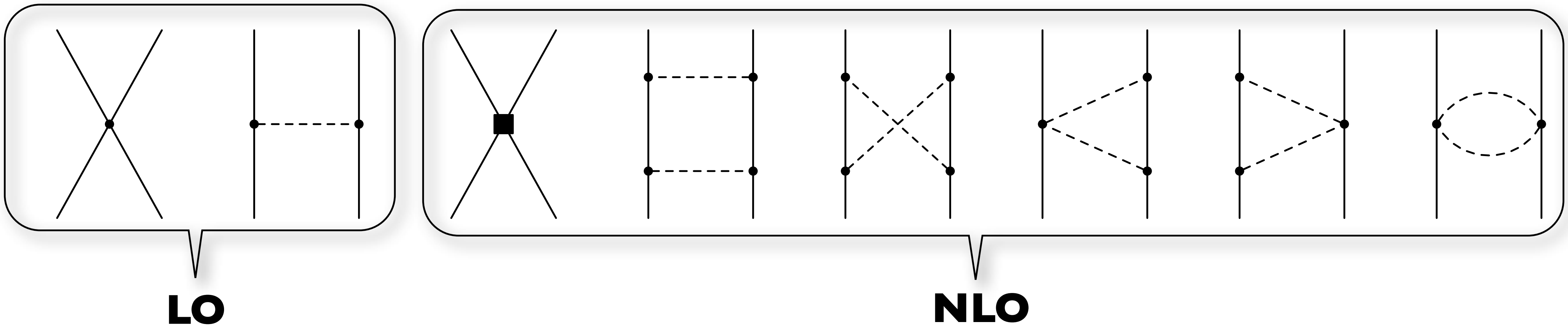
▶ presentation by Tomo Nagae

PART II:

Hyperon-Nucleon Interactions
and
Strangeness in Dense Matter

Chiral SU(3) Effective Field Theory and Hyperon-Nucleon Interactions

J. Haidenbauer, S. Petschauer, N. Kaiser, U.-G. Meißner, A. Nogga, W.W.: Nucl. Phys. A 915 (2013) 24



- Interaction terms involving baryon and pseudoscalar meson octets …

$$P = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} & K^0 \\ K^- & \bar{K}^0 & -\frac{2\eta}{\sqrt{6}} \end{pmatrix} \qquad B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ -\Xi^- & \Xi^0 & -\frac{2\Lambda}{\sqrt{6}} \end{pmatrix}$$

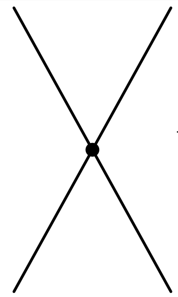
$$\mathcal{L}_1 = -\frac{\sqrt{2}}{2 f_0} \mathrm{tr}\left(D \bar{B} \gamma^\mu \gamma_5 \{\partial_\mu P, B\} + F \bar{B} \gamma^\mu \gamma_5 [\partial_\mu P, B]\right)$$

$$\mathcal{L}_2 = \frac{1}{4 f_0^2} \mathrm{tr}\left(\mathrm{i} \bar{B} \gamma^\mu \left[[P, \partial_\mu P], B\right]\right)$$

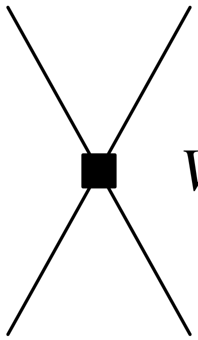
- … generate Nambu-Goldstone boson exchange processes

Hyperon - Nucleon Interaction
(contact terms)

see also:
S. Petschauer, N. Kaiser
Nucl. Phys. A 916 (2013) 1-29



$$V^{(0)}_{BB\to BB} = C_S + C_T \boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2$$

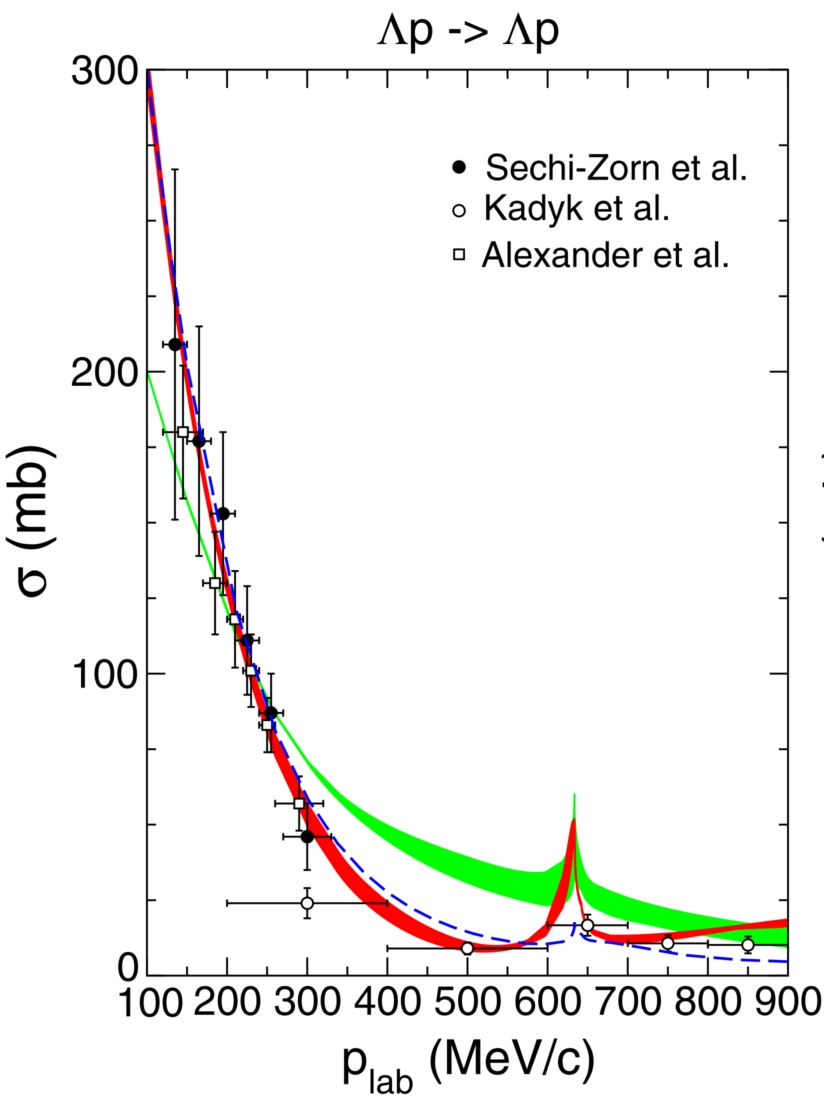


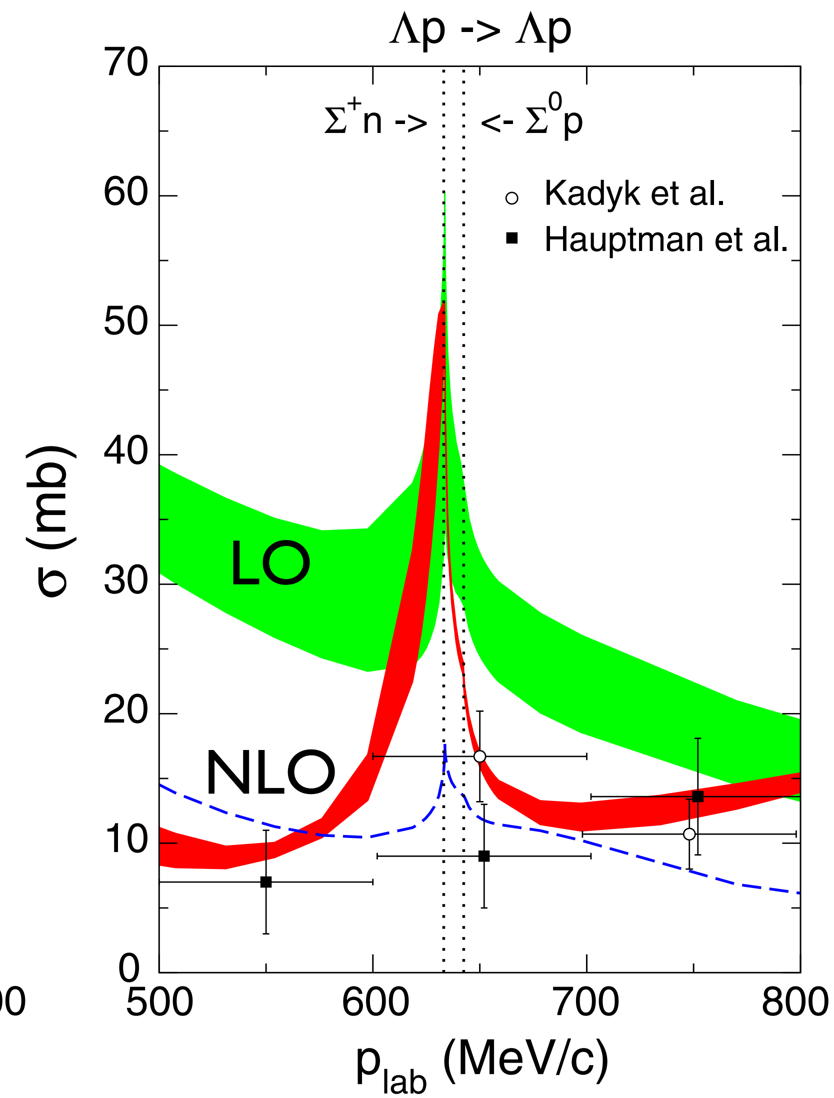
$$V^{(2)}_{BB\to BB} = C_1\mathbf{q}^2 + C_2\mathbf{k}^2 + \left(C_3\mathbf{q}^2 + C_4\mathbf{k}^2\right)\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2 + \frac{\mathrm{i}}{2}C_5(\boldsymbol{\sigma}_1+\boldsymbol{\sigma}_2)\cdot(\mathbf{q}\times\mathbf{k})$$
$$+ C_6(\mathbf{q}\cdot\boldsymbol{\sigma}_1)(\mathbf{q}\cdot\boldsymbol{\sigma}_2) + C_7(\mathbf{k}\cdot\boldsymbol{\sigma}_1)(\mathbf{k}\cdot\boldsymbol{\sigma}_2) + \frac{\mathrm{i}}{2}C_8(\boldsymbol{\sigma}_1-\boldsymbol{\sigma}_2)\cdot(\mathbf{q}\times\mathbf{k})$$

