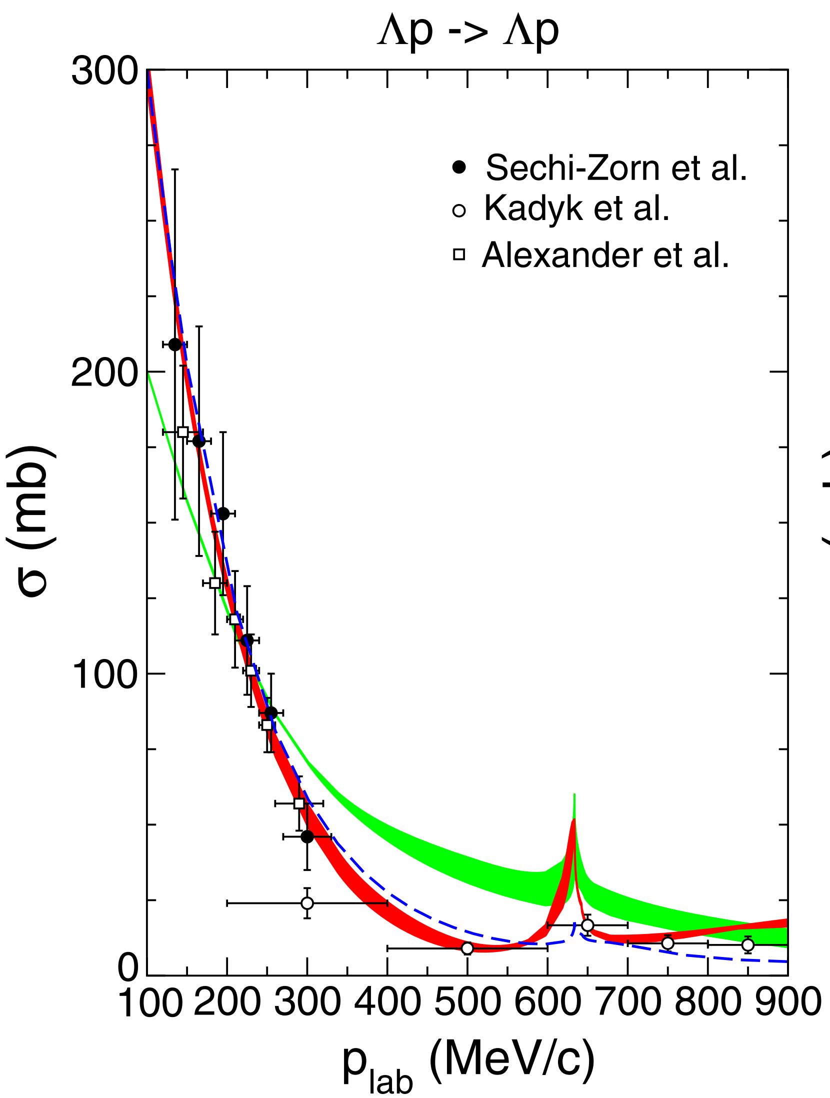
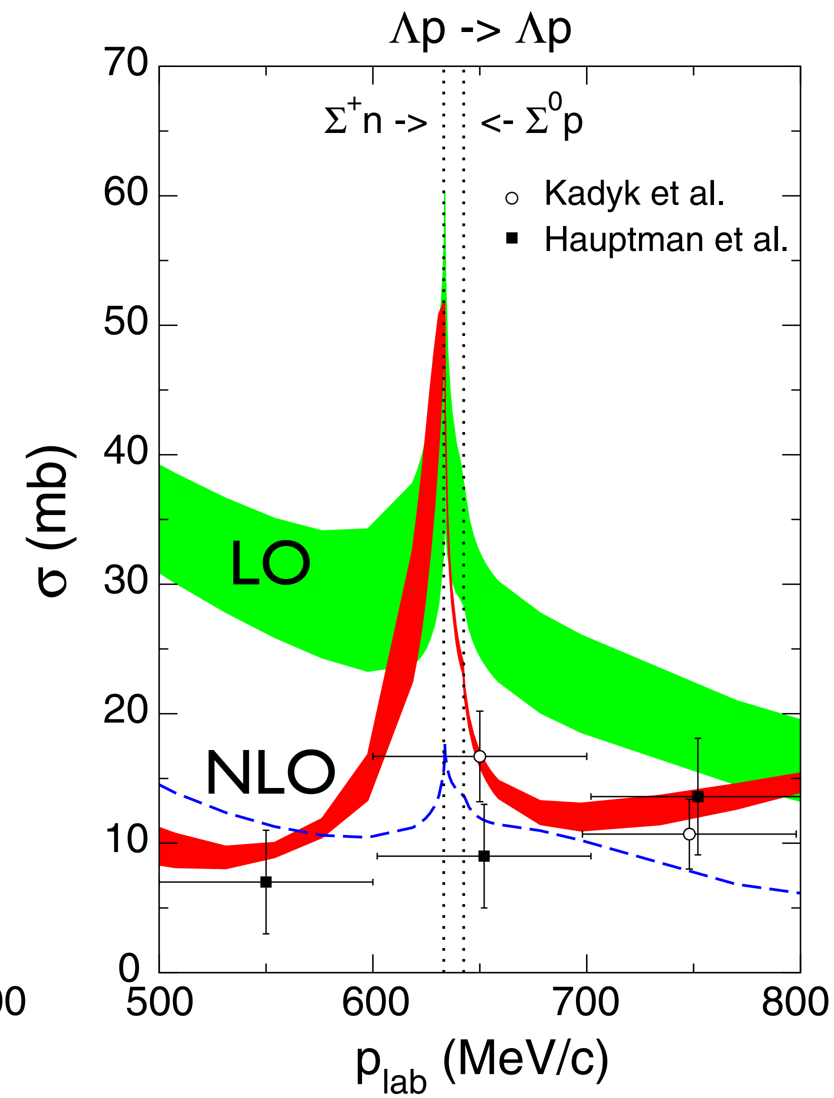
Round Table
on open issues in
Strangeness-Nuclear Physics

ECT*
Wolfram Weise (Coordinator)
Trento and Technische Universität München

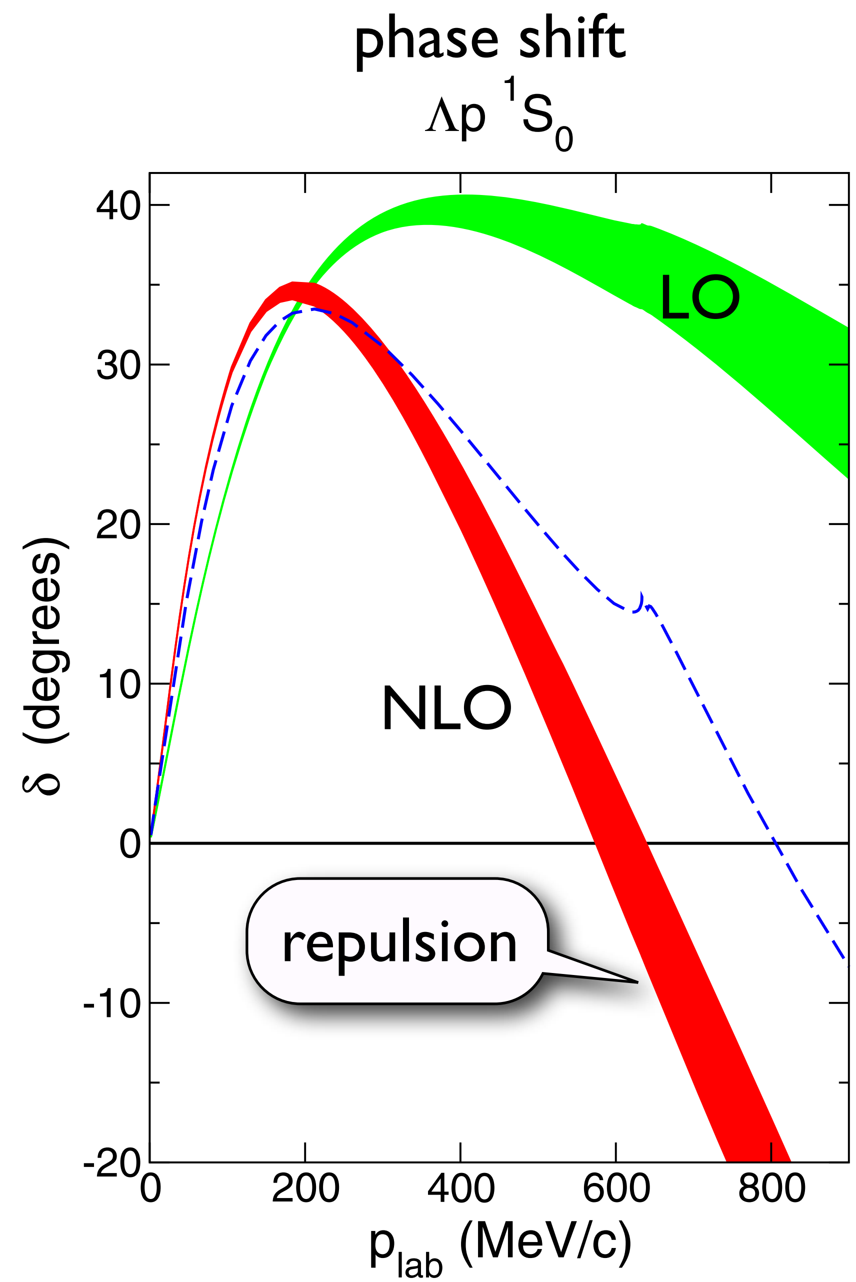
- Strangeness in Low-Energy QCD: **Chiral SU(3) Effective Field Theory**
  - **Hyperon-Nucleon** Interaction from **Chiral SU(3) Dynamics**
  - **Hyper-Three-Body Forces** and **Hypernuclei**
- **Two-Solar-Mass Neutron Stars** and their implications
  - Role of **strangeness** (hyperons and related)
- **Physics** of the $\Lambda(1405)$: new experimental data
- **Kaonic Deuterium** and **K-deuteron scattering length**

Hyperon - Nucleon Interaction





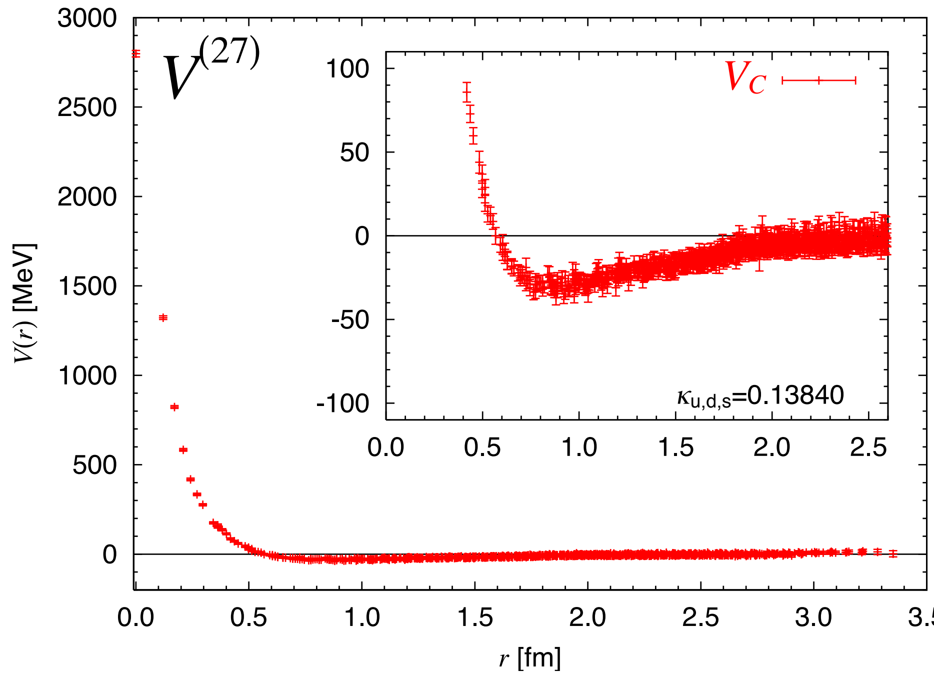
J. Haidenbauer, S. Petschauer, N. Kaiser, U.-G. Meißner, A. Nogga, W.W. Nucl. Phys. A 915 (2013) 24

