universitätbonn

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

WP4 – EPOS

Exciting Physics Of Strong interactions

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CONTENTS

- **Objectives of the network**
- **Network projects and structure**
- **Involved laboratories and scientists**
- **Selected achievements**
- **Summary & Outlook**

EPOS: OBJECTIVES and PROJECTS

- Strong interactions at low & intermediate energies: **strong QCD**
- Manifestation of QCD in hadrons and systems made thereof
- Provide improved theoretical tools
- Detailed analysis of experimental results
- New facilities = new opportunities

$\Rightarrow$ **EPOS - Exciting Physics Of Strong interactions**

- Four project areas: P1 Precision calculations
  P2 Multi-quark and multi-hadron states
  P3 Lattice methods and applications
  P4 Nuclear matter and phases of QCD

NETWORK PROJECTS

- 4 main resarch areas w/ specific tasks

P1 Precision calculations

Roy-Steiner equations for pion-nucleon scattering, $\sigma_{\pi N}$ term,
Δ effects in nucleon and nuclear systems, two-photon effects,
CP violation in D-meson decays, hadronic scattering lengths from 3-body decays, . . .

P2 Multi-quark and multi-hadron states

Theory of hadronic molecules & unique observables, multi-quark states,
decay patterns of X,Y, Z states, universality, three-hadron states,
. . .

P3 Lattice methods and applications

Hadron resonances in a finite volume, channel couplings & decays,
Nucleon resonances at low quark masses and in large volumes,
nuclear lattice simulations, . . .

P4 Nuclear matter and phases of QCD

EFTs for nuclear matter, nuclear energy density functional from chiral dynamics,
pairing in neutron matter, hadron to quark transition in hot QCD,
role of multi-quark interactions, phase diagram, . . .

INVOLVED LABORATORIES & SCIENTISTS

- 26 nodes from 12 countries

  U. Bonn (BN), TU München (MÜ), U. Mainz (MZ), U. Bochum (BO), U. Tübingen (TÜ),
  U. Gießen (GI), FZ Jülich (JÜ), GSI Darmstadt (DA), U. Graz (GZ), U. Valencia (VA),
  U. Barcelona (BA), U. Granada (GA), U. Madrid (MA), U. Murcia (MU), U. Salamanca (SA),
  CPT Marseille (MS), U. Paris-Sud (PA), U. Pavia (PV) , U. Bern (BE) , U. Manchester (MN),
  U. Cracow (CR), U. Lund (LU), IST Lisbon (LI), U. Coimbra (CO),
  ITEP Moscow (MO), ODTU Ankara (ODTUE) (associated nodes)

- $\sim$100 permanent researchers, $\sim$45 post-doc, $\sim$65 students $\rightarrow \sim$ **90 FTE**

- Strong link to lattice QCD activities, all TNAs and many JRAs

$\Rightarrow$ significant contribution to HP3

SUMMARY of OBTAINED RESULTS

- 137 papers published (PRL, PRD, PRC, EPJA, EPJC, JHEP, NPA, NPB, ...)
- two dozen papers submitted to peer reviewed journals
- $\sim$100 talks at conferences/workshops [submitted to the arXives]
- 2 conferences/workshops (co-)sponsored / important contributions,