SU(3) relations for the various contact potentials in the isospin basis. C^{27}_ξ etc. refers to the corresponding irreducible SU(3) representation for a particular partial wave ξ. The actual potential still needs to be multiplied by pertinent powers of the momenta p and p'.

	Channel	I	$V(\xi)$		
			$\xi = {}^1S_0, {}^3P_0, {}^3P_1, {}^3P_2$	$\xi = {}^3S_1, {}^3S_1-{}^3D_1, {}^1P_1$	$\xi = {}^1P_1-{}^3P_1$
$S=0$	$NN\to NN$	0	–	$C^{10^*}_\xi$	–
	$NN\to NN$	1	C^{27}_ξ	–	–
$S=-1$	$\Lambda N\to\Lambda N$	$\frac{1}{2}$	$\frac{1}{10}(9C^{27}_\xi + C^{8_s}_\xi)$	$\frac{1}{2}(C^{8_a}_\xi + C^{10^*}_\xi)$	$\frac{-1}{\sqrt{20}}C^{8_s8_a}_\xi$
	$\Lambda N\to\Sigma N$	$\frac{1}{2}$	$\frac{3}{10}(-C^{27}_\xi + C^{8_s}_\xi)$	$\frac{1}{2}(-C^{8_a}_\xi + C^{10^*}_\xi)$	$\frac{-3}{\sqrt{20}}C^{8_s8_a}_\xi$
	$\Sigma N\to\Lambda N$				$\frac{1}{\sqrt{20}}C^{8_s8_a}_\xi$
	$\Sigma N\to\Sigma N$	$\frac{1}{2}$	$\frac{1}{10}(C^{27}_\xi + 9C^{8_s}_\xi)$	$\frac{1}{2}(C^{8_a}_\xi + C^{10^*}_\xi)$	$\frac{3}{\sqrt{20}}C^{8_s8_a}_\xi$
	$\Sigma N\to\Sigma N$	$\frac{3}{2}$	C^{27}_ξ	C^{10}_ξ	–

Hyperon - Nucleon Interaction
(contd.)