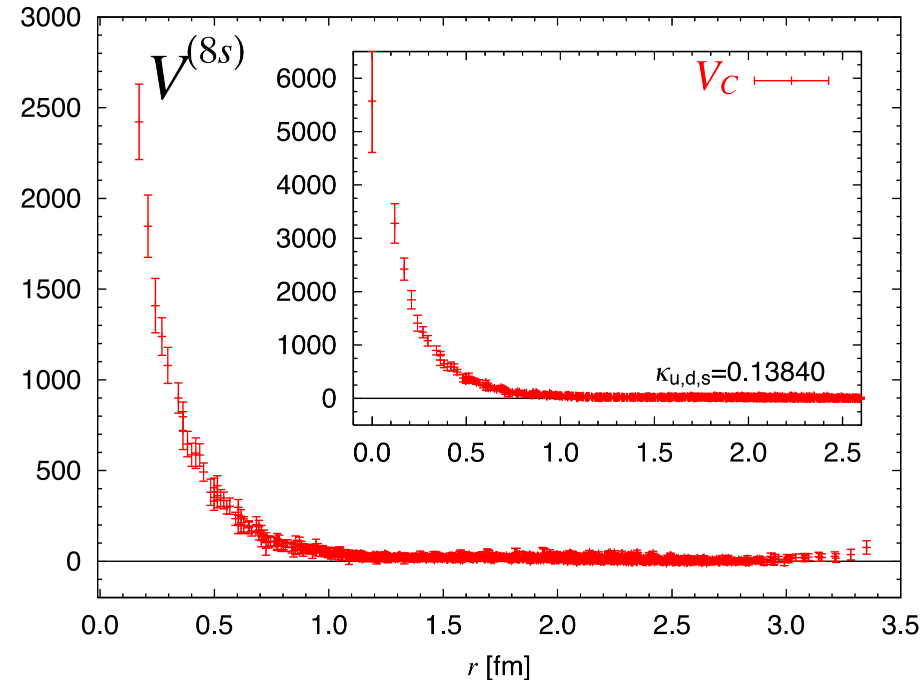


- note:
  moderate **attraction** at low momenta
  strong **repulsion** at higher momenta

Hyperon - Nucleon Interactions from **Lattice QCD**

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

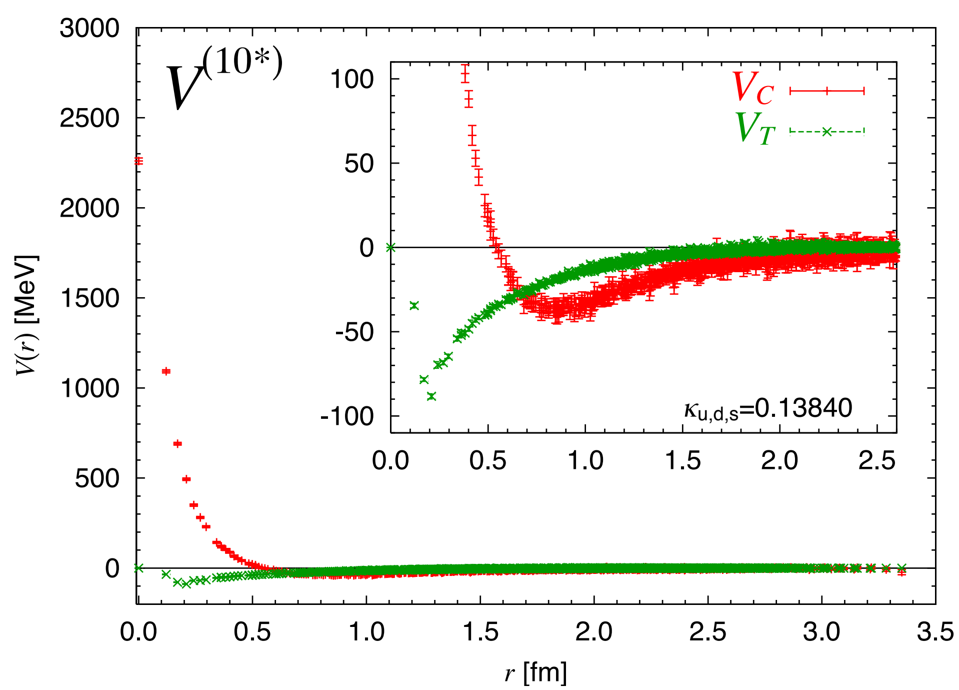


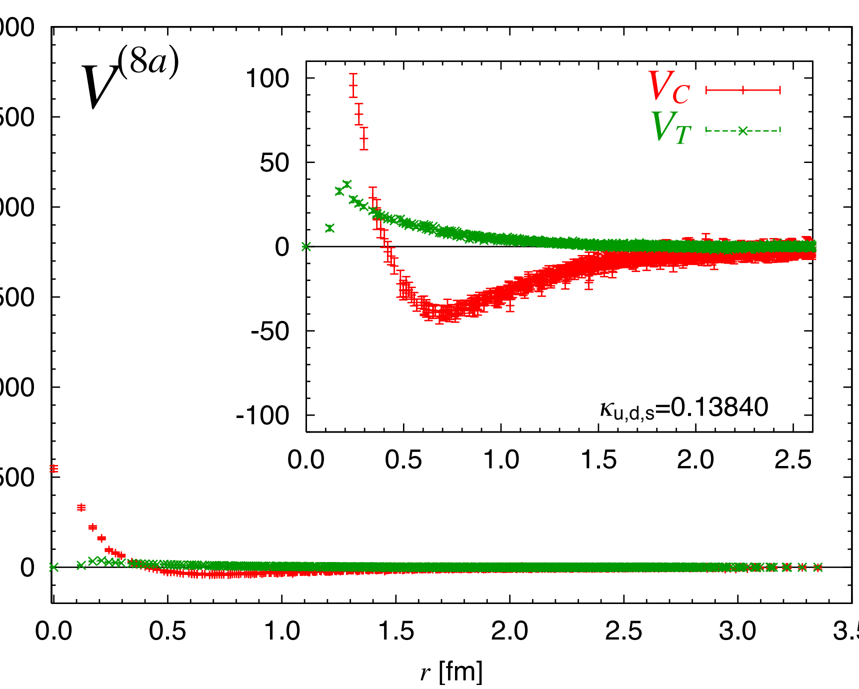


$$\mathrm{m_{ps}} = 0.47\,\mathrm{GeV}$$

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

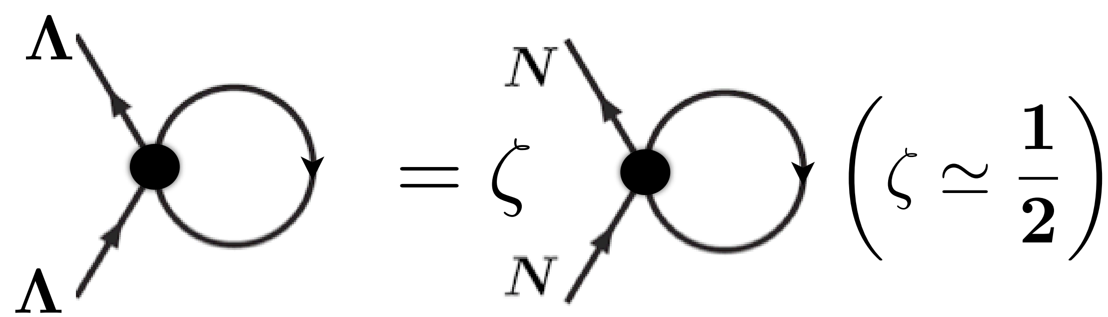
$$\Lambda \mathrm{N}(^3\mathrm{S}_1) = \frac{1}{2}[\mathbf{10^*}] + \frac{1}{2}[\mathbf{8_a}]$$





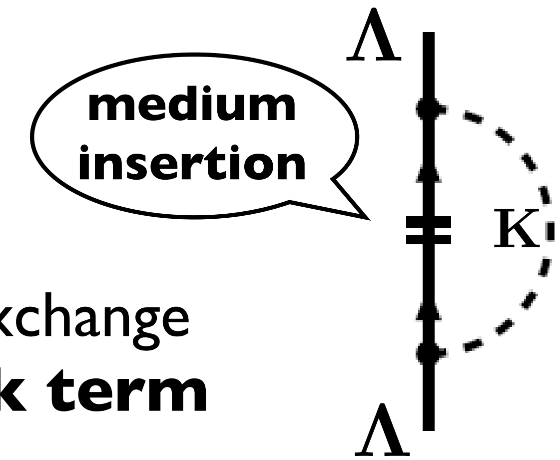
Hypernuclei and **Chiral SU(3) Effective Field Theory**

- **Input**:



short-distance (contact) terms

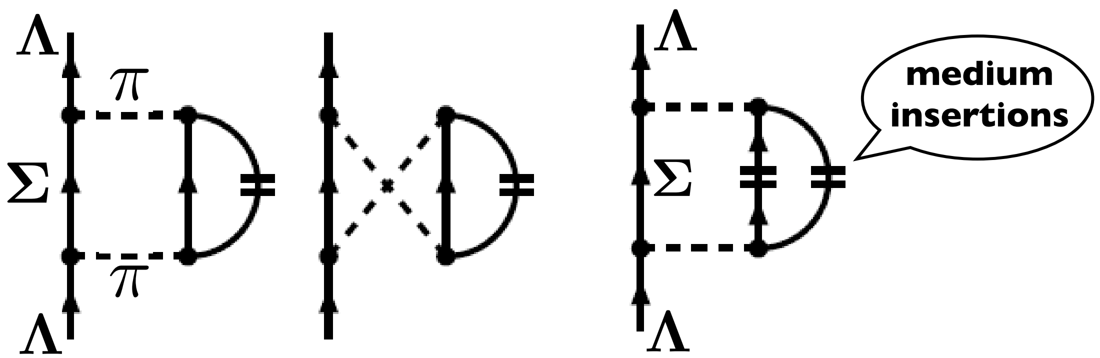
- **small**:



K exchange
Fock term

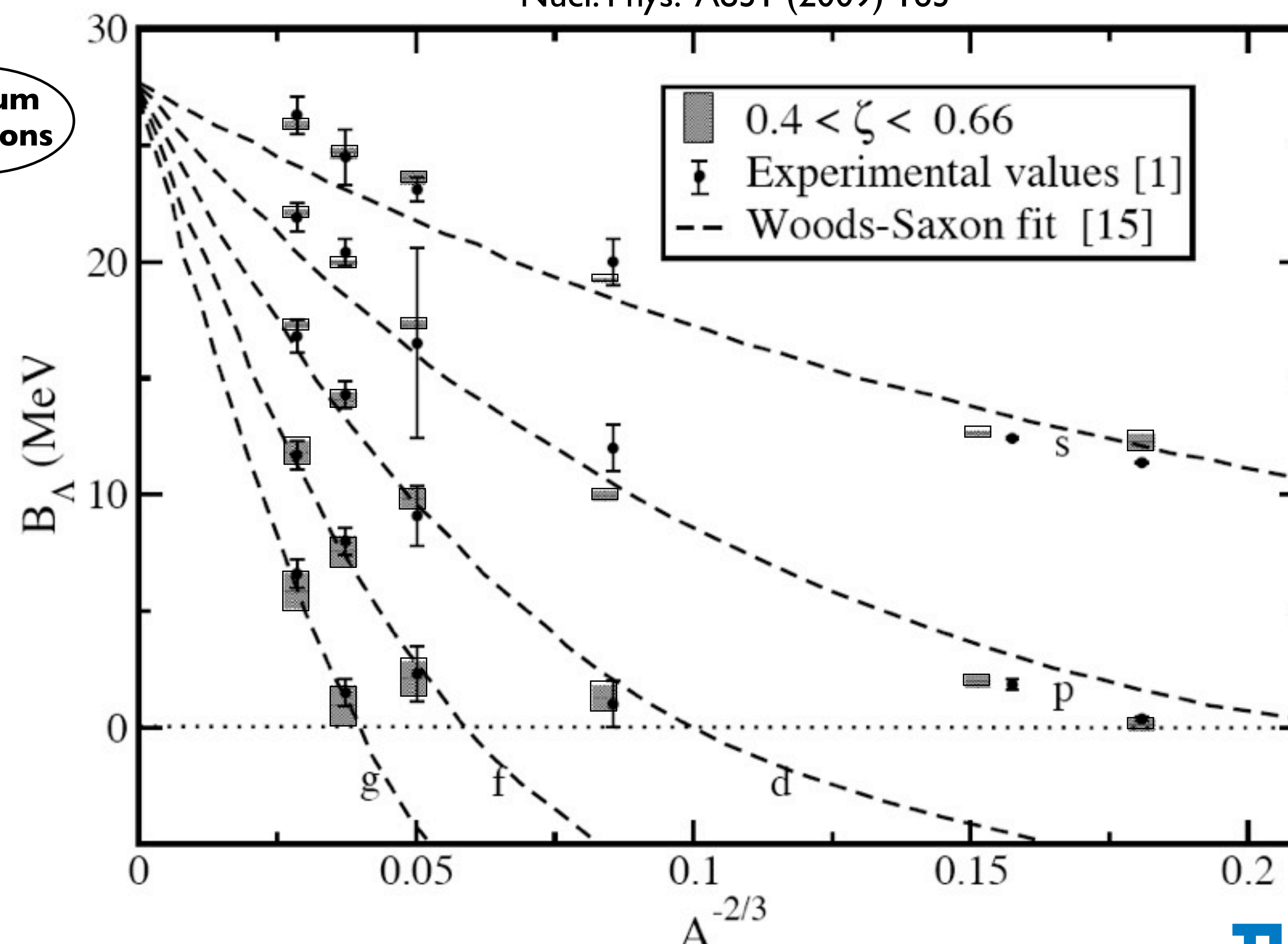
- **large**:

two-pion exchange mechanisms



N. Kaiser, W.W. Phys. Rev. C71 (2005) 015203

P. Finelli, N. Kaiser, D.Vretenar, W.W.
Nucl. Phys. A831 (2009) 163



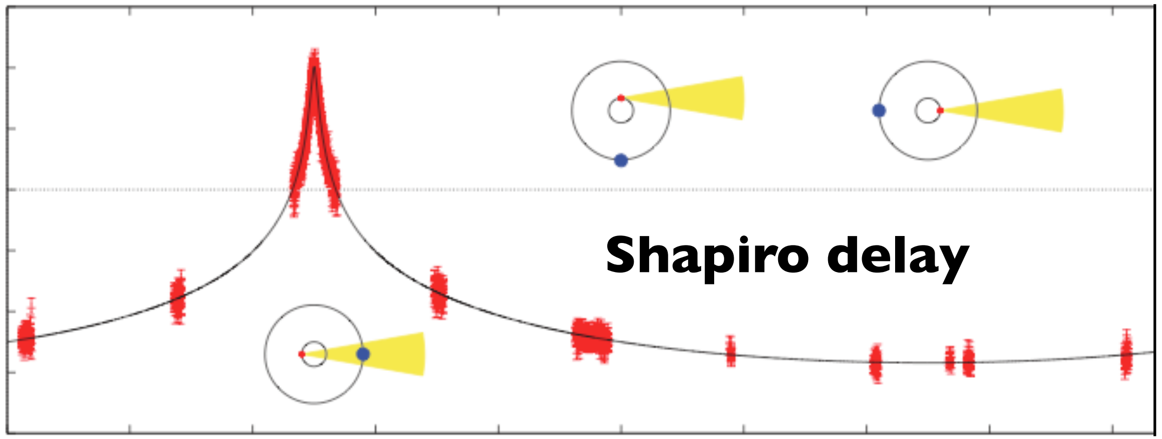
- **Issues**:

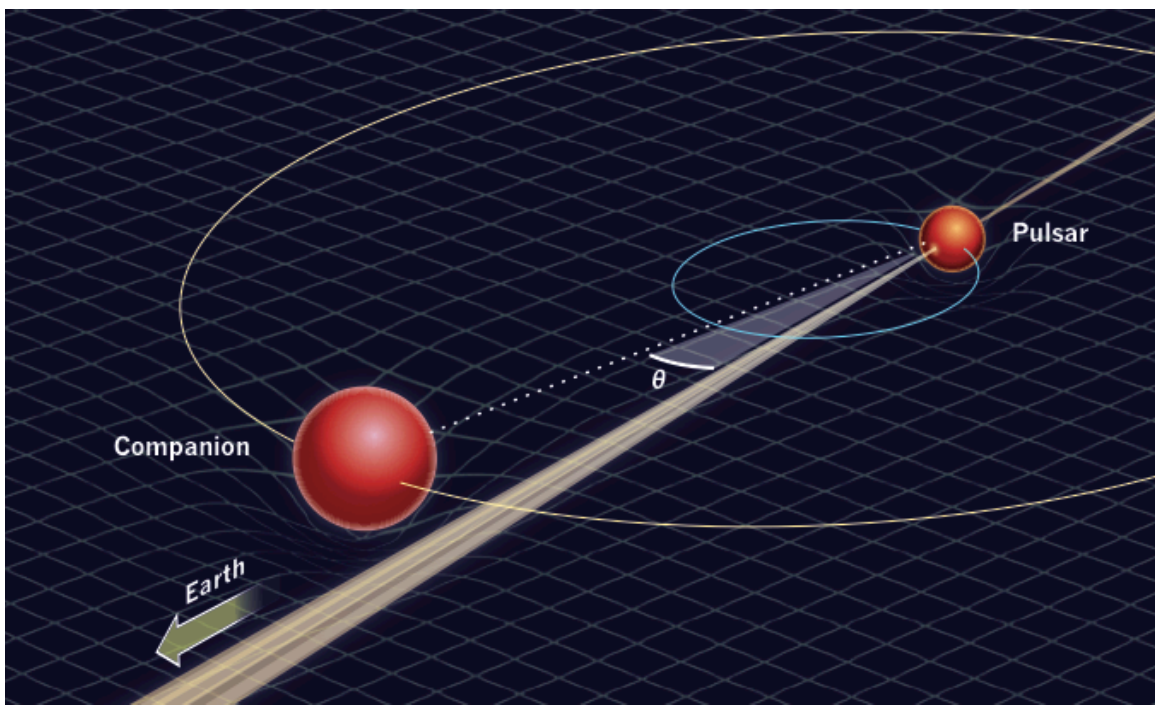
Short-range repulsion
and
YNN three-body forces

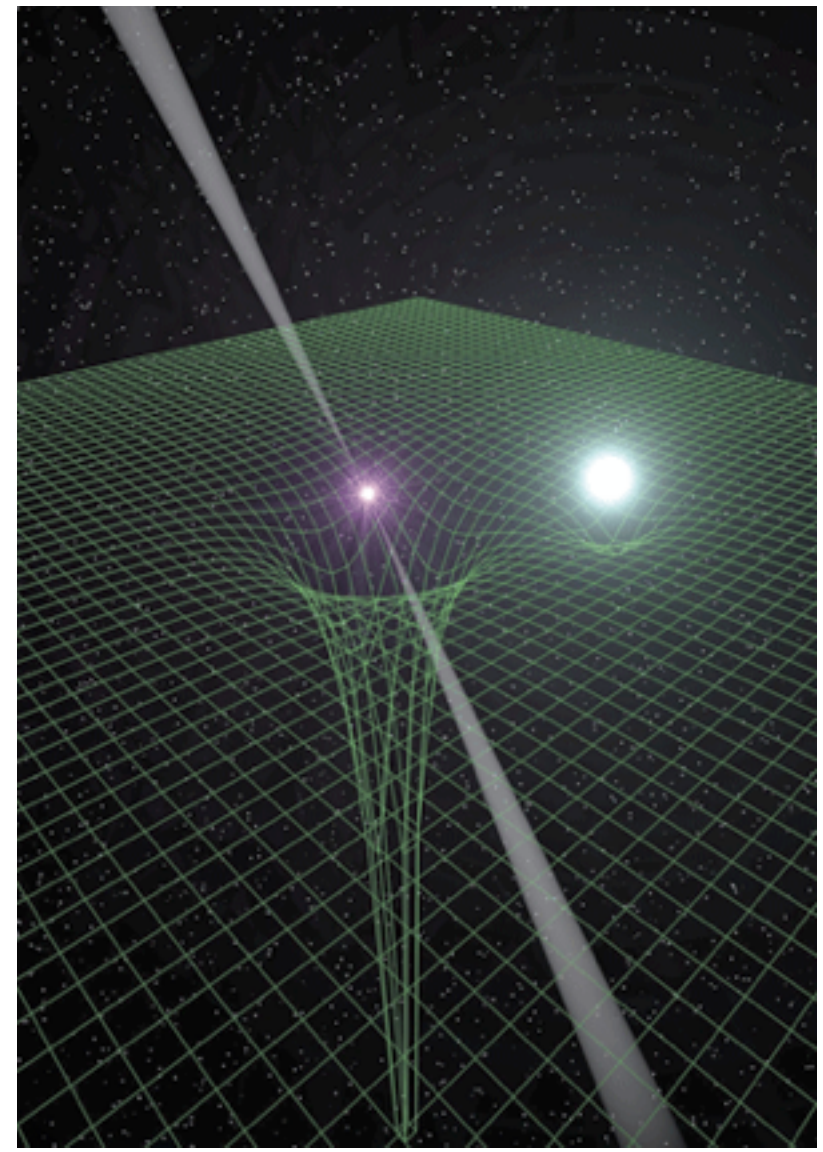
New constraints from NEUTRON STARS

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

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







PSR J1614-2230

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

PSR J0348+0432

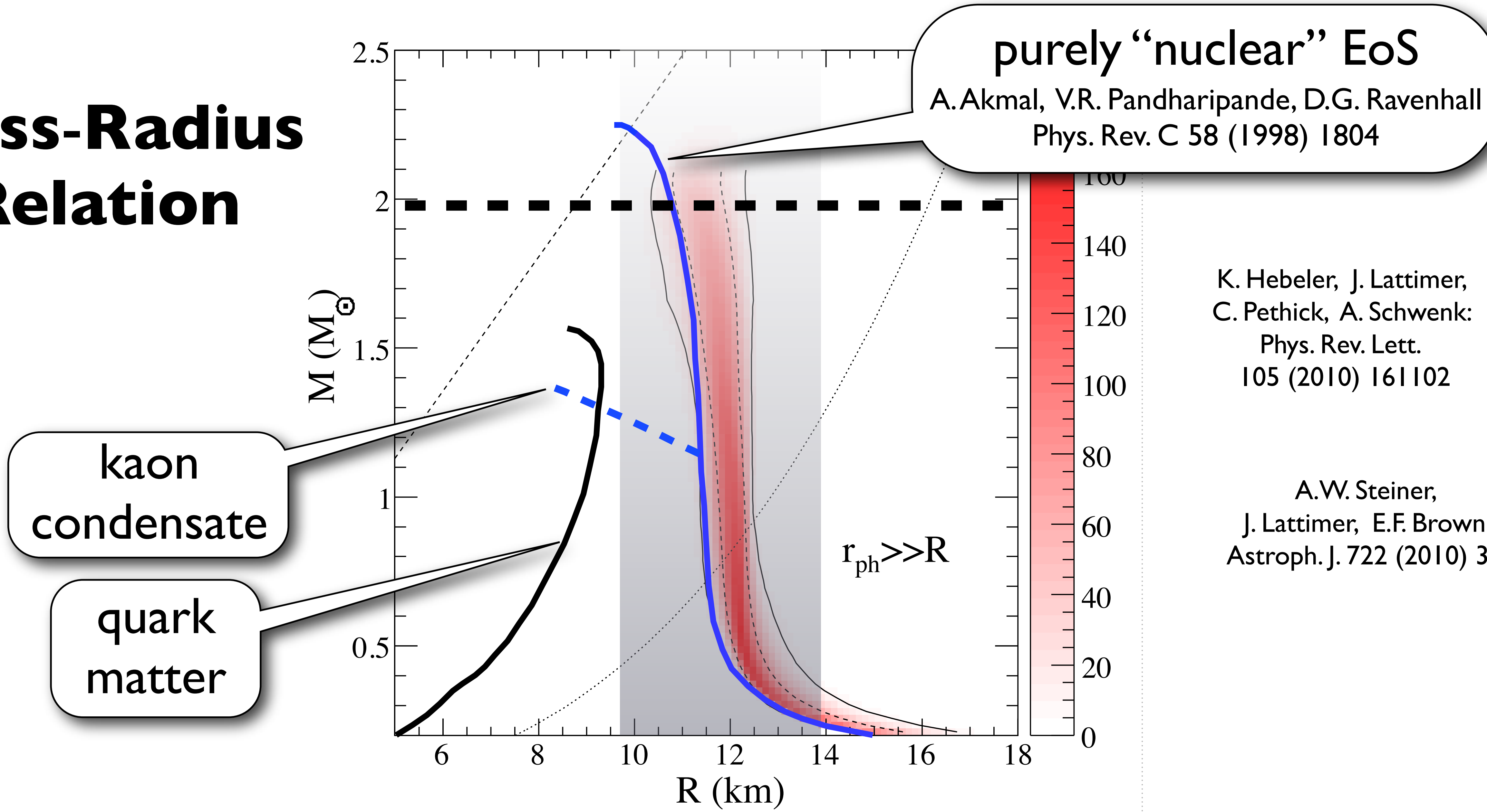
$$\mathrm{M} = 2.01 \pm 0.04 \ \mathrm{M}_{\odot}$$

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 ?