  "Nuclear Matter and Phases of QCD," Graz, Austria, May 21-23, 2013

  32 participants, 21 talks, project area 4

  http://phyk247055.uni-graz.at/i3hp2013/

  "NSTAR 2013," Peniscola, Spain, May 27-30, 2013

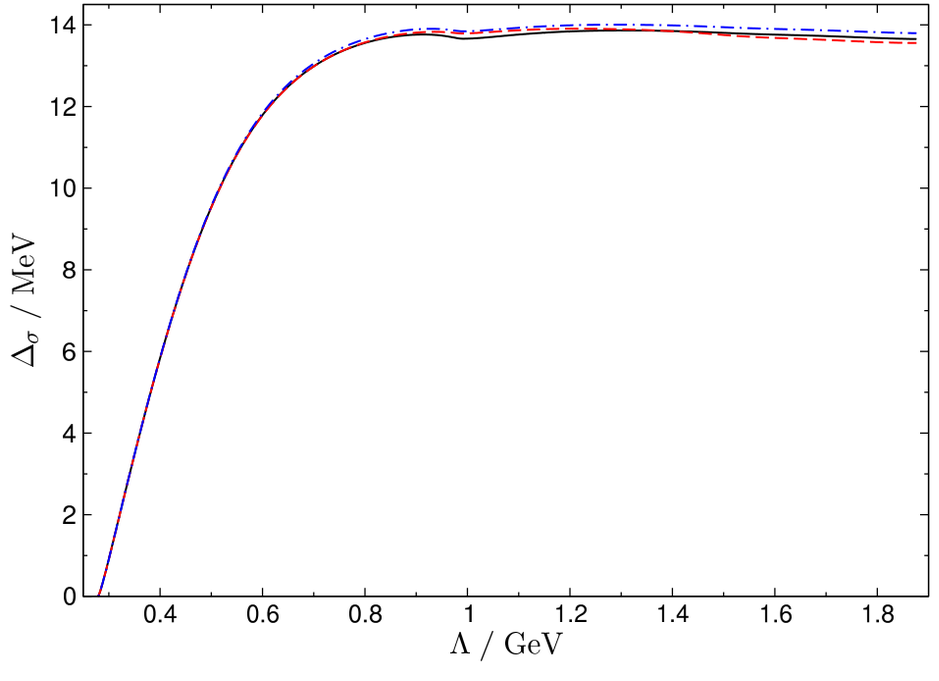
  9 plenary talks by EPOS members, project areas 1,2,3

  http://ific.uv.es/nucth/nstar/

A FEW SELECTED HI-LITES I

• "Improved dispersive analysis of the scalar form factor of the nucleon,"
M. Hoferichter, C. Ditsche, B. Kubis, U.-G. Meißner, JHEP **1206** (2012) 063.

Based on Roy-Steiner equations, the two-channel Muskhelishvili-Omnes problem is solved and the correction $\boldsymbol{\Delta_\sigma = \sigma_{\pi N}(2M_\pi^2) - \sigma_{\pi N}(0)}$ is reanalyzed.



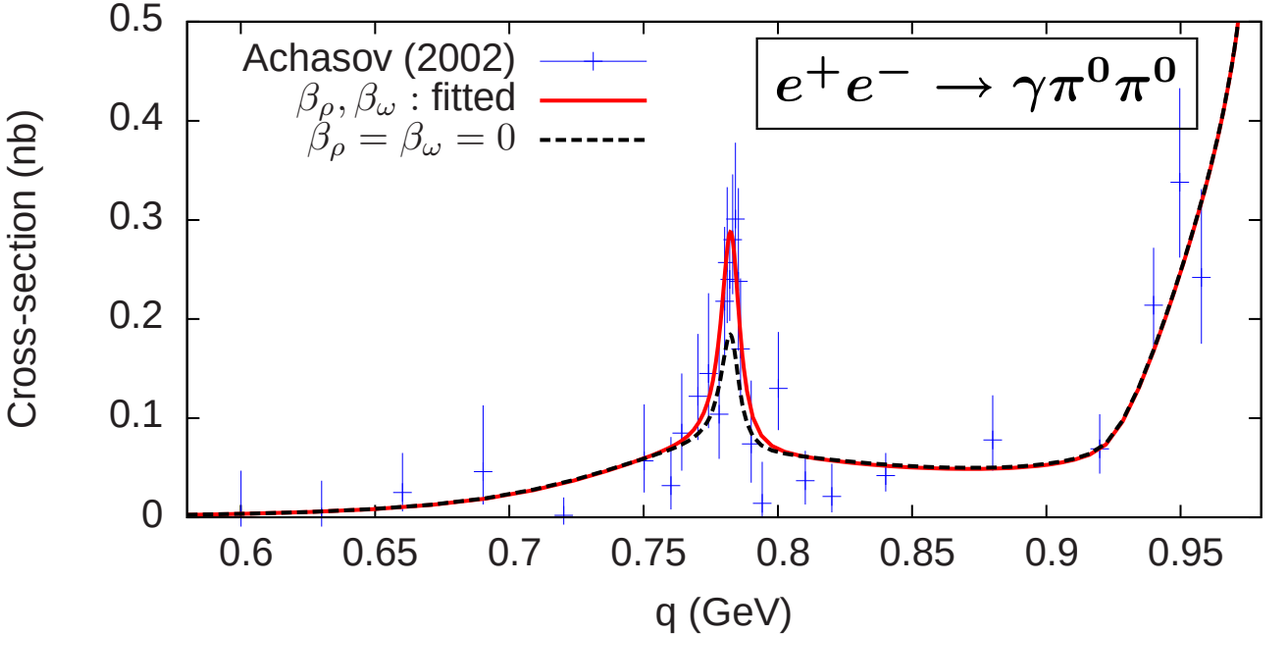
Shift in the scalar ff:

$$\boldsymbol{\Delta_\sigma = (13.9 \pm 0.3)}\ \text{MeV}$$
$$\boldsymbol{+Z_1\left(\frac{g^2}{4\pi} - 14.28\right)}$$
$$\boldsymbol{+Z_2\left(d_{00}^+\, M_\pi + 1.46\right)}$$
$$\boldsymbol{+Z_3\left(d_{01}^+\, M_\pi^3 - 1.14\right)}$$
$$\boldsymbol{+Z_4\left(b_{00}^+\, M_\pi^3 + 3.54\right)}$$

A FEW SELECTED HI-LITES II

• "Unified dispersive approach to real and virtual photon-photon scattering at low energy," B. Moussallam, arXiv:1305.3143.

A representations is obtained for the pion pair production amplitude from a photon plus a virtual photon, which applies for both positive and negative virtualities, by combining dispersion theoretical and soft-photon constraints and matching with the NLO chiral expansion.



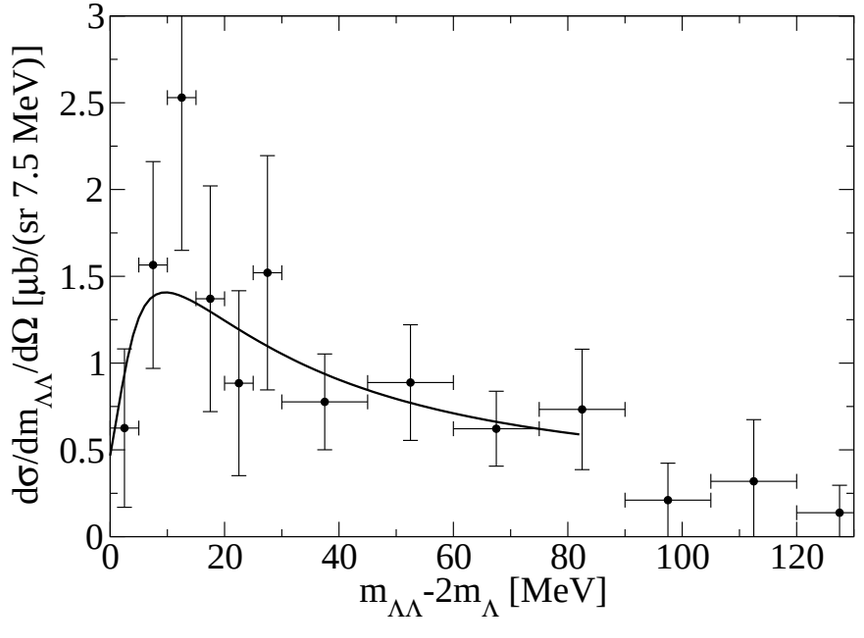
Achasov et al.,

Phys. Lett. B537 (2002) 201

A FEW SELECTED HI-LITES III

- "Scattering lengths of strangeness S=-2 baryon-baryon interactions,"
A. M. Gasparyan, J. Haidenbauer, C. Hanhart, Phys.Rev. C **85** (2012) 015204.