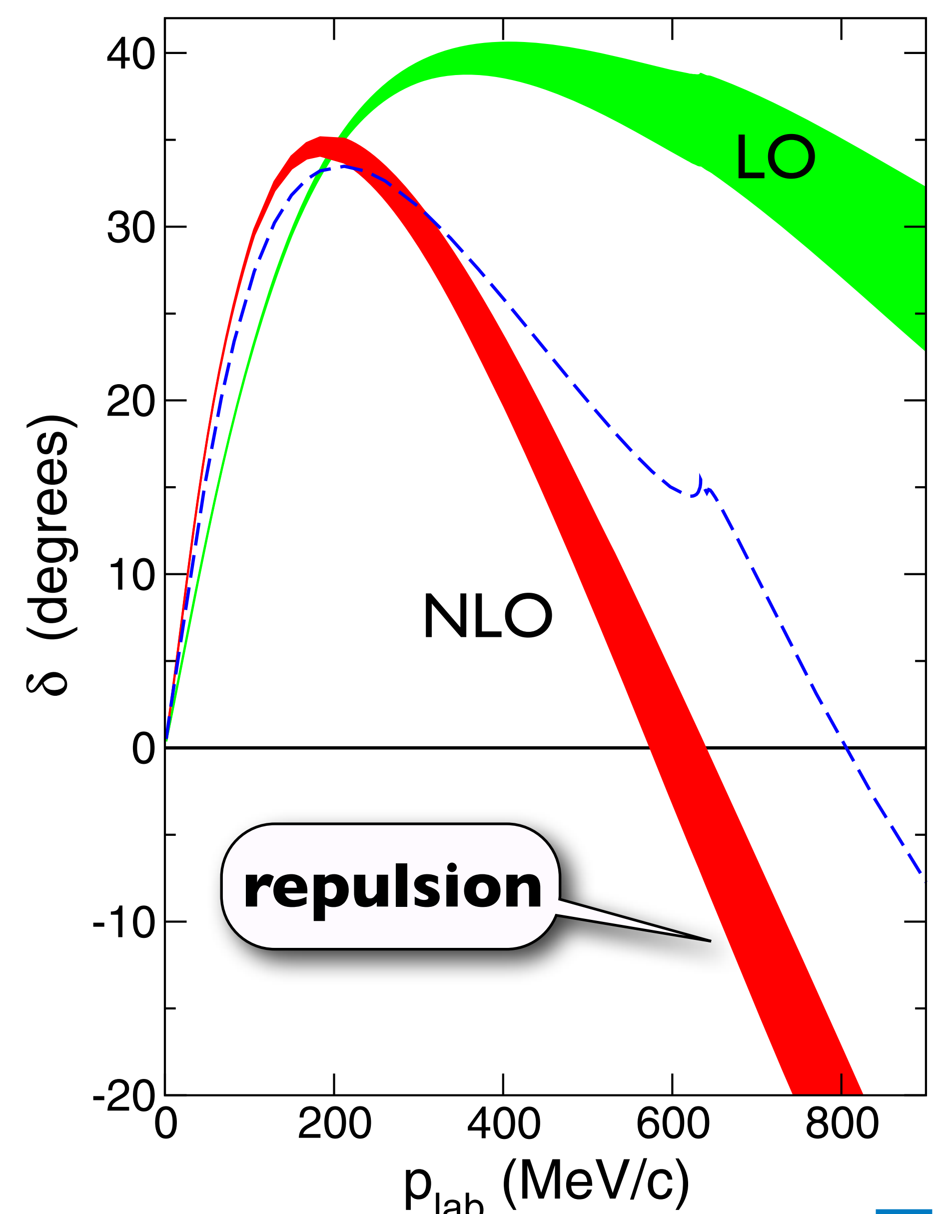




J. Haidenbauer, S. Petschauer, N. Kaiser,
U.-G. Meißner, A. Nogga, W.W.
Nucl. Phys. A 915 (2013) 24

phase shift

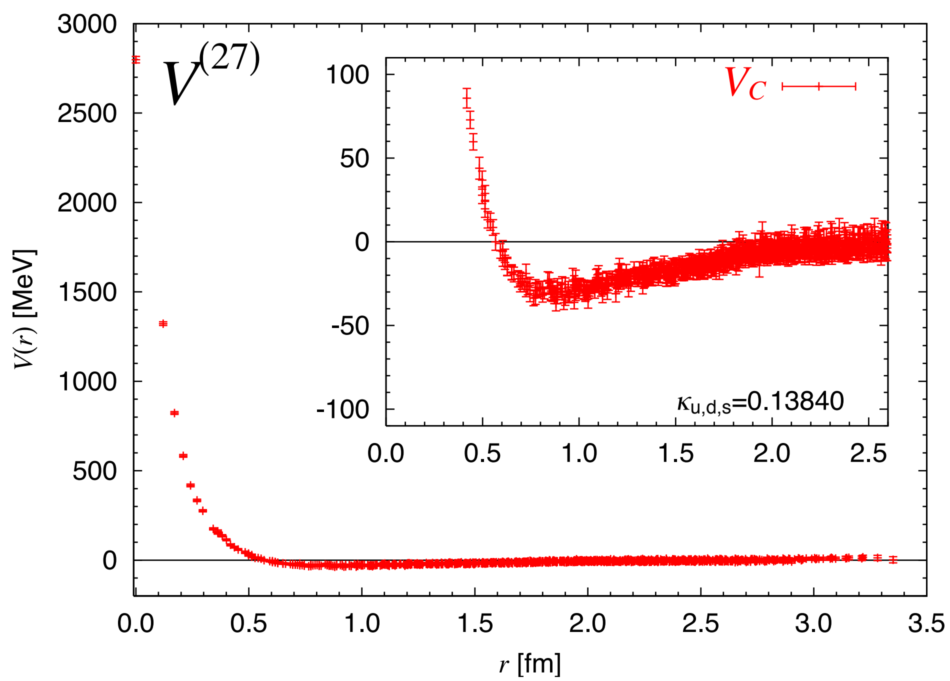
$\Lambda p\ ^1S_0$

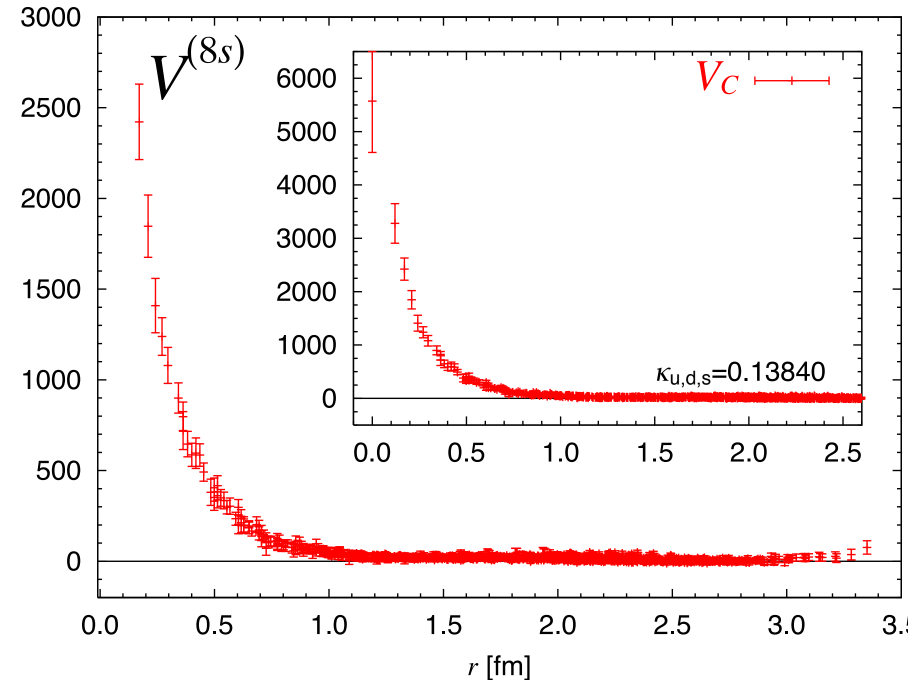


- note:
moderate attraction at low momenta
strong repulsion at higher momenta

Hyperon - Nucleon Interactions from Lattice QCD

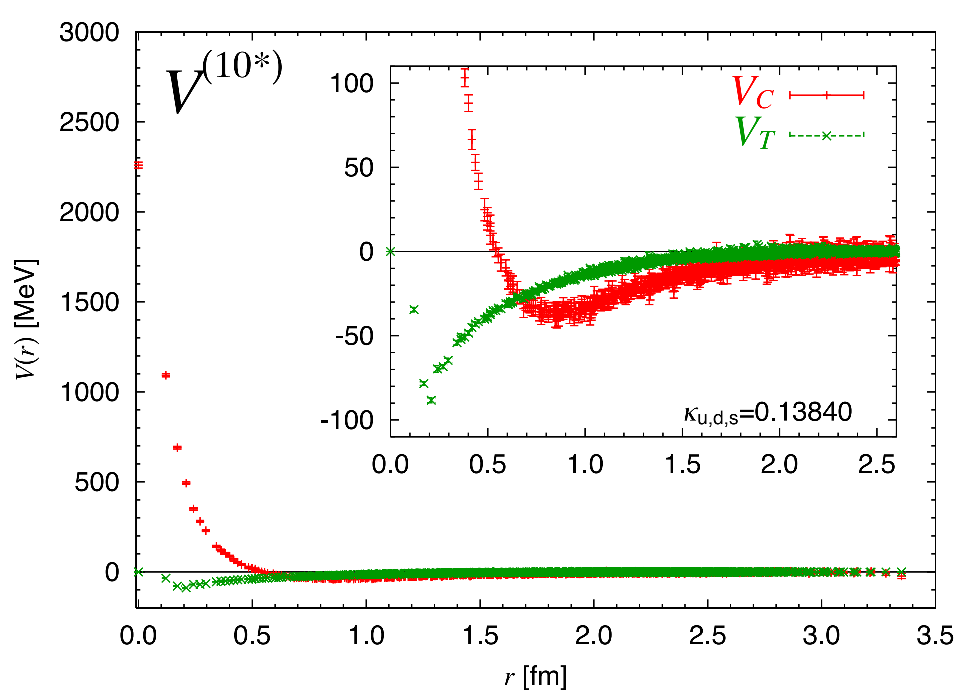
$$\Lambda\mathrm{N}(^1\mathrm{S}_0) = \frac{9}{10}[\mathbf{27}] + \frac{1}{10}[\mathbf{8_s}]$$

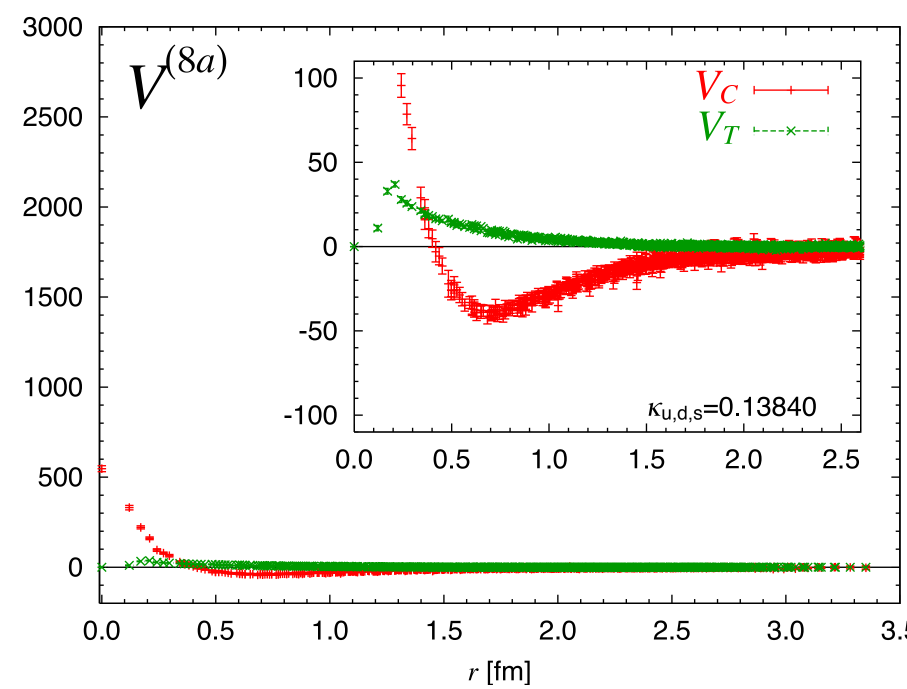




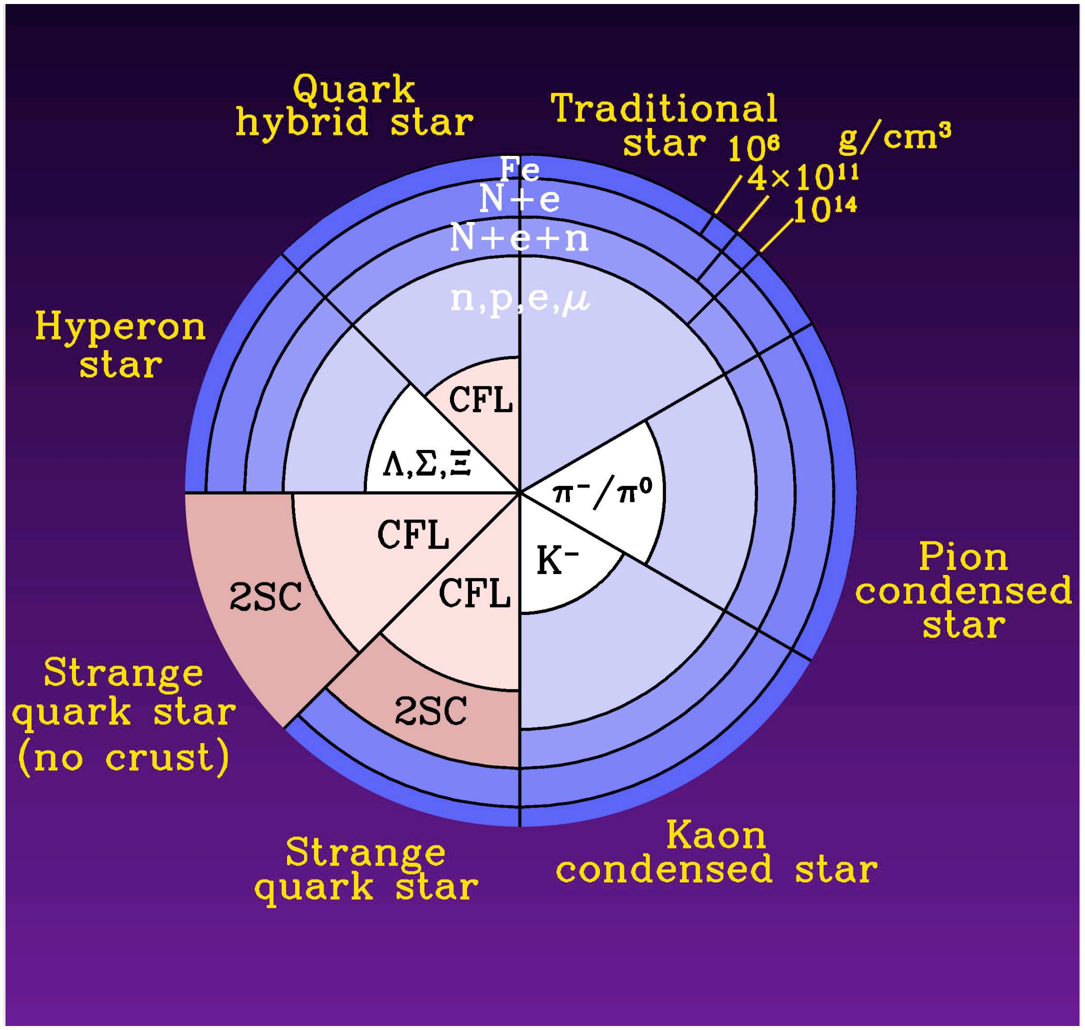
$$\mathrm{m_{ps}} = 0.47\,\mathrm{GeV}$$