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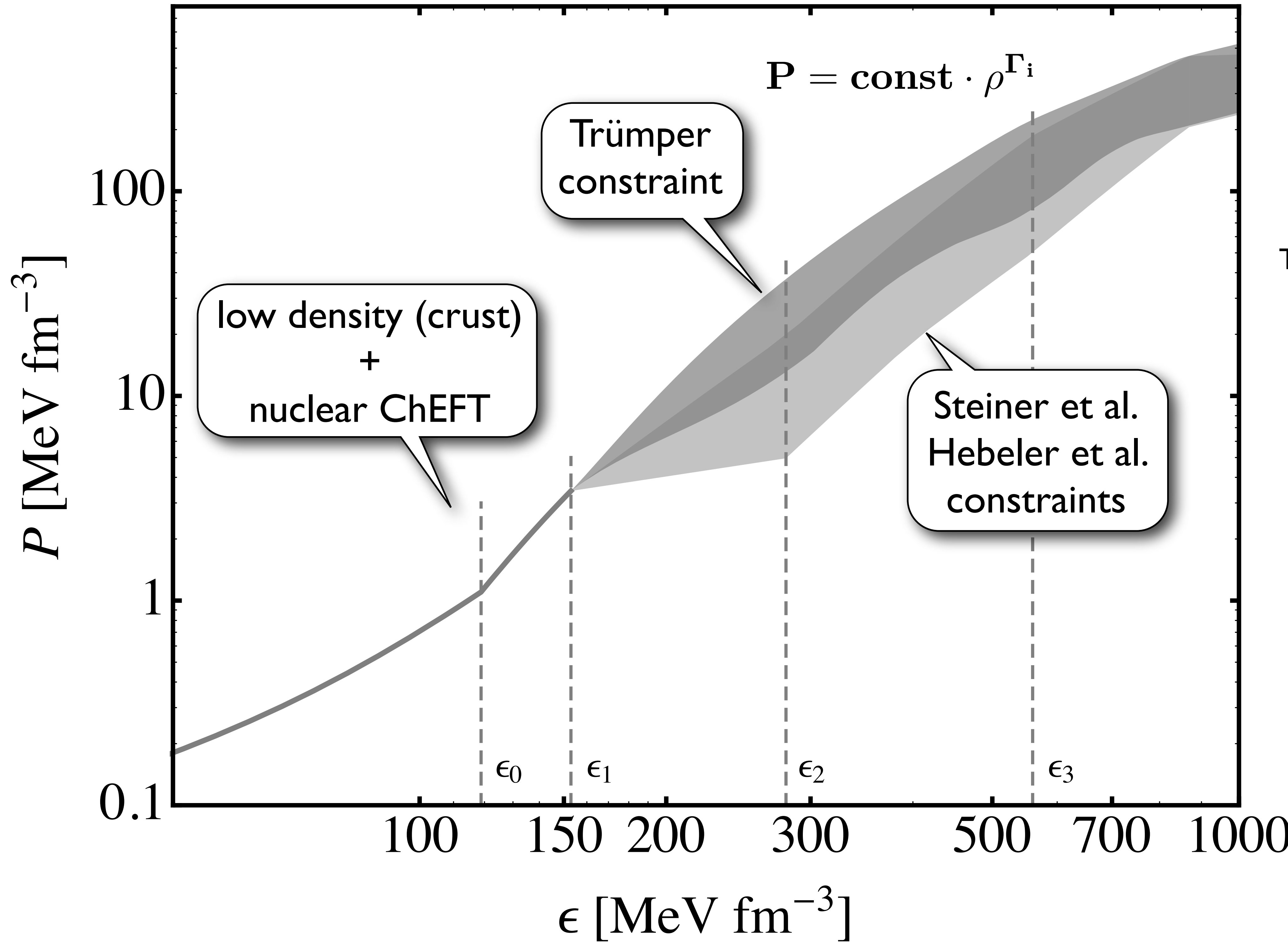
NEUTRON STAR MATTER

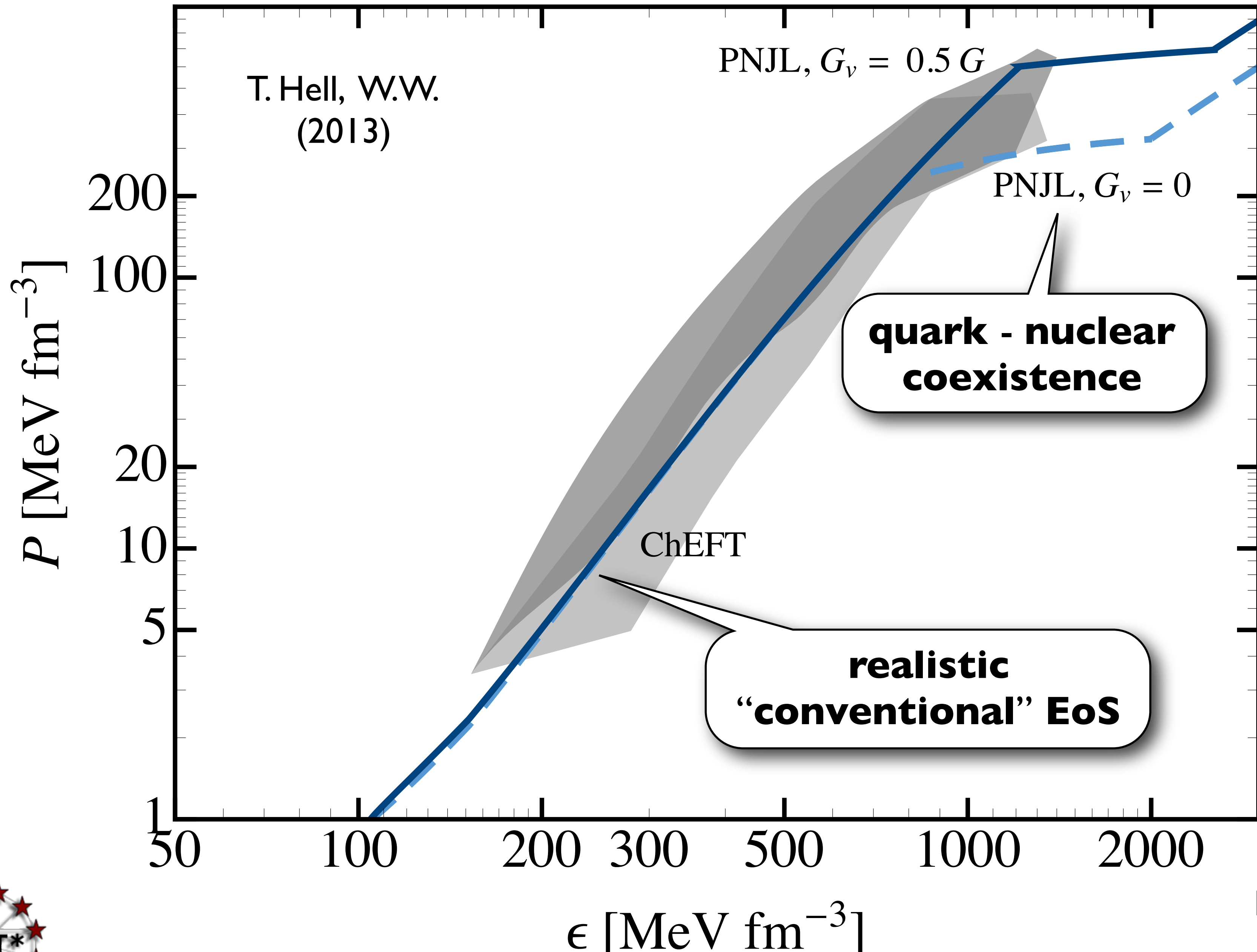
Equation of State



T. Hell, B. Röttgers, W.W.
arXiv:1307.4582

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** 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

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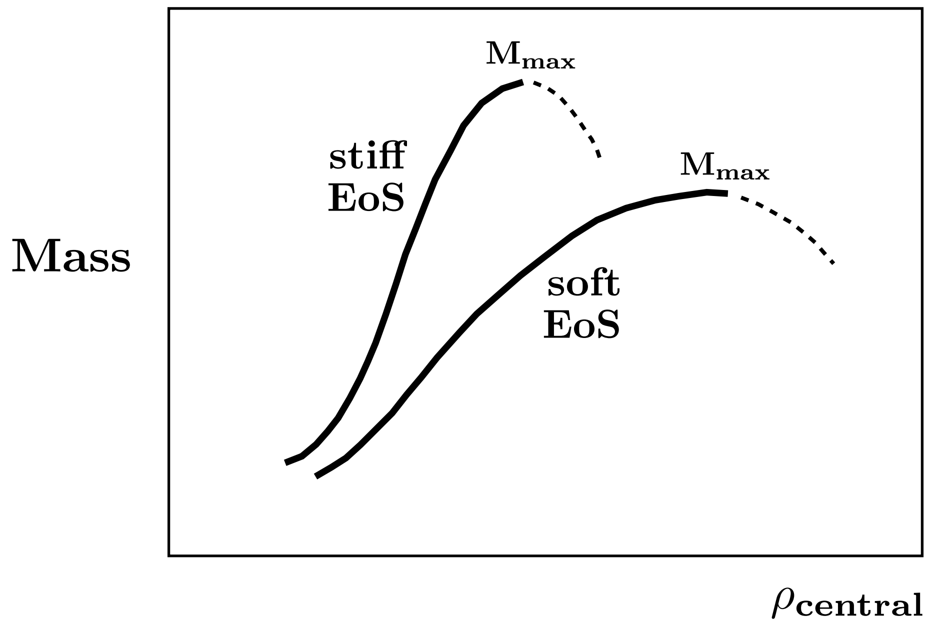
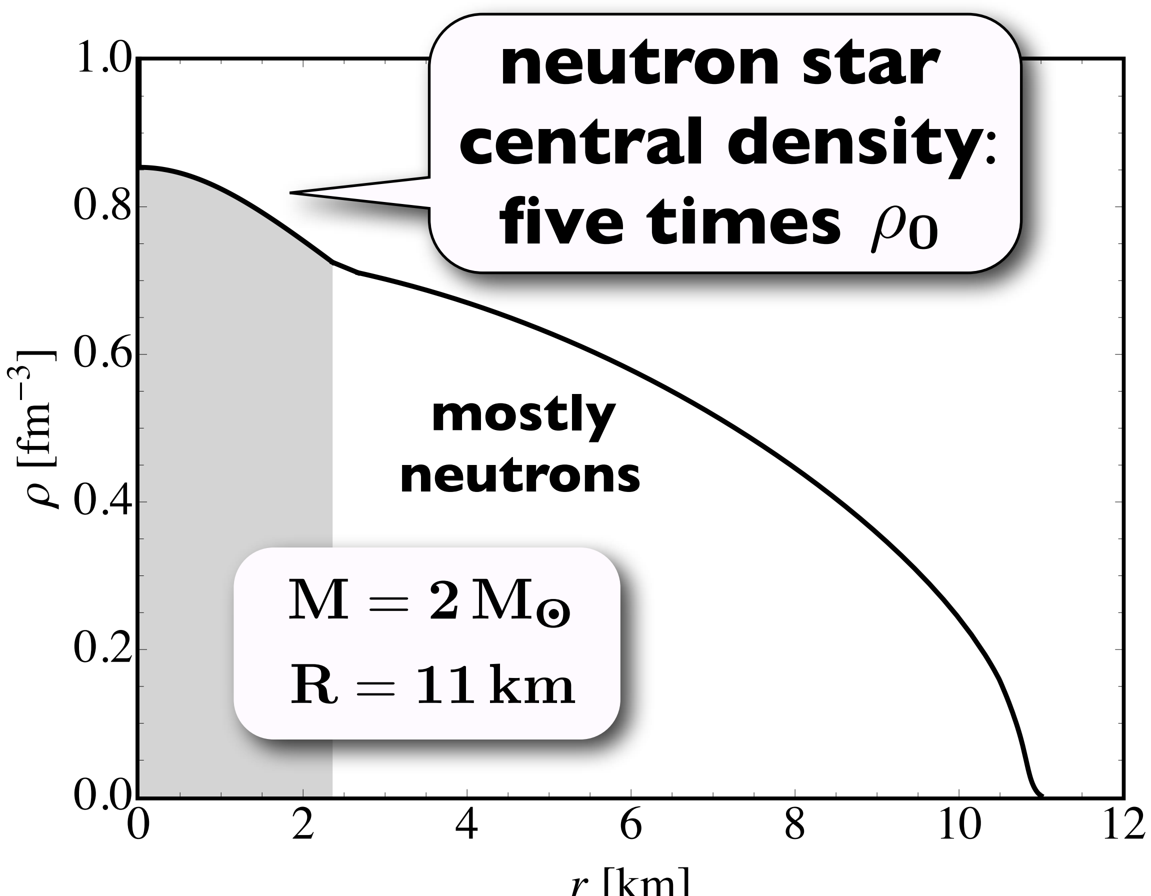
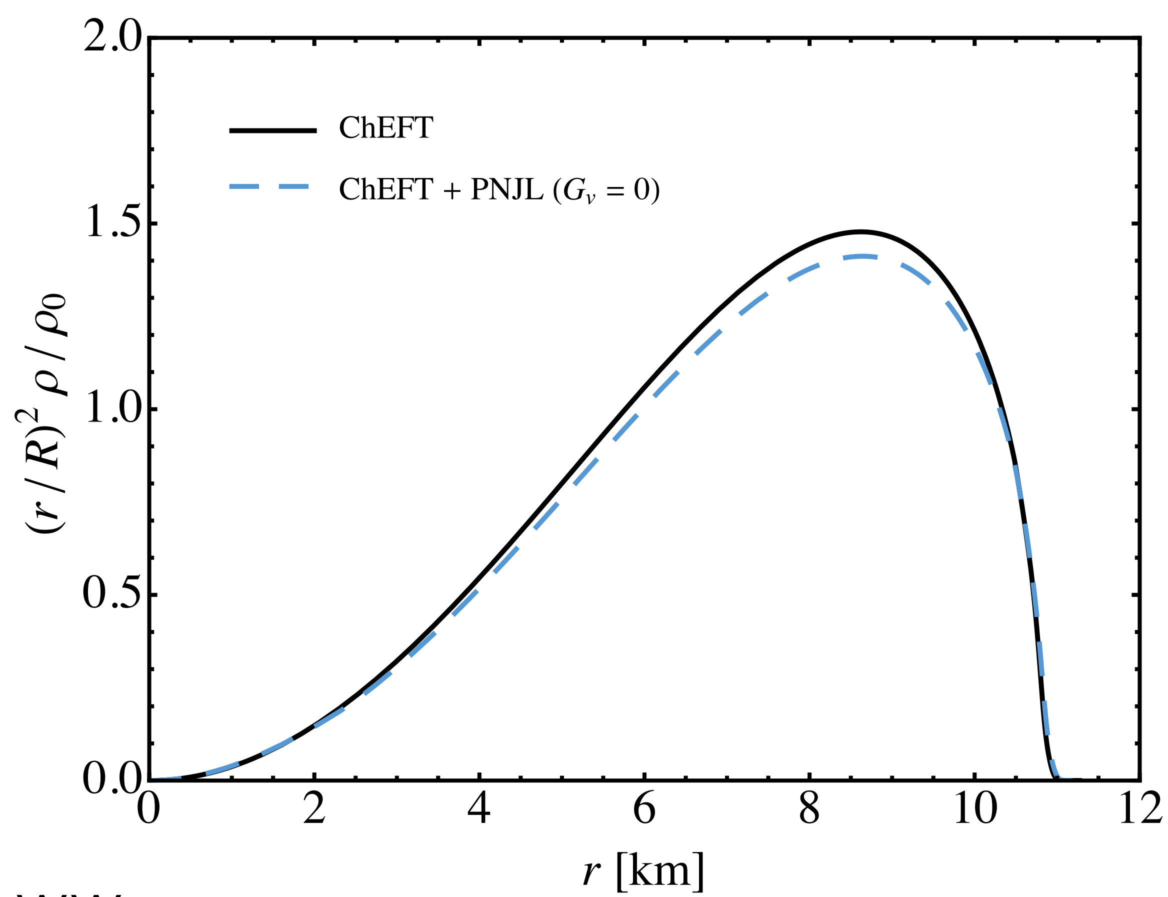
NEUTRON STAR MATTER