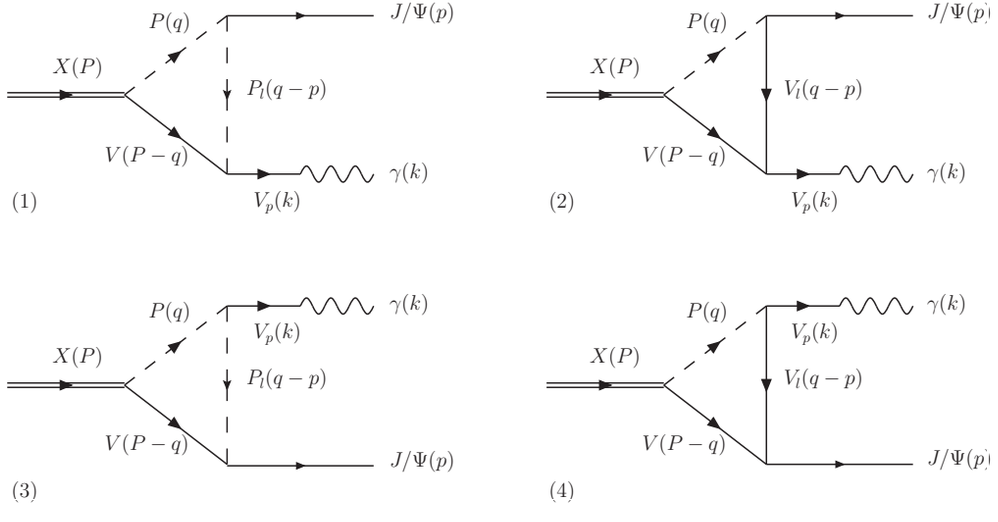
A method based on dispersion theory, that allows one to extract the scattering length of any two-baryon system from corresponding final-state interactions in production reactions, is reconsidered. Employing the method to available data on the $\boldsymbol{\Lambda\Lambda}$ invariant mass from the reaction $\boldsymbol{^{12}C(K^-, K^+\Lambda\Lambda X)}$, a $\boldsymbol{^1S_0}$ scattering length of $\boldsymbol{a(\Lambda\Lambda) = (-1.2 \pm 0.6)}$ fm is deduced.



A FEW SELECTED HI-LITES IV

• "The $X(3872) \to J/\psi\gamma$ decay in the $D\bar{D}^*$ molecular picture,"
F. Aceti, R. Molina, E. Oset, Phys. Rev. D **86** (2012) 113007.

From a picture of the X(3872), where the resonance is a bound state of $\bar{D}D^* - c.c.$, the decay width into the $J/\psi\gamma$, $J/\psi\omega$ and $J/\psi\rho$ channels, which are sensitive to the internal structure of this state, are evaluated. The importance of the charged $D\bar{D}^\star$ threshold is pointed out.



Predictions:

$$\Gamma(X \to J/\psi\gamma) = (117 \pm 40) \text{ keV}$$

$$\frac{\Gamma(X \to J/\psi\gamma)}{\Gamma(X \to J/\psi\pi\pi)} = (0.17 \pm 0.02)$$