$$\Lambda\mathrm{N}(^3\mathrm{S}_1) = \frac{1}{2}[\mathbf{10^*}] + \frac{1}{2}[\mathbf{8_a}]$$





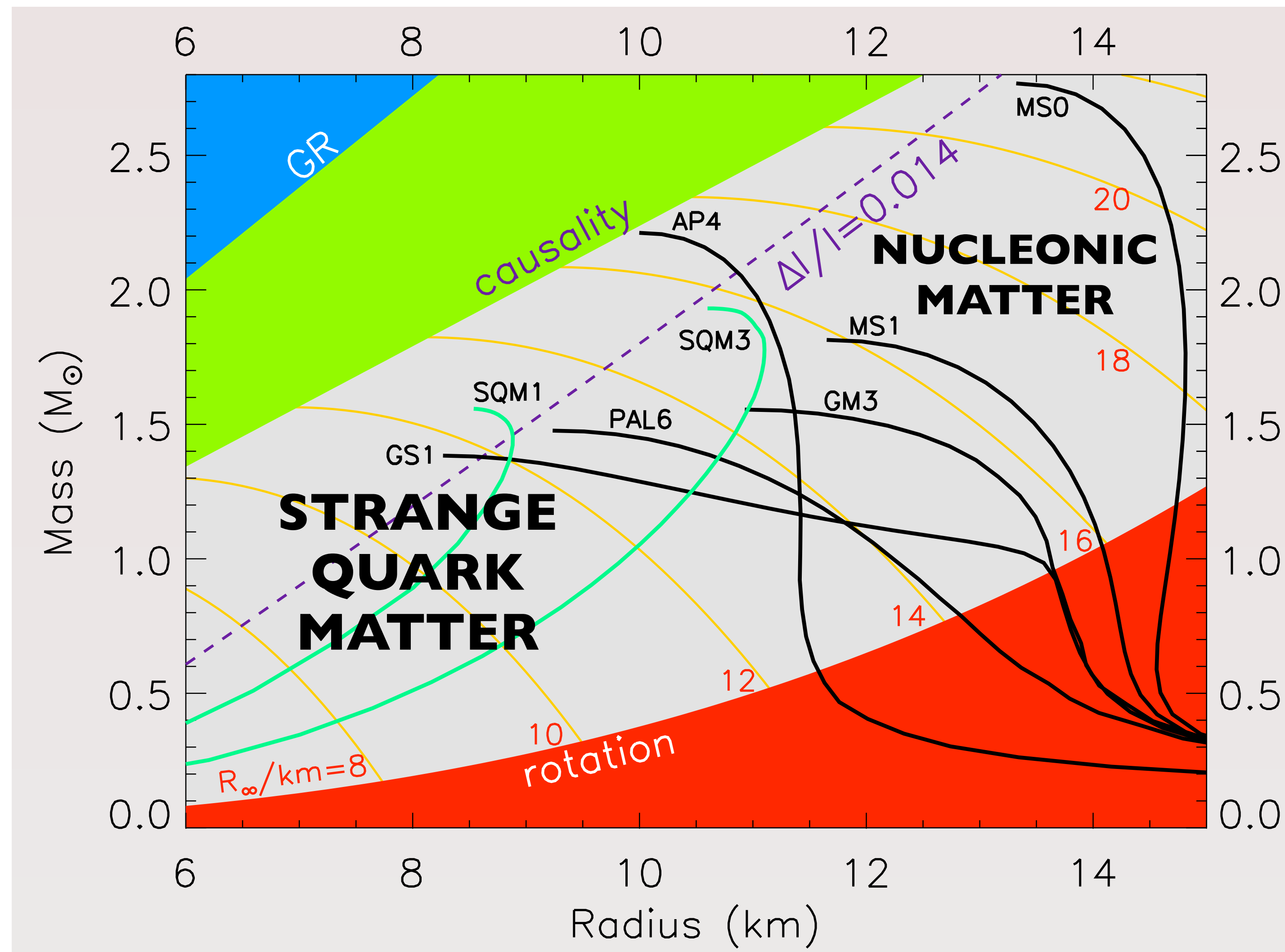
T. Inoue et al.
(HAL QCD)
PTP 124 (2010) 591
Nucl. Phys.
A881 (2012) 28



NEUTRON STARS and the EQUATION OF STATE of DENSE BARYONIC MATTER

J. Lattimer, M. Prakash: Astrophys. J. 550 (2001) 426
Phys. Reports 442 (2007) 109

- **Mass-Radius Relation**



Neutron Star Scenarios

Tolman-**O**ppenheimer-**V**olkov Equations

$$\frac{dP}{dr} = -\frac{G}{c^2}\frac{(M+4\pi P r^3)(\mathcal{E}+P)}{r(r-GM/c^2)}$$

$$\frac{dM}{dr} = 4\pi r^2 \frac{\mathcal{E}}{c^2}$$

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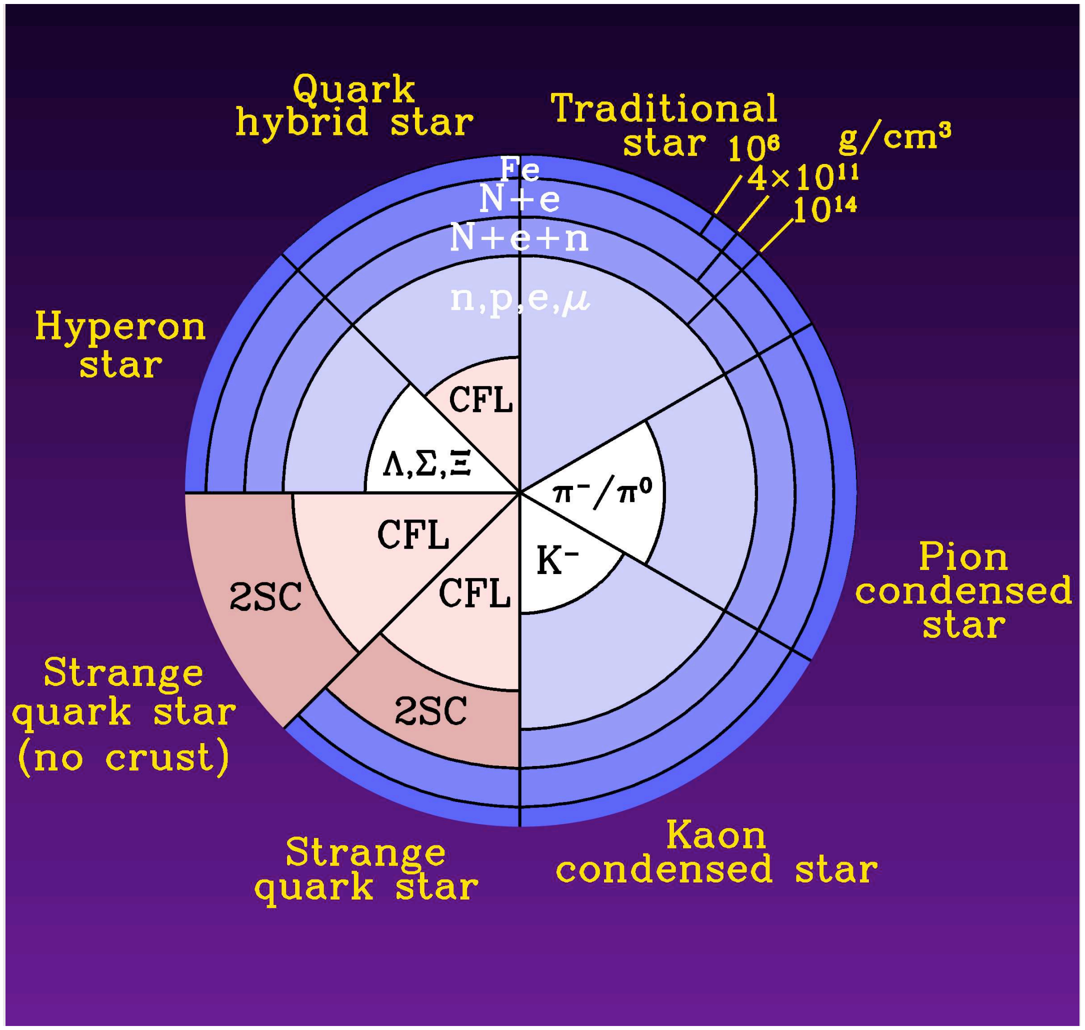