Density Profiles



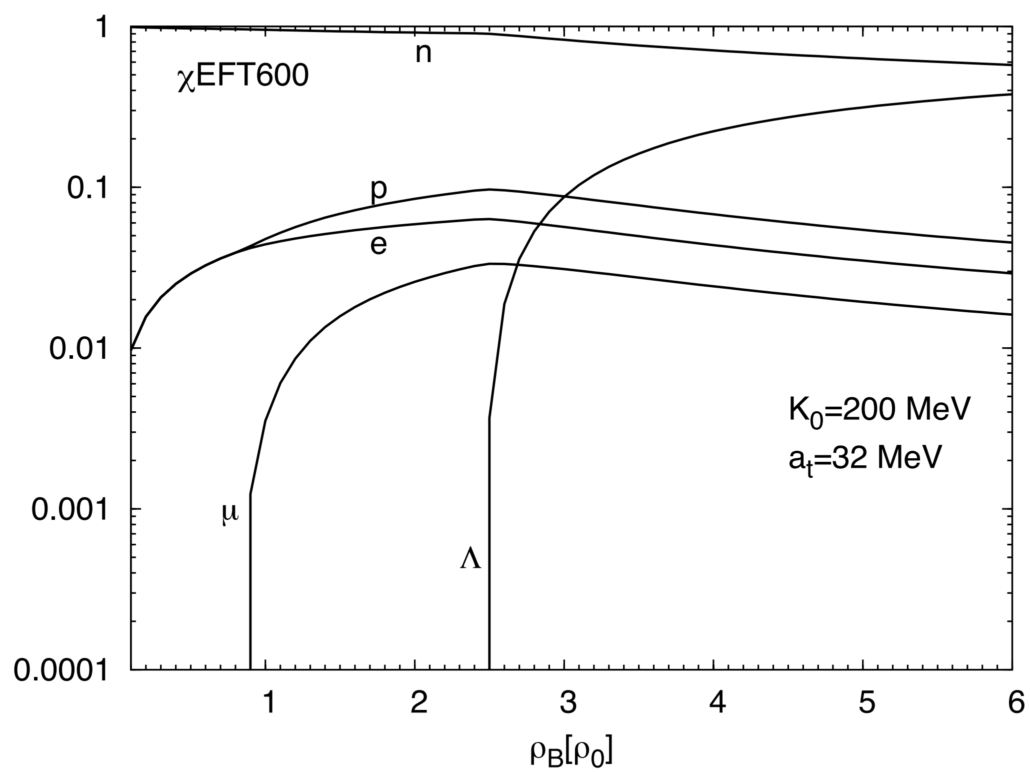
- stiff EoS
  → larger maximum mass
  → lower central density
- $$\mathbf{M(R) = \frac{4\pi}{c^2}\int_0^R dr\, r^2\, \mathcal{E}(r)}$$
  → relevant quantity: $\mathbf{r^2 \rho(r)}$

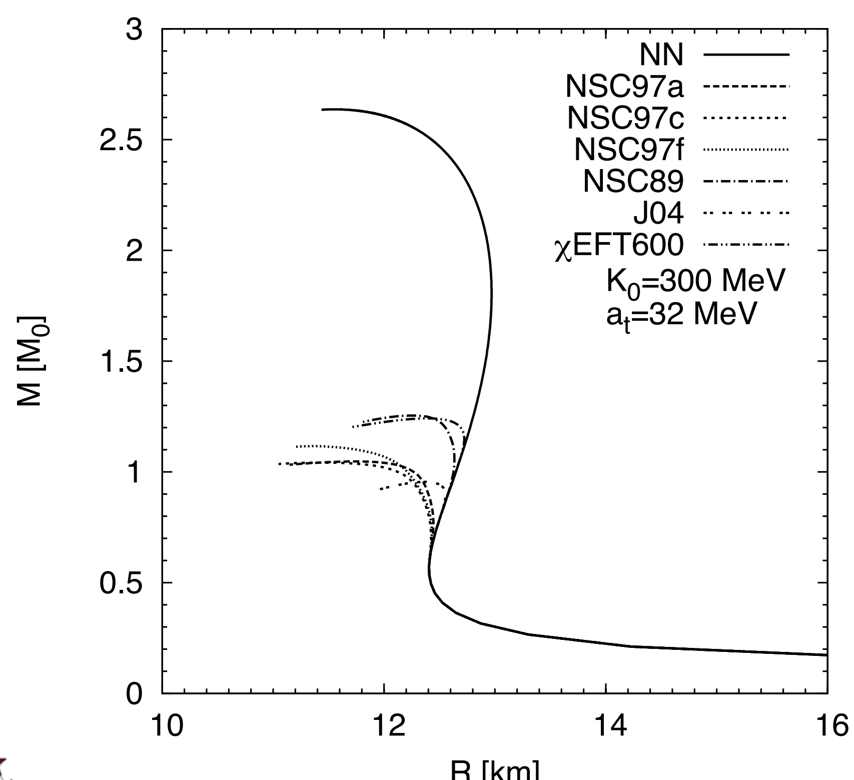




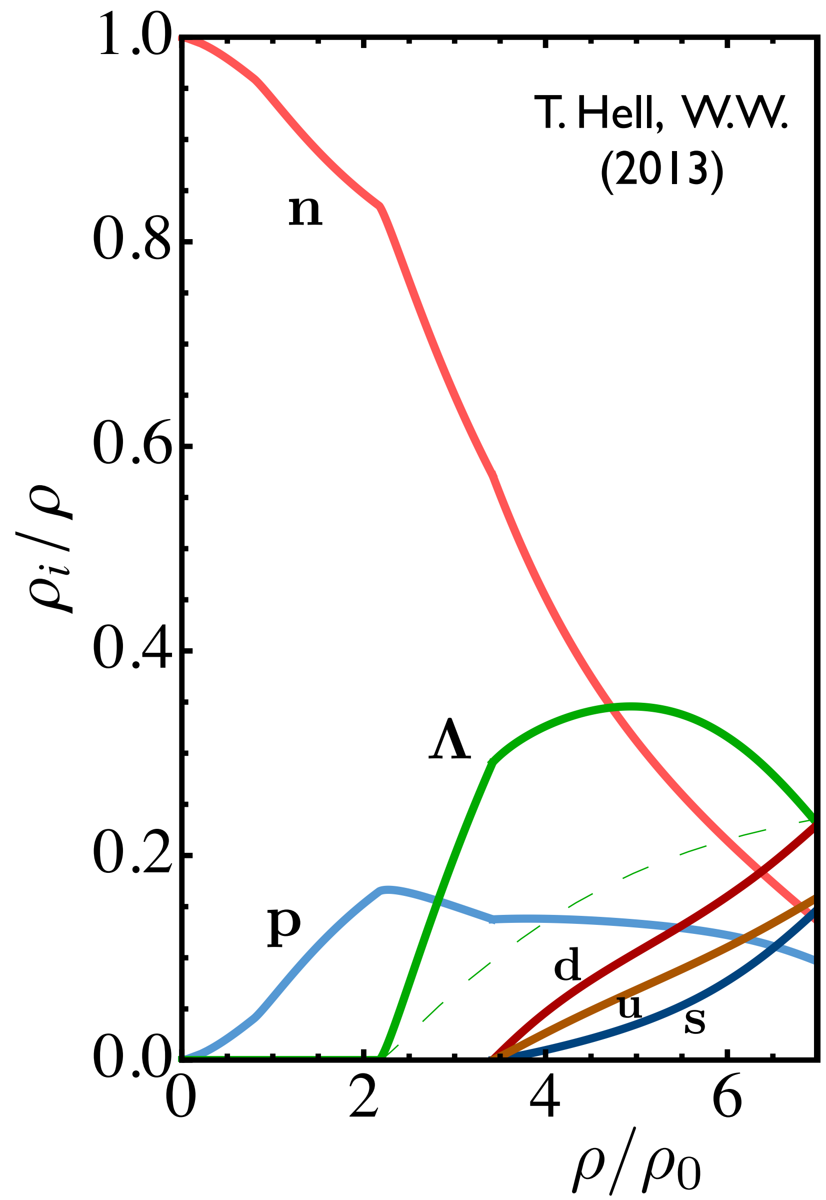
T. Hell, W.W. (2013)