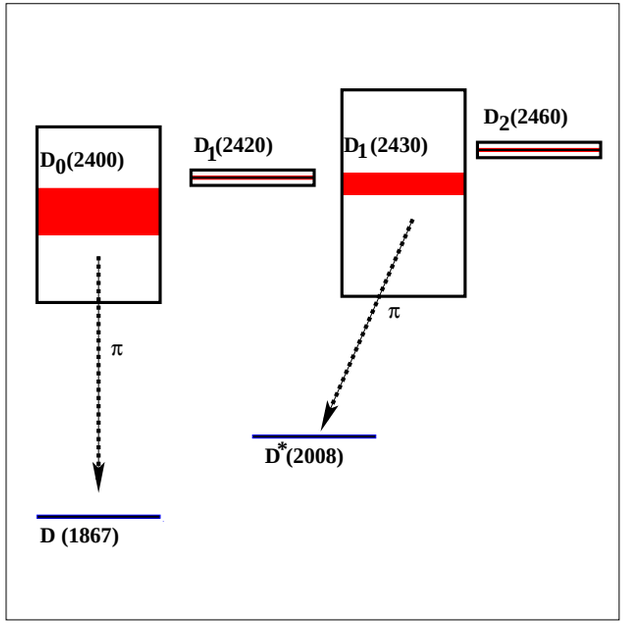
Belle 2005: 0.14 ± 0.05

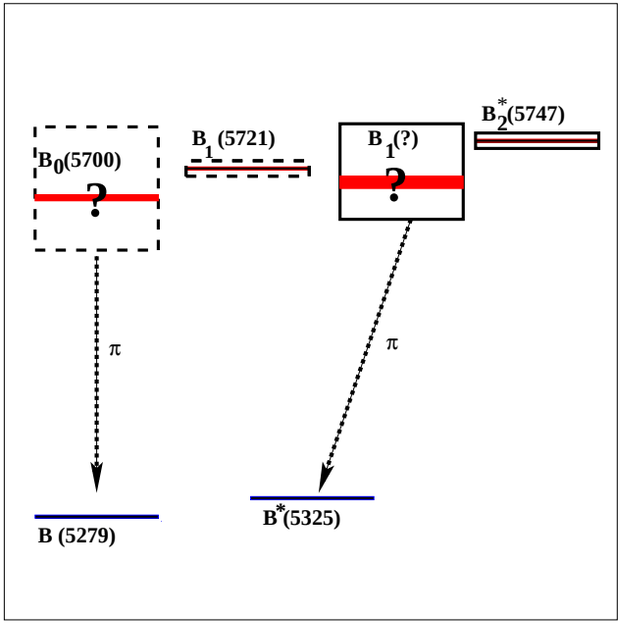
BaBar 2006: 0.22 ± 0.06

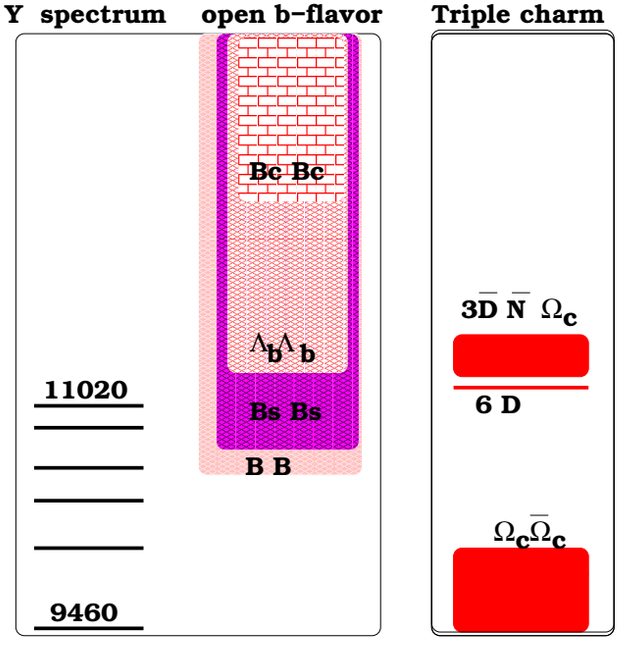
A FEW SELECTED HI-LITES V

• "Hadron physics potential of future high-luminosity B-factories at the $\Upsilon(5S)$ and above," A. G. Drutskoy, F.-K. Guo, F. J. Llanes-Estrada, A. V. Nefediev, J. M. Torres-Rincon, Eur. Phys. J. A **49** (2013) 7.

The physics opportunities of future high-luminosity B-factories at the $\Upsilon(5S)$ resonance and above are analyzed.