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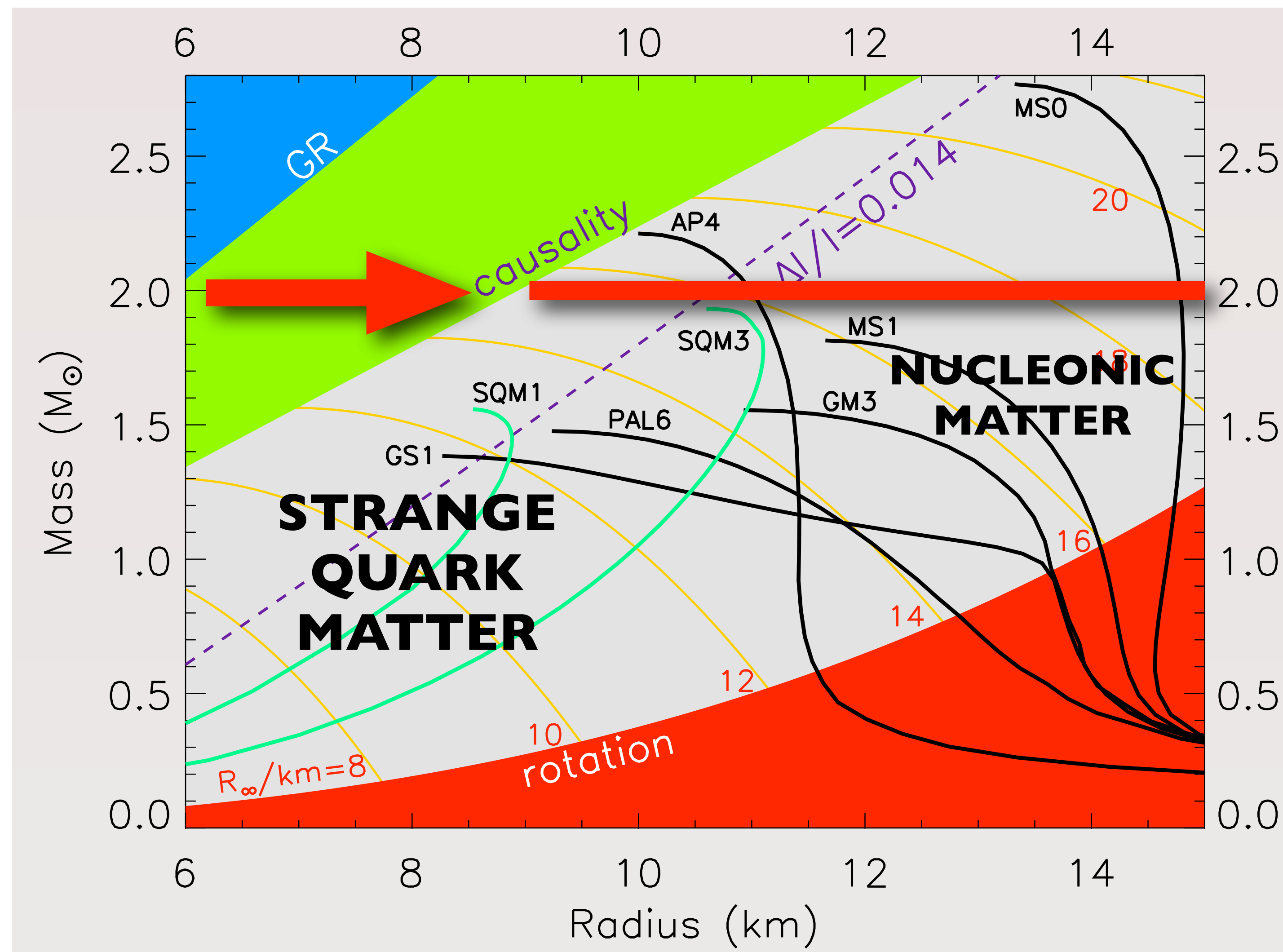

Neutron Star Scenarios

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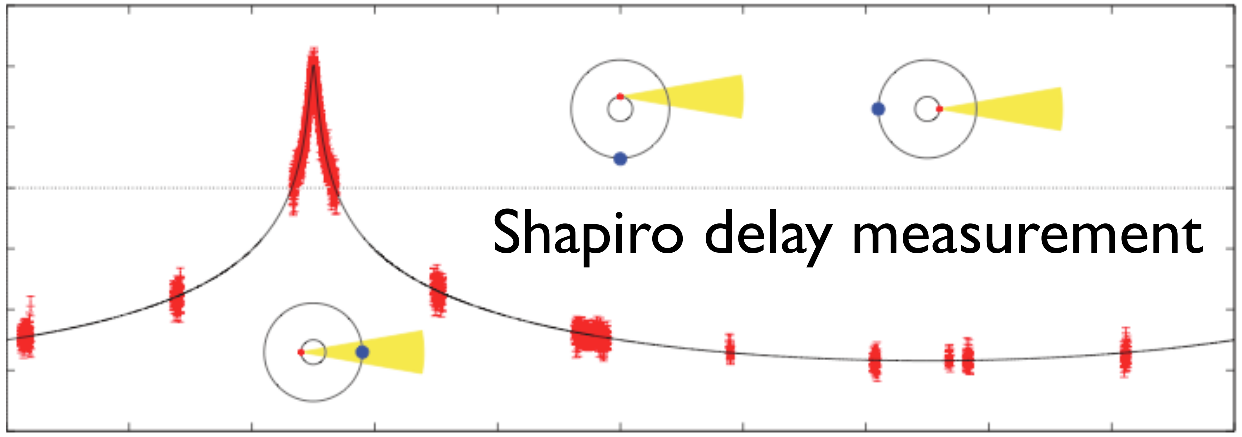
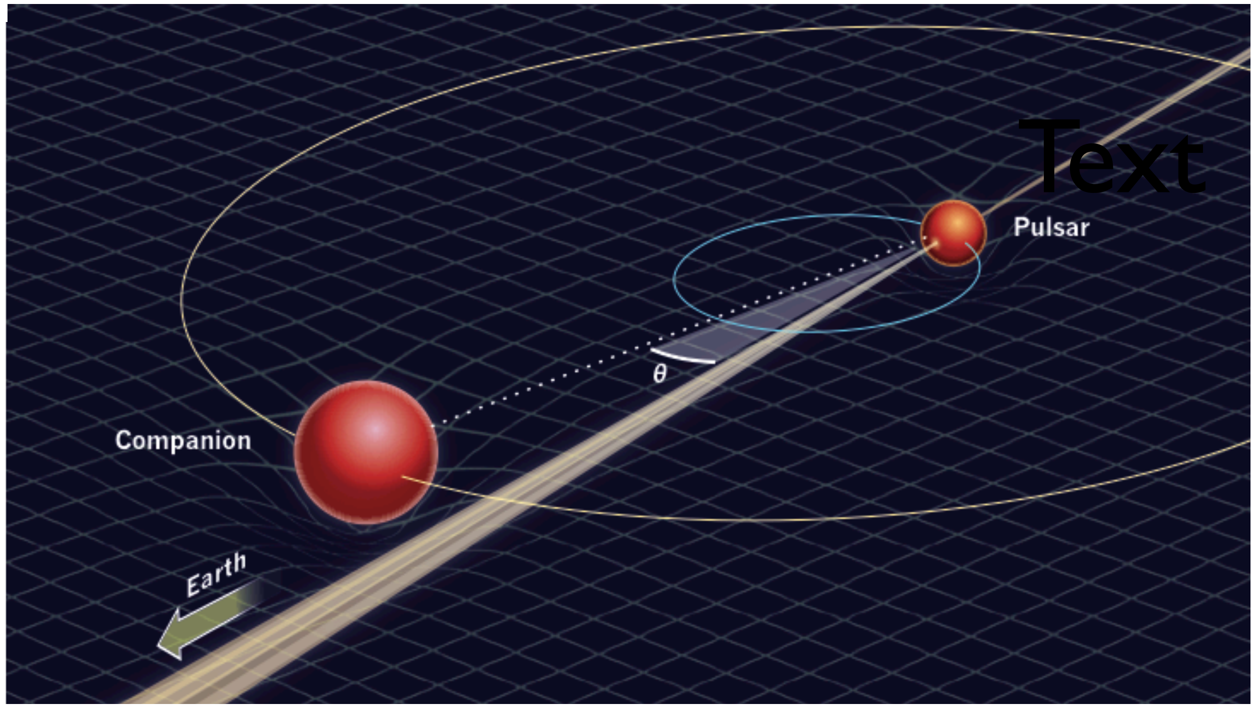
New constraints from NEUTRON STARS