NEUTRON STAR MATTER
with **HYPERONS**



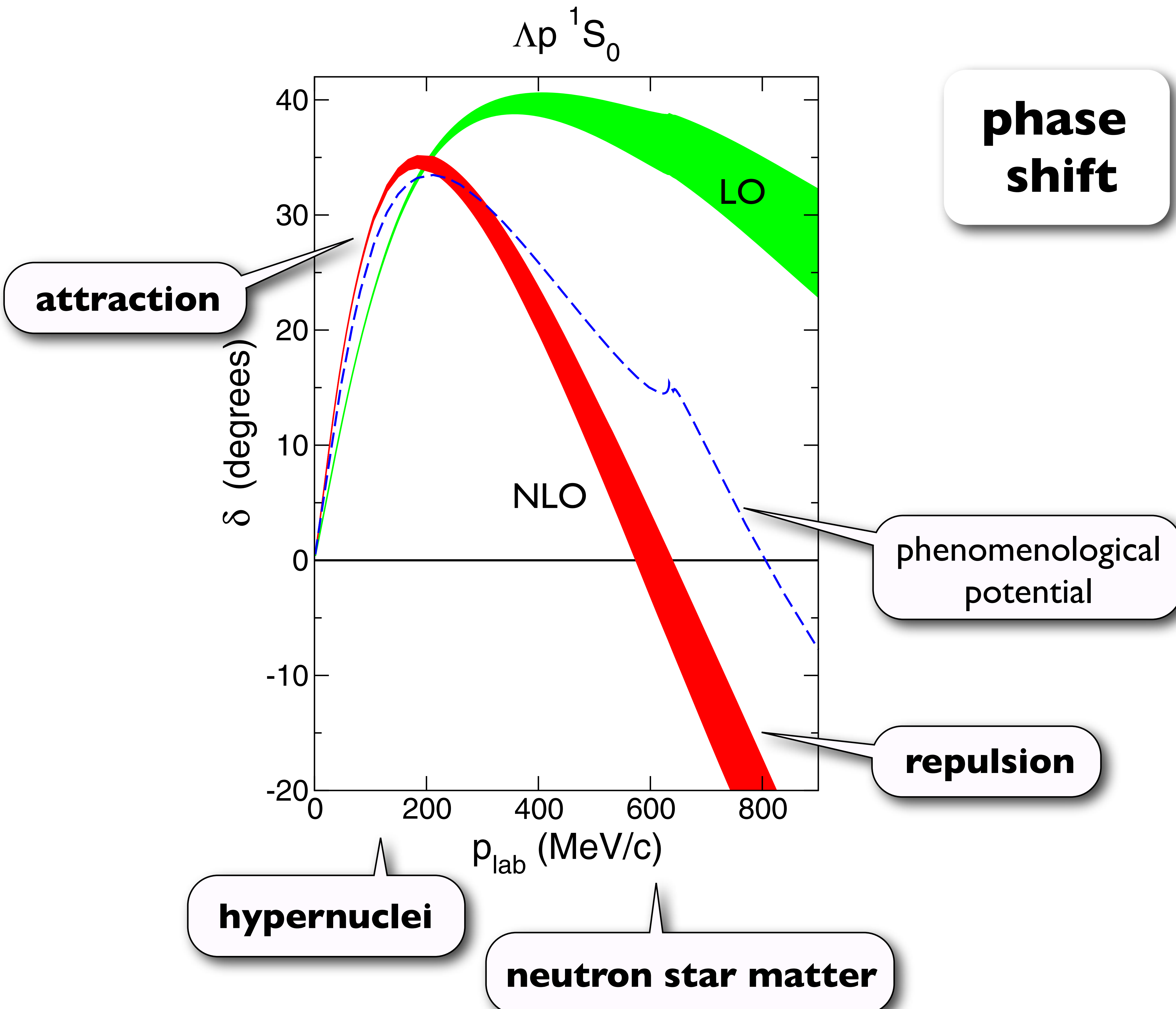


H. Djapo, B.-J. Schaefer, J. Wambach
Phys. Rev. C81 (2010) 035803



- with inclusion of hyperons:
  EoS far too soft to support 2 solar mass star unless strong **repulsion** in **YN** interaction

phase shift



Λp ¹S₀
δ (degrees)
p_lab (MeV/c)
40
30
20
10
0
-10
-20
0
200
400
600
800
LO
NLO
attraction
phenomenological potential
repulsion
hypernuclei
neutron star matter

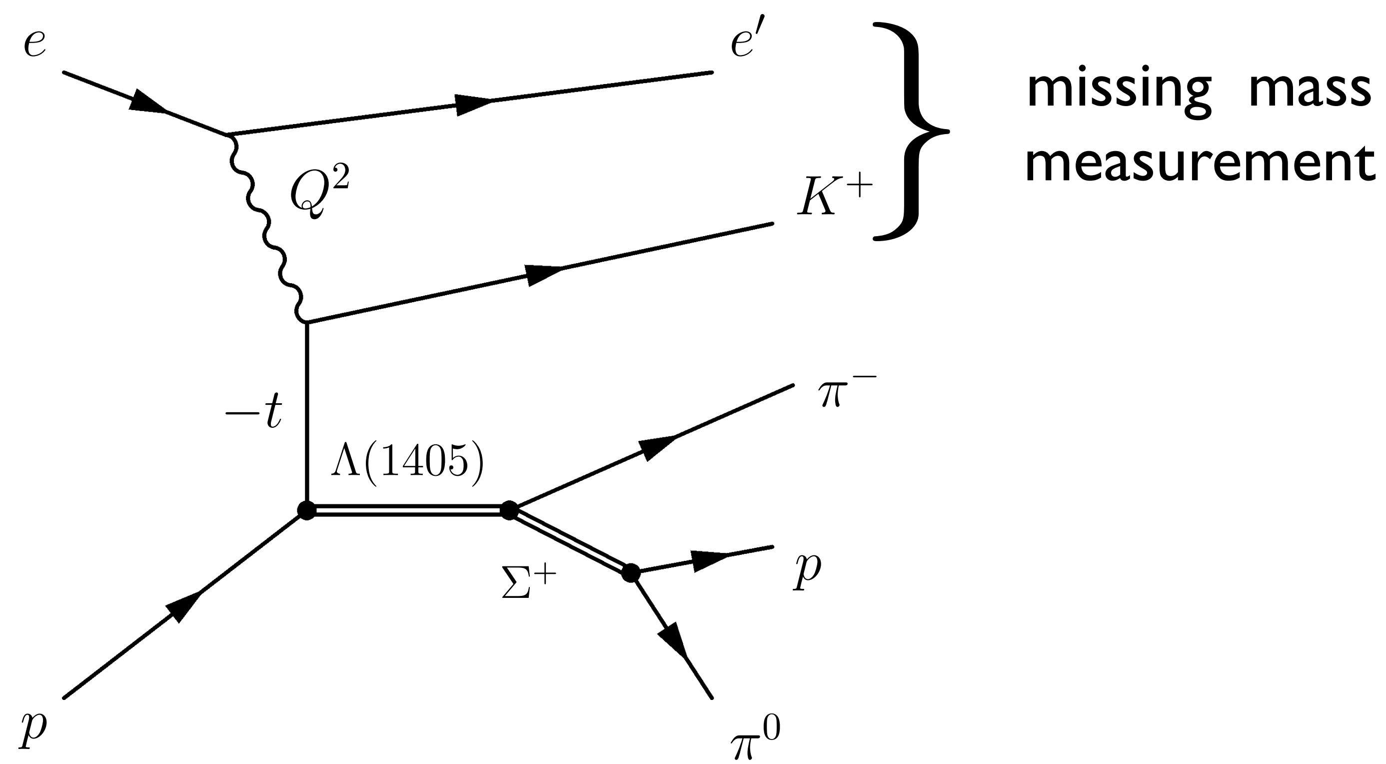
Physics of the $\Lambda(1405)$

First Observation of the $\Lambda(1405)$ Line Shape in Electroproduction

(CLAS Collaboration)

arXiv: 1307.4411 [nucl-ex]

We report the first observation of the line shape of the $\Lambda(1405)$ from electroproduction, and show that it is not a simple Breit-Wigner resonance. Electroproduction of $K^+\Lambda(1405)$ off the proton was studied by using data from CLAS at Jefferson Lab in the range $1.0 < Q^2 < 3.0$ $(\mathrm{GeV/c})^2$. The analysis utilized the decay channels $\Sigma^+\pi^-$ of the $\Lambda(1405)$ and $p\pi^0$ of the Σ^+. Neither the standard (PDG) resonance parameters, nor free parameters fitting to a single Breit-Wigner resonance represent the line shape. In our fits, the line shape corresponds approximately to predictions of a two-pole meson-baryon picture of the $\Lambda(1405)$, with a lower mass pole near 1368 MeV/c^2 and a higher mass pole near 1423 MeV/c^2. Furthermore, with increasing photon virtuality the mass distribution shifts toward the higher mass pole.



- Fits prefer two-pole scenario with $\mathbf{m_1 = 1423\,MeV}, \quad \mathbf{m_2 = 1386\,MeV}$

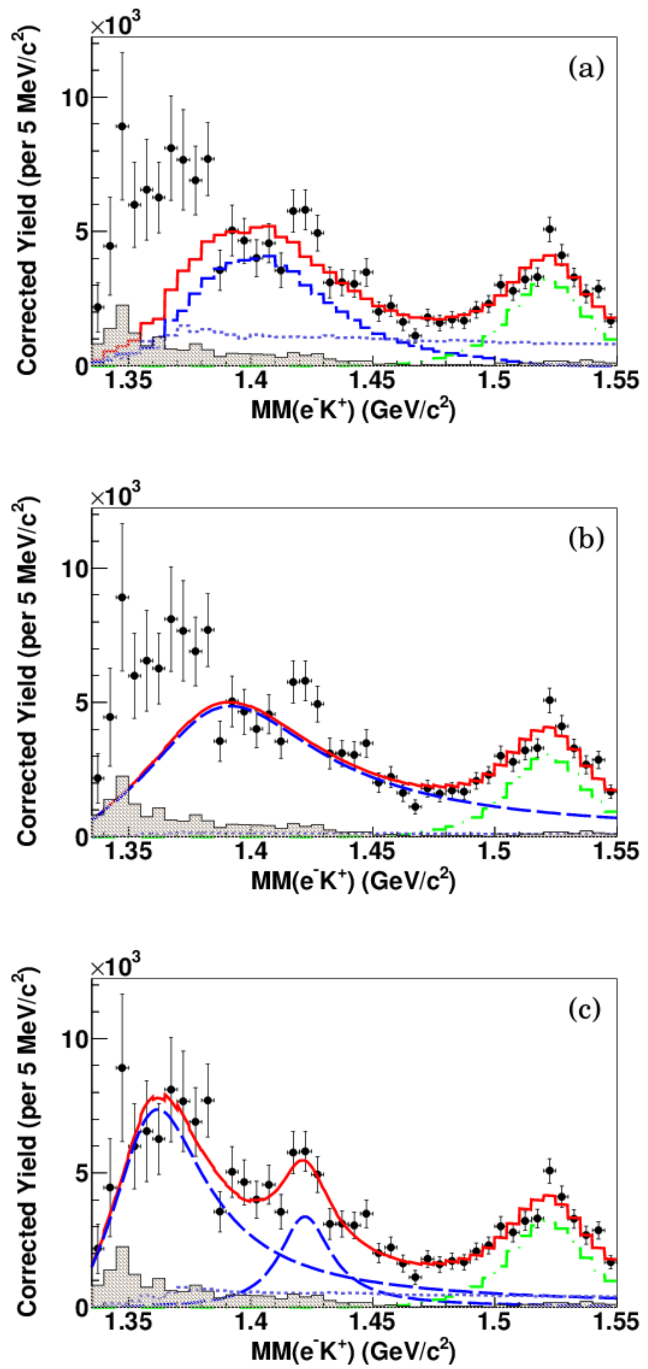


FIG. 7. (Color online) Fits of the missing mass of $e^- K^+$ for $1.5 < Q^2 < 3.0$ (GeV/c)^2. Points with error bars are measured data, solid (red) lines are overall fits, dash-dotted (green) lines around 1.52 GeV/c^2 are from the $\Lambda(1520)$ simulation. The dashed (blue) lines are from the $\Lambda(1405)$ simulation parametrized by PDG values (a), by one relativistic Breit-Wigner function (b), and by two relativistic Breit-Wigner functions (c). The dotted (purple) lines show the summed background contributions. The shadowed histograms at the bottom show the estimated systematic uncertainty.