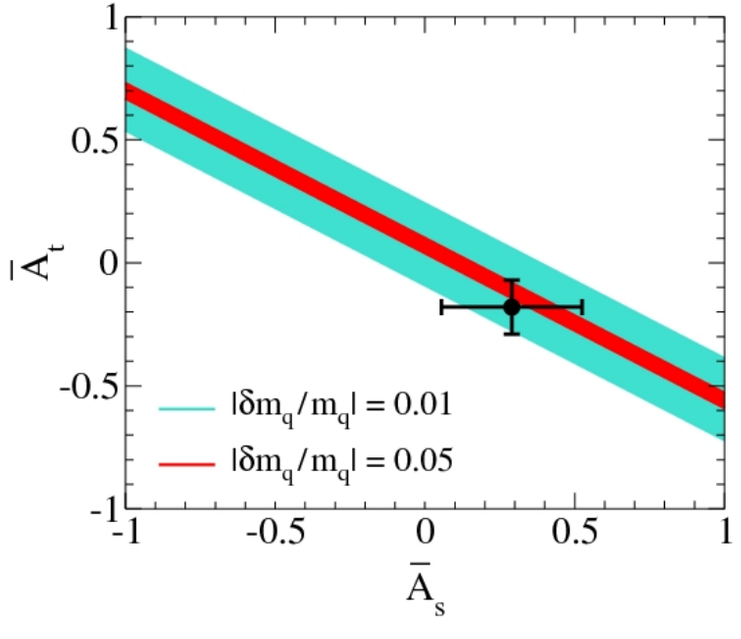




A FEW SELECTED HI-LITES VI

• "Viability of carbon-based life as a function of the light quark mass," E. Epelbaum, H. Krebs, T. Lähde, D. Lee, U.-G. Meißner, Phys. Rev. Lett. **110** (2013) 112502.

The Hoyle state plays a crucial role in the helium burning of stars that have reached the red giant stage. The close proximity of this state to the triple-alpha threshold is needed for the production of carbon, oxygen, and other elements necessary for life. Its is investigated whether this life-essential condition is robust or delicately fine-tuned for variations on the fundamental constants of nature, specifically the light quark mass and the strength of the electromagnetic interaction.



Quark mass dependence of the inverse nucleon-nucleon scattering lengths:

$$\bar{A}_{s,t} = \frac{\partial a_{s,t}^{-1}}{\partial M_\pi}$$

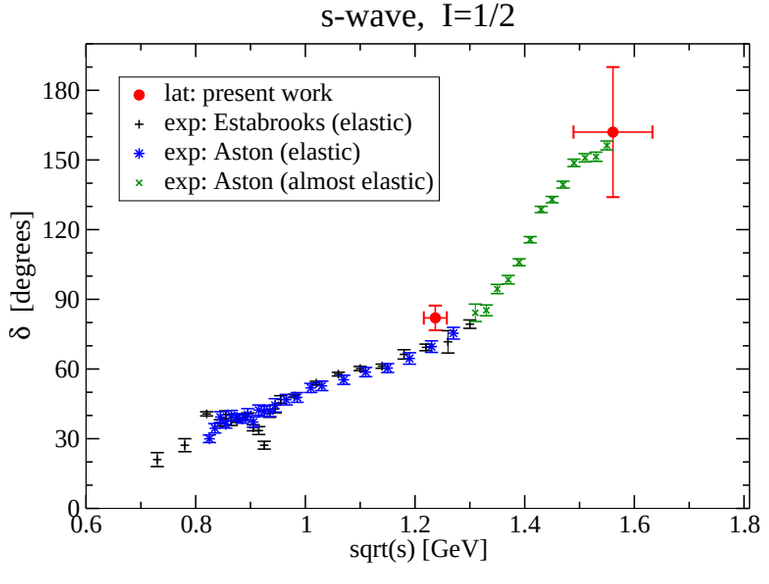
$$\Rightarrow |\delta m_q/m_q| \lesssim 2 \ldots 3\,\%$$