P.B. Demorest et al.
Nature 467 (2010) 1081

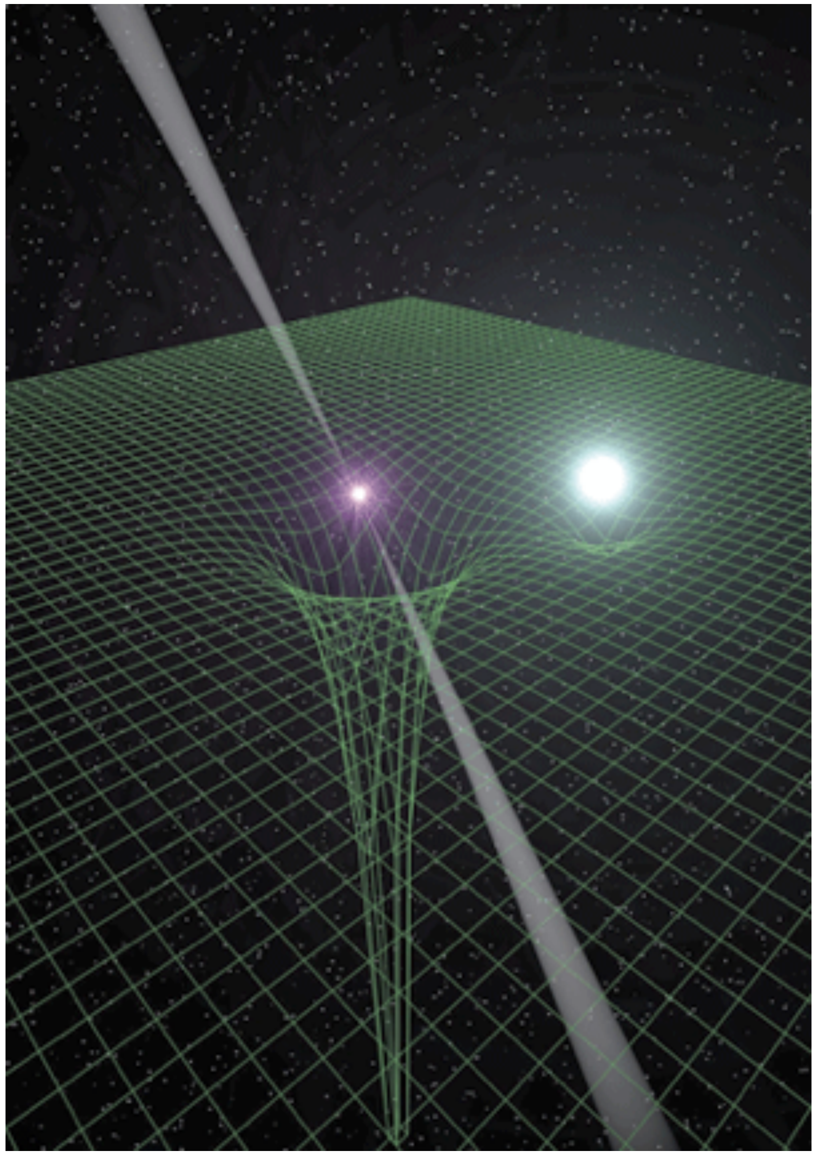




PSR J1614+2230

$$\mathrm{M} = 1.97 \pm 0.04\ \mathrm{M}_\odot$$

J. Antoniadis et al.
Science 340 (2013) 6131



PSR J0348+0432

$$\mathrm{M} = 2.01 \pm 0.04\ \mathrm{M}_\odot$$

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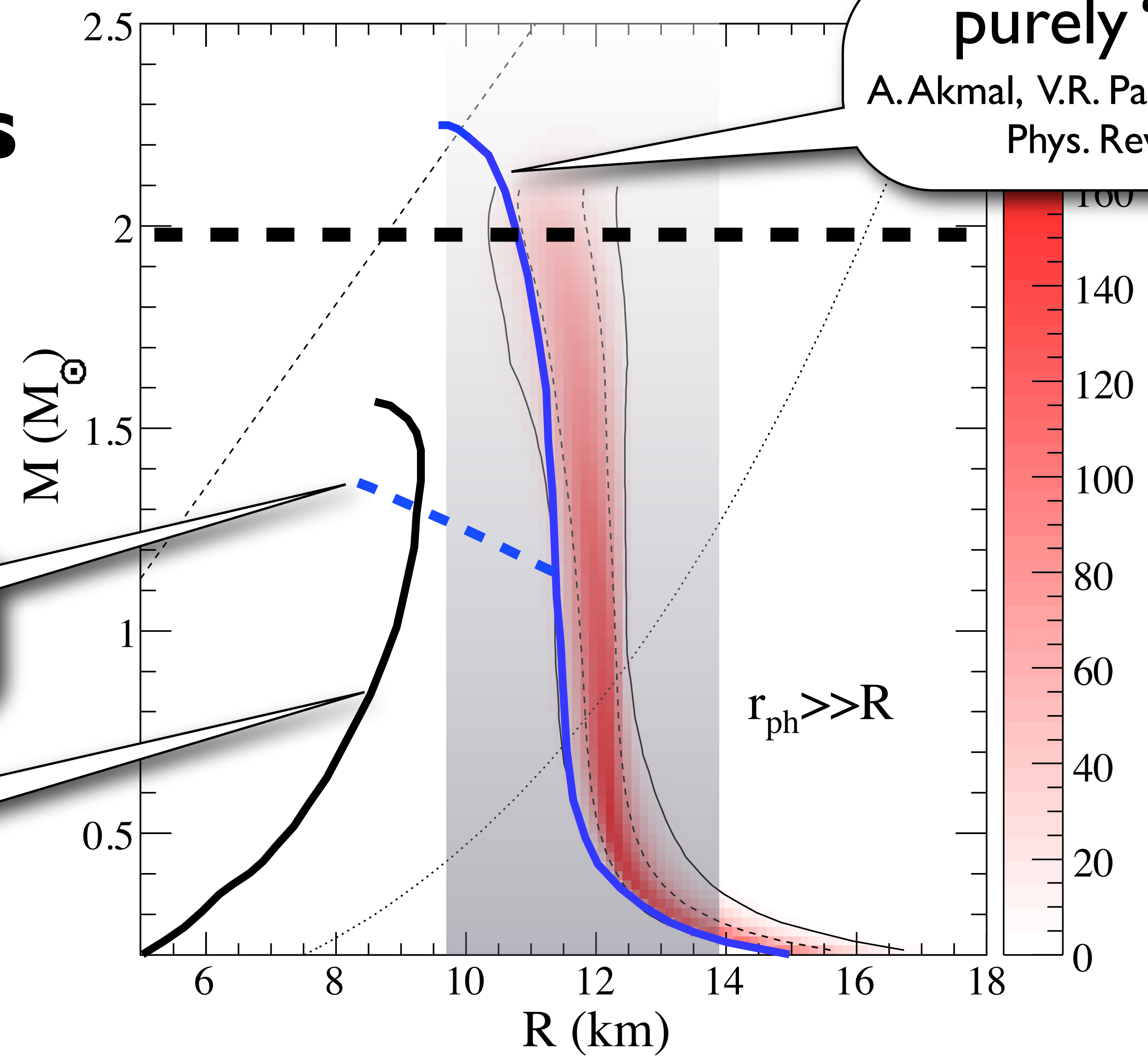
News from NEUTRON STARS