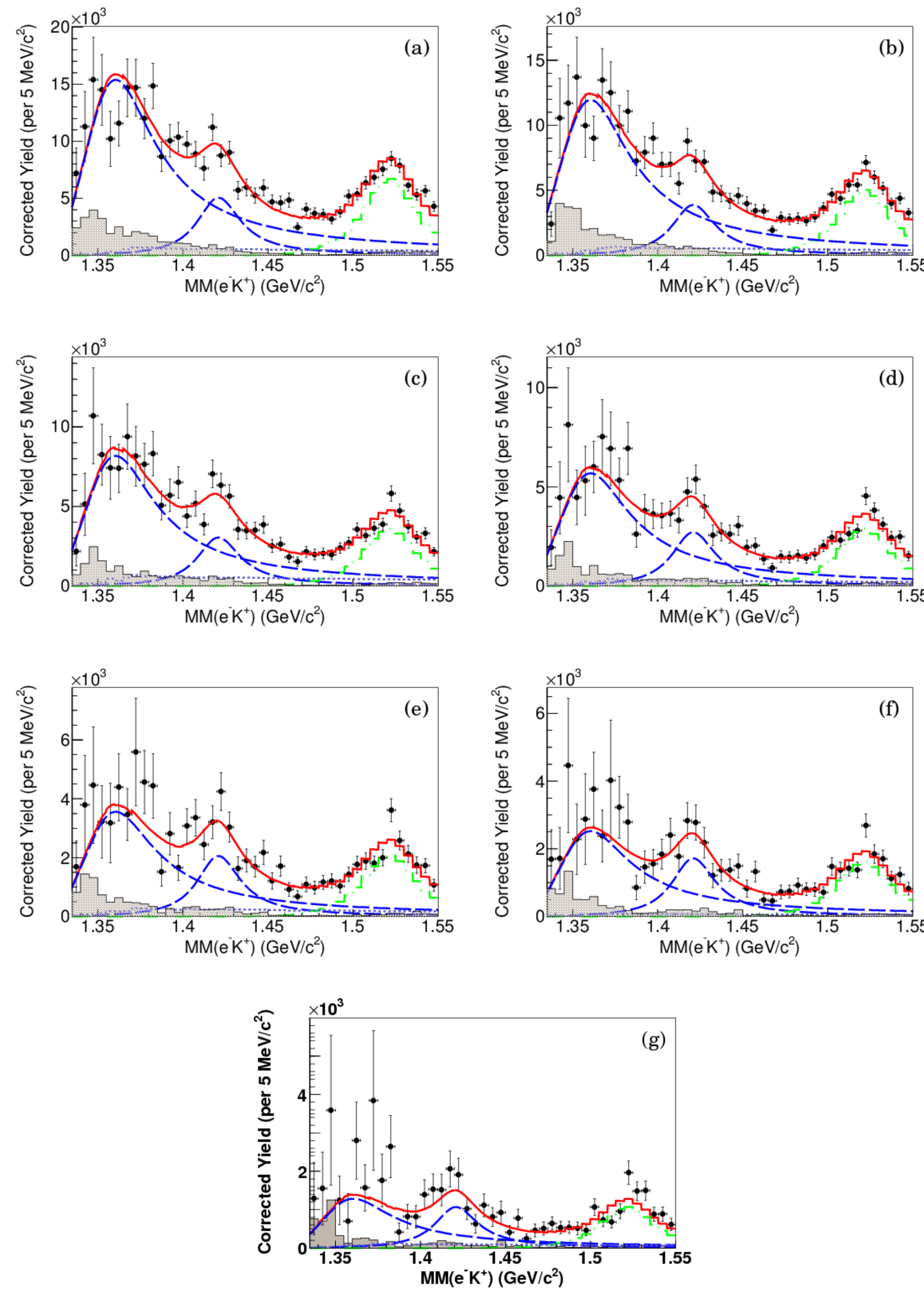


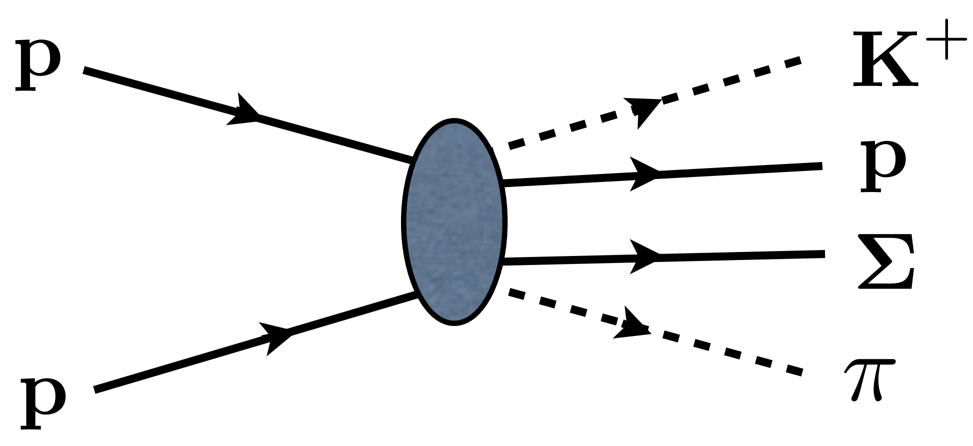
FIG. 8. (Color online) Overall fit of the acceptance-corrected missing mass of $e^- K^+$ with simulated background, simulated production of the $\Lambda(1520)$, and two relativistic Breit-Wigner functions in the ranges $Q^2_{min} \leq Q^2 \leq 3.0$ (GeV/c)^2, where Q^2_{min} is: (a) 1.0 (GeV/c)^2, (b) 1.2 (GeV/c)^2, (c) 1.4 (GeV/c)^2, (d) 1.6 (GeV/c)^2, (e) 1.8 (GeV/c)^2, (f) 2.0 (GeV/c)^2, and (g) 2.2 (GeV/c)^2. The fit takes the statistical uncertainties (error bars on points) into account. The shadowed histograms show the estimated systematic uncertainties.

Investigation of the $\Lambda(1405)$ line shape in pp collisions

J. Siebenson[1] and L. Fabbietti[1]
[1] *Excellence Cluster 'Origin and Structure of the Universe', Technische Universität München , 85748 Garching, Germany*

In this work we investigate different possible interpretations of the $\Lambda(1405)$ signal associated with the production of the $\Lambda(1405)$ in $p + p$ reactions at 3.5 GeV beam kinetic energy measured by the HADES collaboration. We study the influence of interference effects between the $\Lambda(1405)$ resonance and the non−resonant background. The two poles nature of the $\Lambda(1405)$, which is supported by most of the theoretical models, is also discussed with emphasis on the relative contributions of the two complex poles to the formation of the resonance in $p + p$ reactions.

Phys. Rev. C 88 (2013) 055201,   arXiv: 1306.5183 [nucl-ex]



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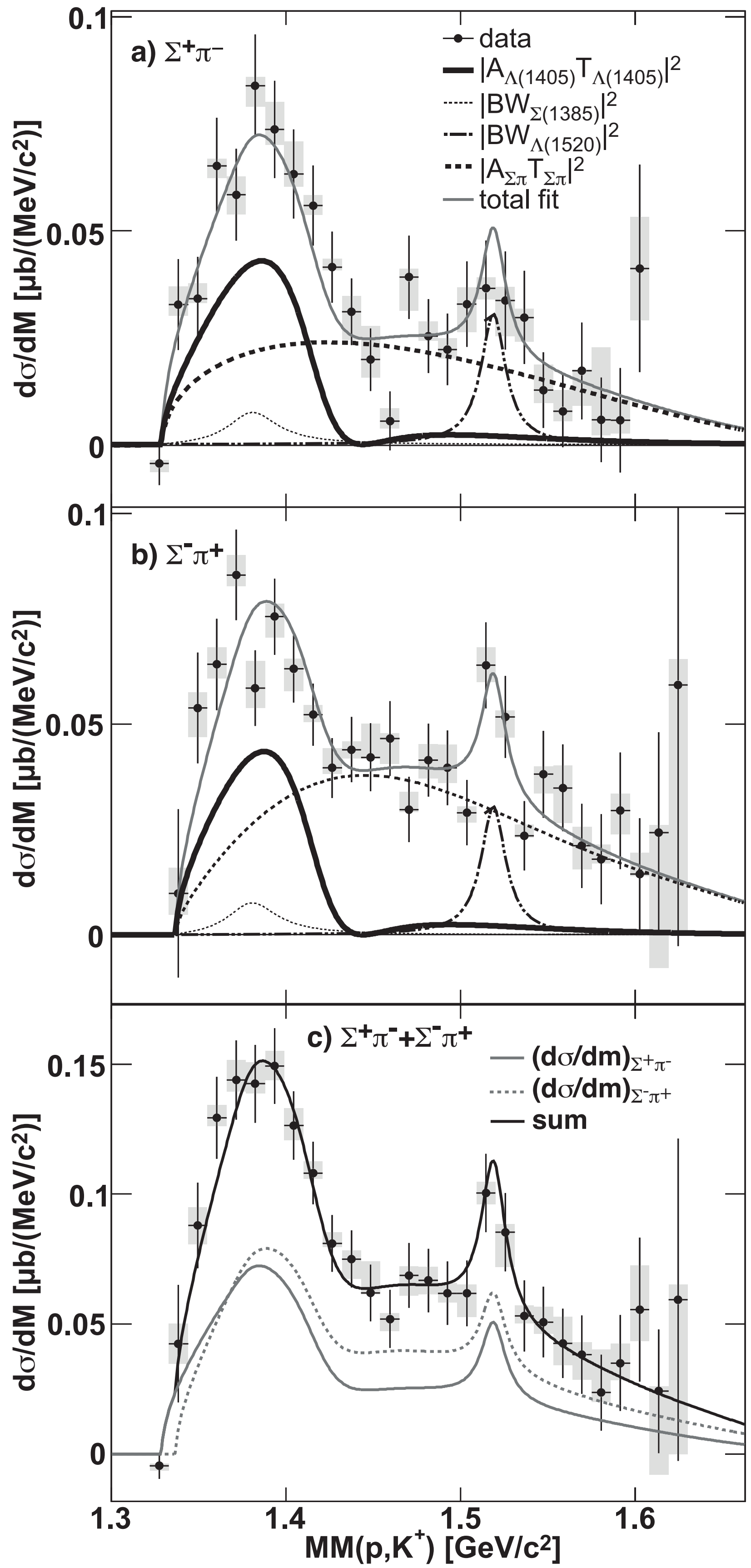
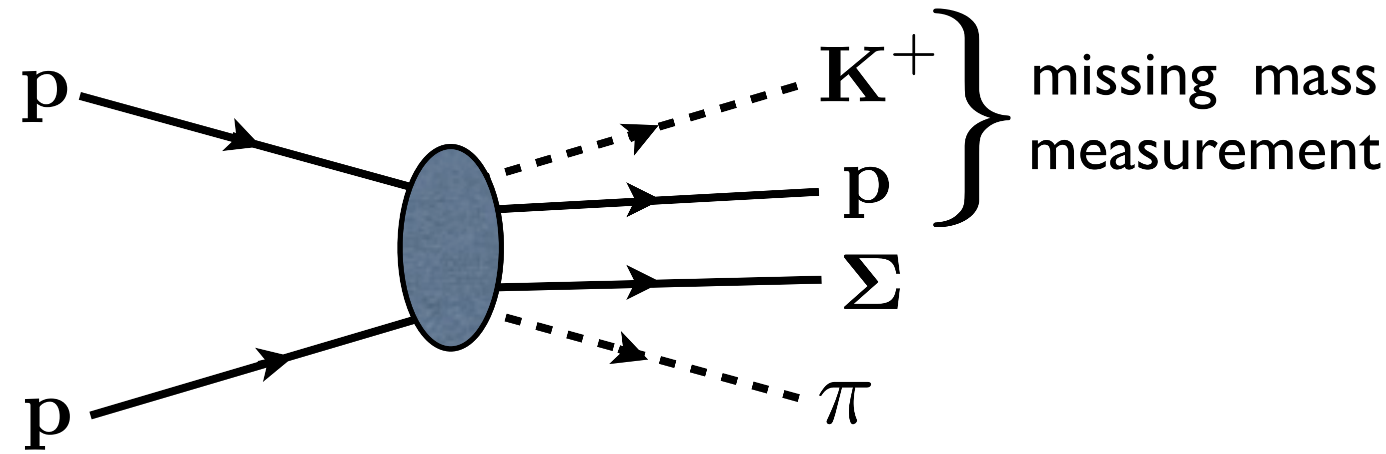


FIG. 3. Missing mass spectrum to proton and K^+. The black data points are the measurements of [1], for the $\Lambda(1405)$ in the $\Sigma^+\pi^-$ (a) and $\Sigma^-\pi^+$ (b) decay channel. Panel c) shows the summed spectrum of a) and b). The black lines in a) and b) are the results from the simultaneous fit with Eq. (2) and (3), the gray line represents the sum of all fitted functions. In c) the fit functions corresponding to the $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ channels respectively are shown in gray and the sum of both functions is shown in the black line.



- Fits prefer two-pole scenario with poles located at:

$$z_1 = 1418 - i\,29 \text{ MeV} \quad z_2 = 1375 - i\,73 \text{ MeV}$$

- Compare with : Chiral SU(3) coupled channels calculation

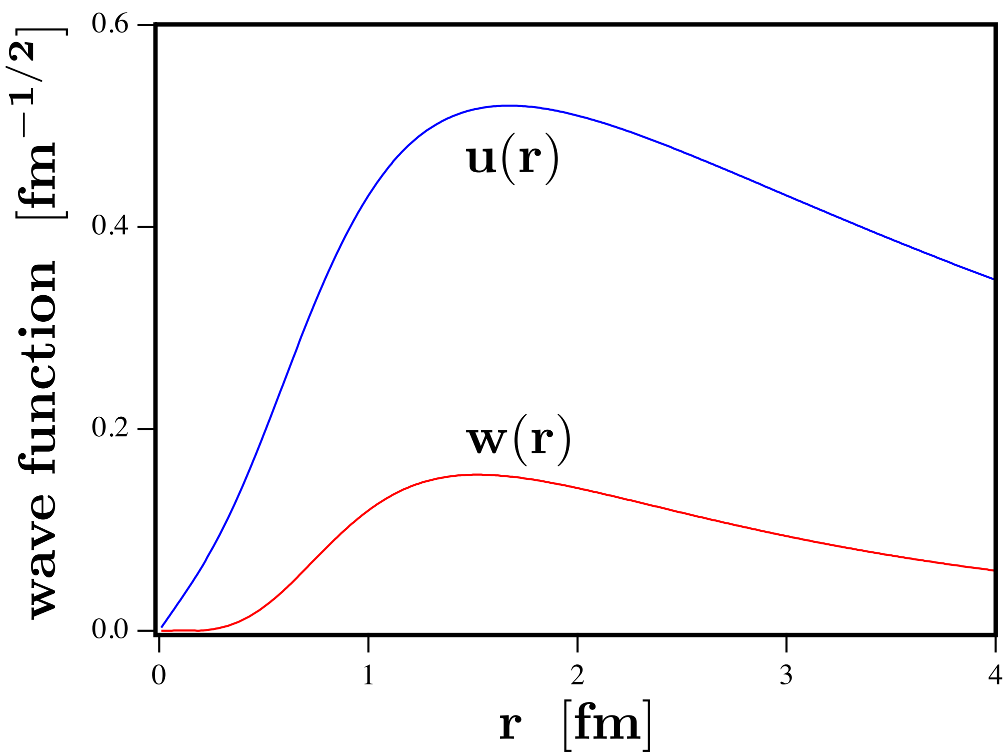
$$z_1 = 1424 - i\,26 \text{ MeV} \quad z_2 = 1381 - i\,81 \text{ MeV}$$

Y. Ikeda, T. Hyodo, W.W.
Nucl. Phys. A881 (2012) 98

ANTIKAON - DEUTERON THRESHOLD PHYSICS

... looking forward to **SIDDHARTA 2**

- **Strategies**: Multiple scattering (MS) theory vs. three-body (Faddeev) calculations with Chiral SU(3) Coupled Channels input
- **MS approach** (fixed scatterer approximation): $K^- d$ **scattering length**



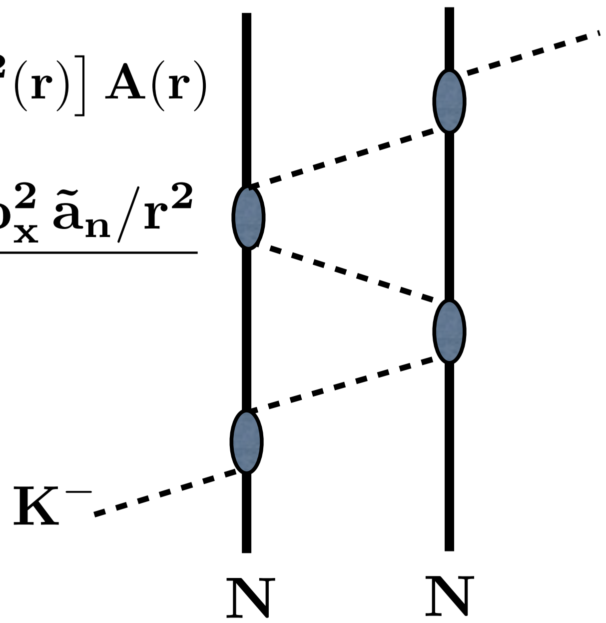
S.S. Kamalov, E. Oset, A. Ramos: Nucl. Phys. A 690 (2001) 494

$$a(K^-d) = \left(1 + \frac{m_K}{M_d}\right)^{-1} \int_0^\infty dr\, \left[u^2(r) + w^2(r)\right] A(r)$$

$$A(r) = \frac{\tilde{a}_p + \tilde{a}_n + (2\,\tilde{a}_p\,\tilde{a}_n - b_x^2)/r - 2\,b_x^2\,\tilde{a}_n/r^2}{1 - \tilde{a}_p\,\tilde{a}_n/r^2 + b_x^2\,\tilde{a}_n/r^3}$$

$$\tilde{a}_p = \left(1 + \frac{m_K}{M_N}\right) a(K^-p \to K^-p)$$

$$\tilde{a}_n = \left(1 + \frac{m_K}{M_N}\right) a(K^-n \to K^-n)$$



b_x incorporates $K^-p \to \bar{K}_0\,n$ and $\bar{K}_0\,n \to \bar{K}_0\,n$

- Using input scattering lengths constrained by SIDDHARTA kaonic hydrogen:

$a(K^-d)$ [fm]

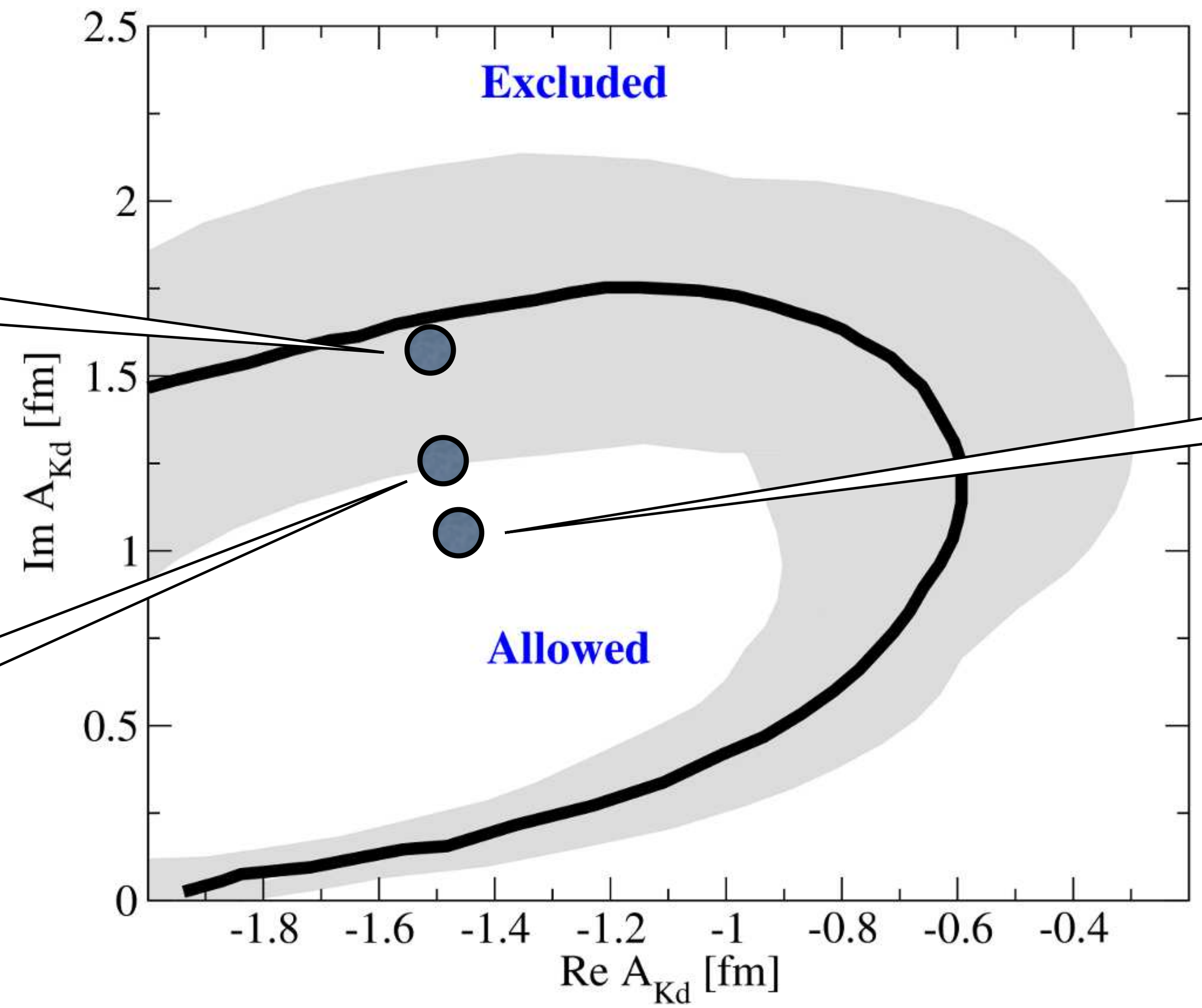
full MS	$-1.54 + i1.64$
no charge exchange	$-1.04 + i1.34$
impulse approximation	$-0.13 + i1.81$

ANTIKAON - DEUTERON SCATTERING LENGTH

- Recent calculations using SIDDHARTA - constrained input

Multiple scattering using IHW scattering lengths

T. Hyodo, Y. Ikeda, W.W. (2012-13) preliminary



Non-relativistic effective field theory

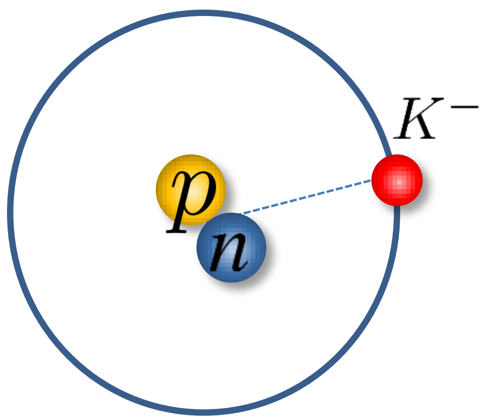
M. Döring, U.-G. Meißner Phys. Lett. B 704 (2011) 663

Faddeev calculation separable "chiral" amplitudes

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

- Primary theoretical uncertainties from $\mathbf{K^- n}$ amplitude
- **Not** included: $\mathbf{K^- d \rightarrow YN}$ absorption

Kaonic deuterium and **K-deuteron scattering length**



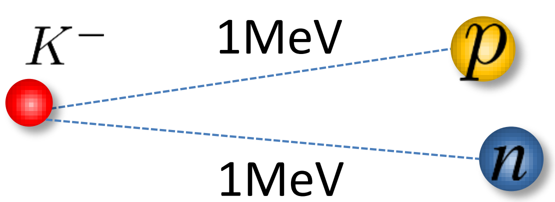
- Improved Deser formula

  Meissner, Raha, Rusetsky, Eur. Phys. J. C41 (2005) 213

$$\Delta E - i\frac{\Gamma}{2} = -2\mu_{K-d}^2 \alpha^3 A_{K-d}\left[1 + 2\alpha\mu_{K-d}(1-\ln\alpha)A_{K-d}\right]$$

. . . and beyond :

- Binding energy corrections



5 % on energy shift
10 % on width

- Wave function overlap . . . **large** effect on width

  S. Ohnishi, Y. Ikeda, T. Hyodo, E. Hiyama, W.W. : work in progress

$$U(\vec{r}) = -\frac{2\pi}{\mu_{Kd}} F_{K-d}(r)\, \rho_d(\vec{r}) \qquad \Delta E_{1S} - i\frac{\Gamma}{2} = \int d^3r\, |\phi_{1S}(\vec{r})|^2\, U(\vec{r})$$

	Potential approach	MRR-improved Deser
$(\Delta E,\Gamma)$eV of K^-d	(825,1988)	(870,1186)
$(\Delta E,\Gamma)$eV of K^-p	(283,616)	(285,606)