- Constraints from **neutron star observables**

F. Özil, D. Psaltis: Phys. Rev. D80 (2009) 103003
F. Özil, G. Baym, T. Güver: Phys. Rev. D82 (2010)101301

Mass-Radius Relation



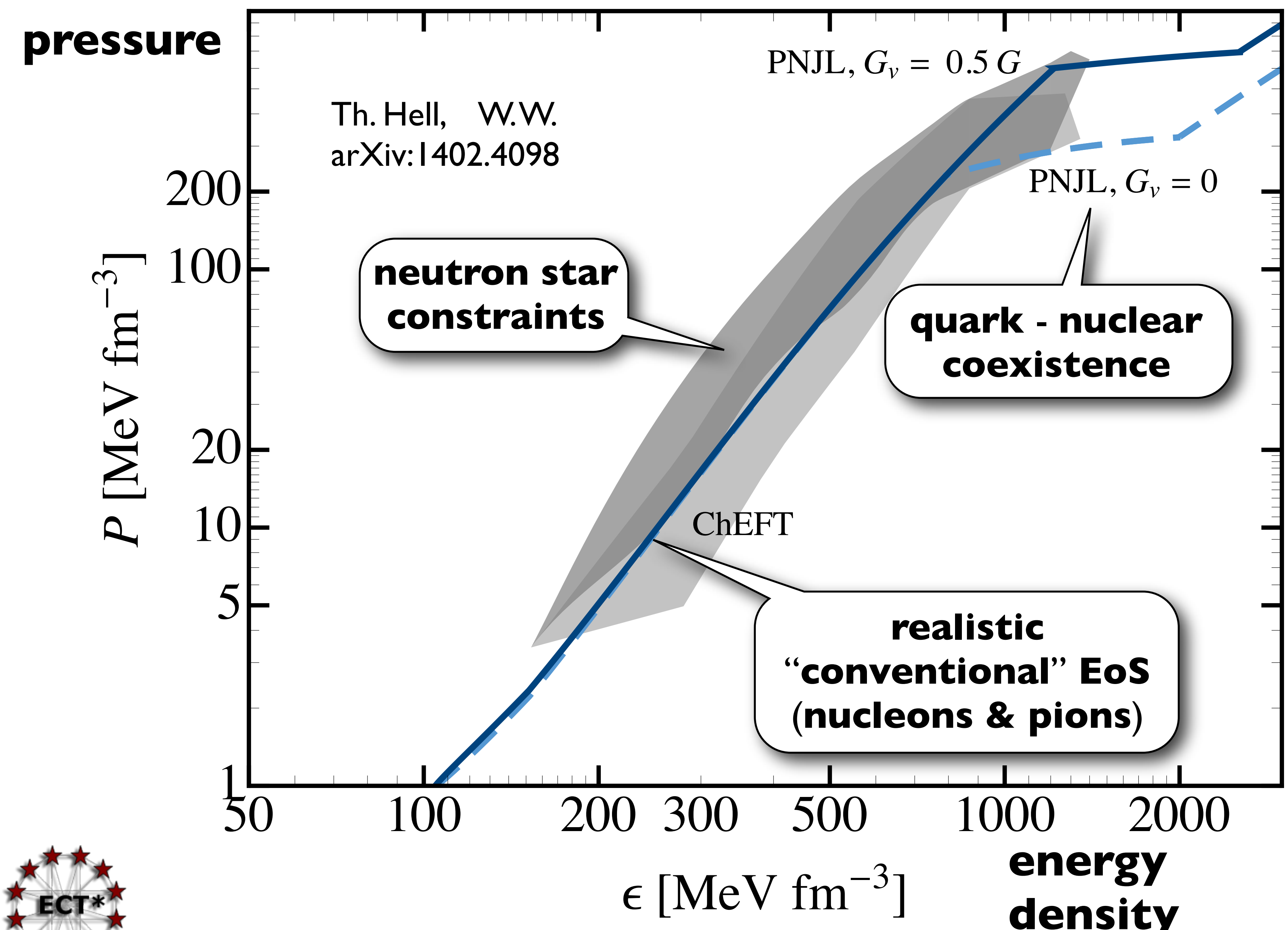
K. Hebeler, J. Lattimer, C. Pethick, A. Schwenk: Phys. Rev. Lett. 105 (2010) 161102

A.W. Steiner, J. Lattimer, E.F. Brown Astroph. J. 722 (2010) 33

- "**Exotic**" equations of state ruled out ?

NEUTRON STAR MATTER
Equation of State

- In-medium **C**hiral **E**ffective **F**ield **T**heory up to 3 loops (reproducing thermodynamics of normal nuclear matter)
- 3-flavor PNJL (chiral quark) model at high densities (incl. **strange** quarks)

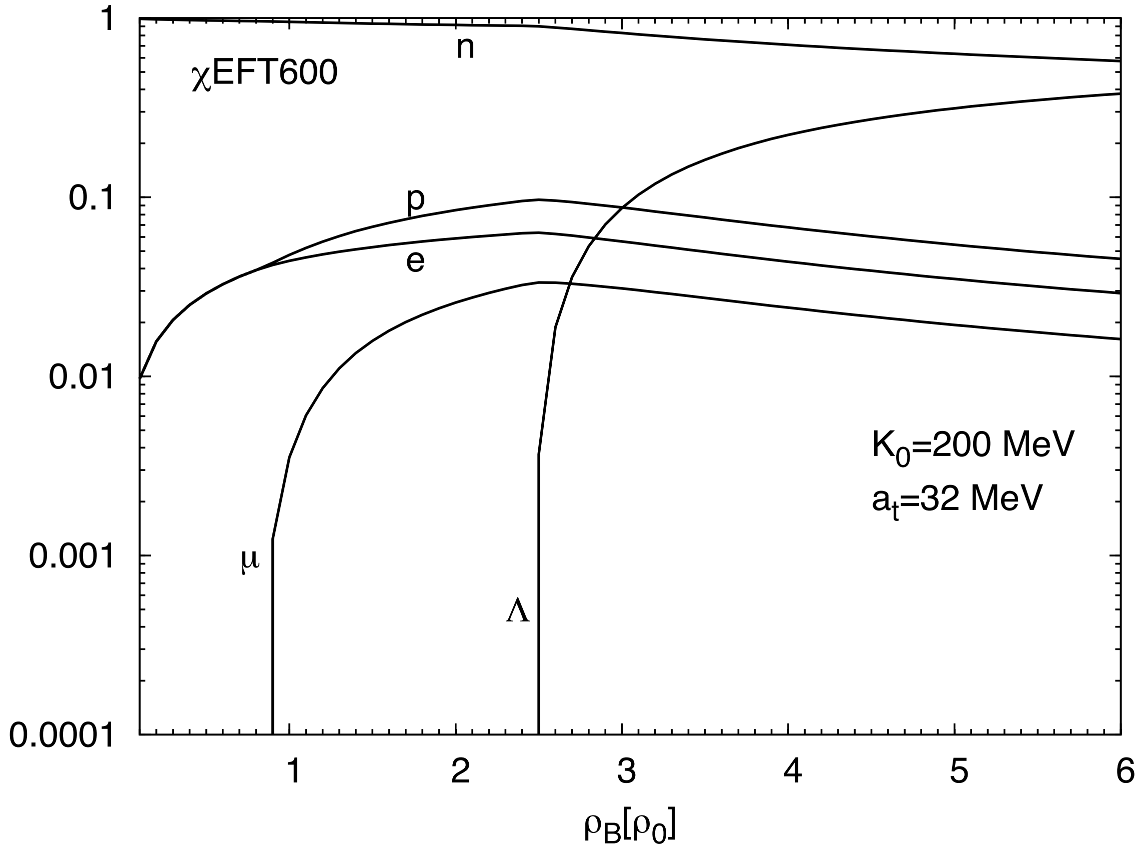


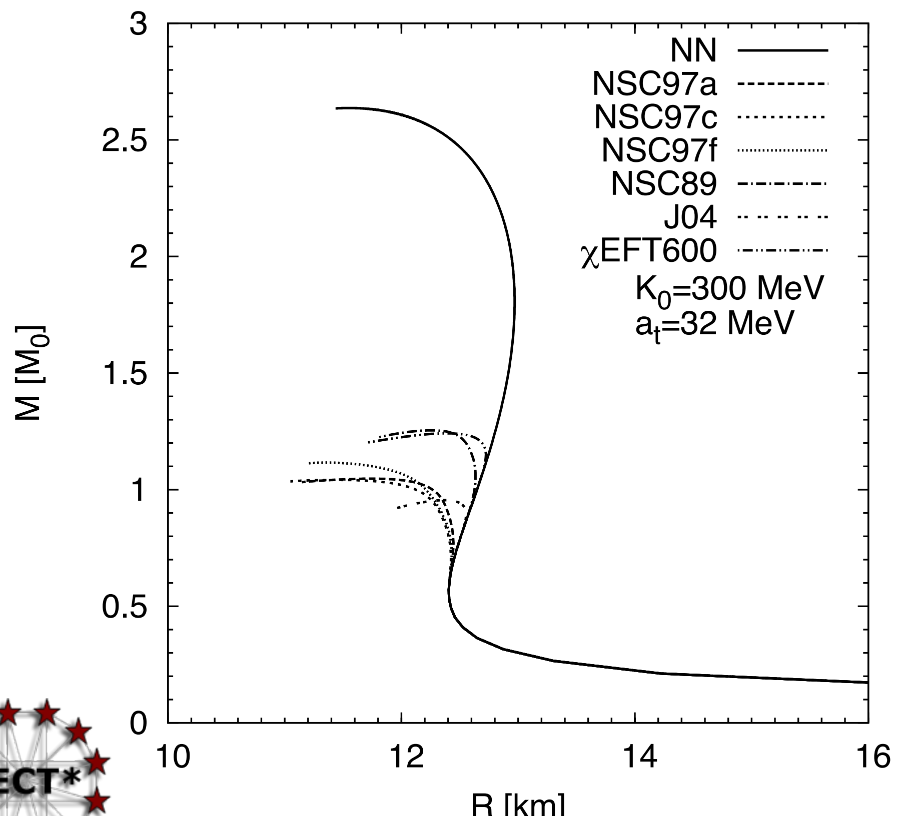
- beta equilibrium
  $\mathbf{n} \leftrightarrow \mathbf{p} + e, \mu$
- charge conservation
- coexistence region: **Gibbs conditions**

- **quark-nuclear** coexistence occurs (if at all) at baryon densities $\rho > \mathbf{5}\ \rho_0$

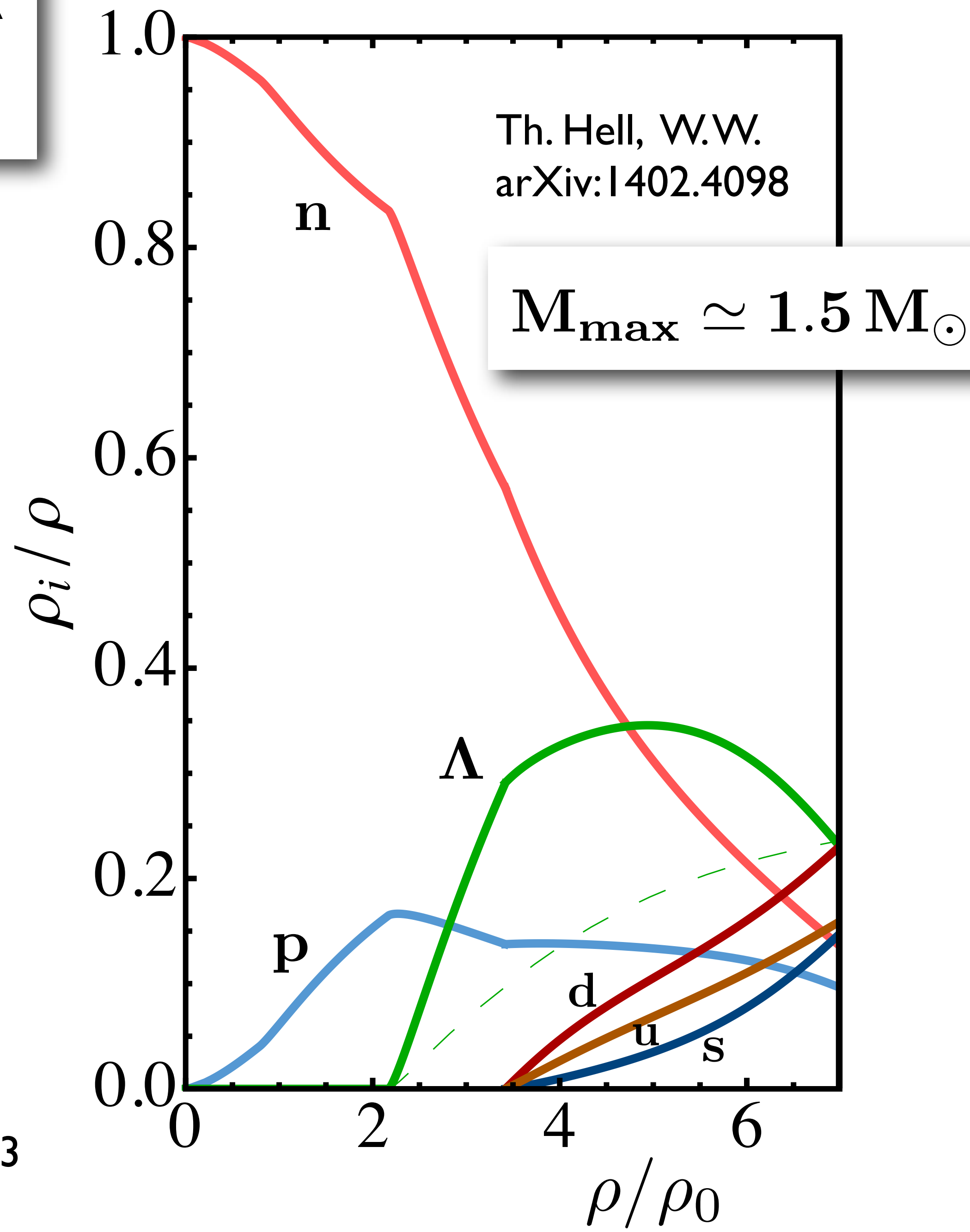
see also:
K. Masuda, T. Hatsuda, T. Takatsuka
PTEP (2013) 7, 073D01

NEUTRON STAR MATTER including HYPERONS





H. Djapo,
B.-J. Schaefer,
J. Wambach
Phys. Rev. C81 (2010) 035803



with inclusion of hyperons:
EoS **too soft** to support 2 solar mass star unless strong short-range **repulsion** in YN and / or YNN interactions

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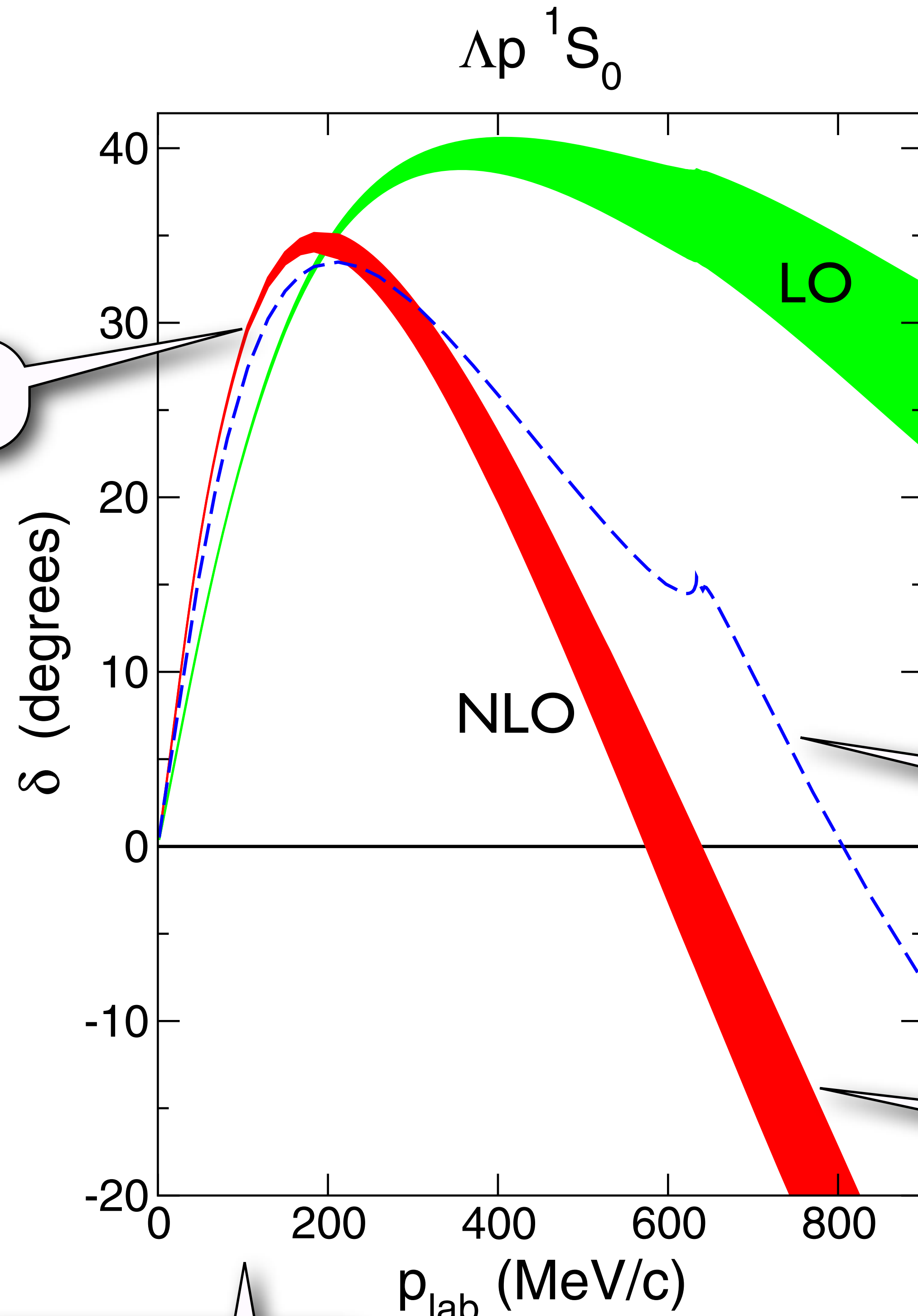
recall:

Chiral SU(3) Effective Field Theory and Hyperon-Nucleon Interactions



phase shift

attraction

phenomenological potential

repulsion

hypernuclei

neutron star matter

SUMMARY

- **Chiral SU(3) Effective Field Theory**
  - realization of **low-energy QCD** with **strange quarks**
  - well-defined framework
    both for **antikaon**- and **hyperon**-nuclear systems
- Active communication between **theory** and **experiment**
  - **progress** in understanding the $\Lambda(1405)$
  - $\bar{\mathrm{K}}\mathrm{NN}$ **threshold** and **subthreshold** physics:
    focused experimental programmes
- Role of **strangeness** in **dense matter**
  - new constraints from **two-solar-mass neutron stars**:
    stiff equaton-of-state
  - consequences for hyperon-nuclear two- and three-body interactions:
    quest for strong short-distance **repulsion**