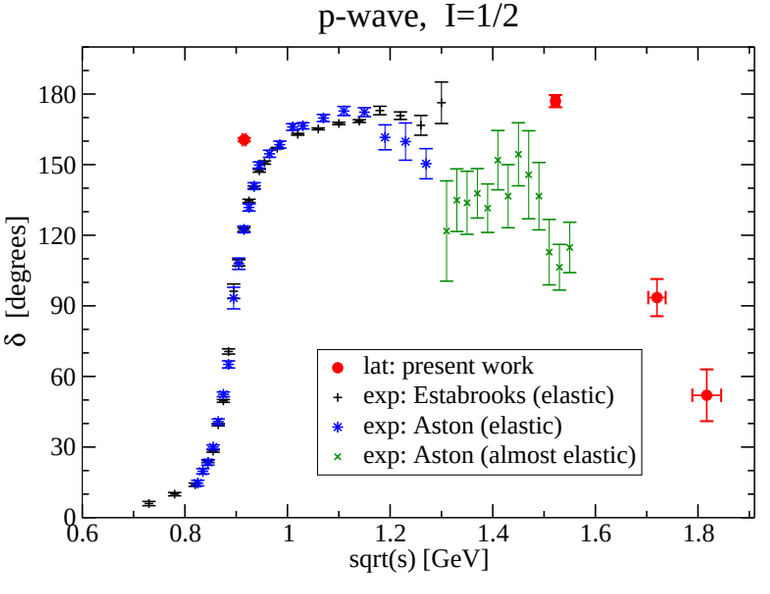
for carbon-based life

A FEW SELECTED HI-LITES VII

- "K pi scattering for isospin 1/2 and 3/2 in lattice QCD," C. B. Lang, L. Leskovec, D. Mohler, S. Prelovsek, Phys. Rev. D **86** (2012) 054508.

$K\pi$ scattering in s-wave and p-wave for both isospins I=1/2, 3/2 using quark-antiquark and meson-meson interpolating fields is simulated in lattice QCD for two dynamical quarks with $M_\pi = 266$ MeV and $M_K = 552$ MeV. The extracted elastic phase shifts delta at several values of the $K - \pi$ relative momenta exhibit qualitative agreement with the experimental phases in all four channels.

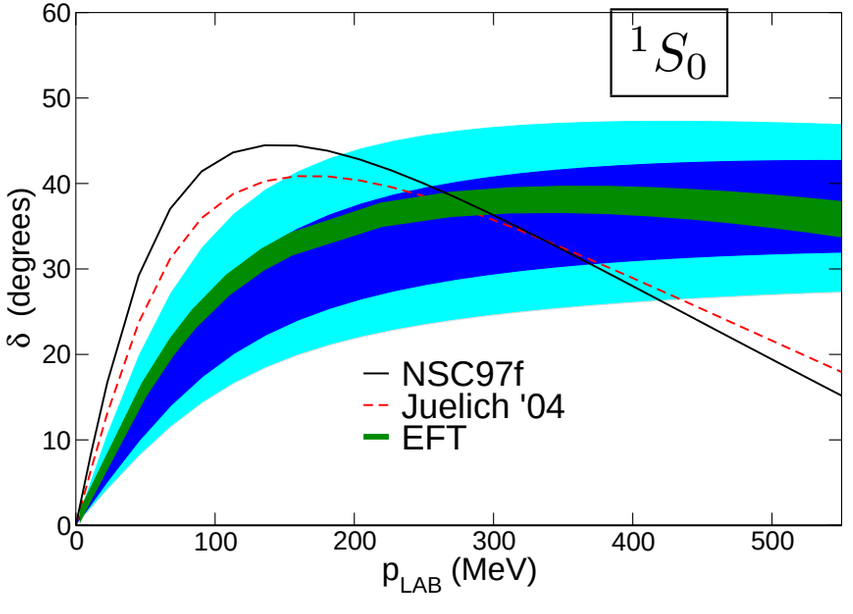


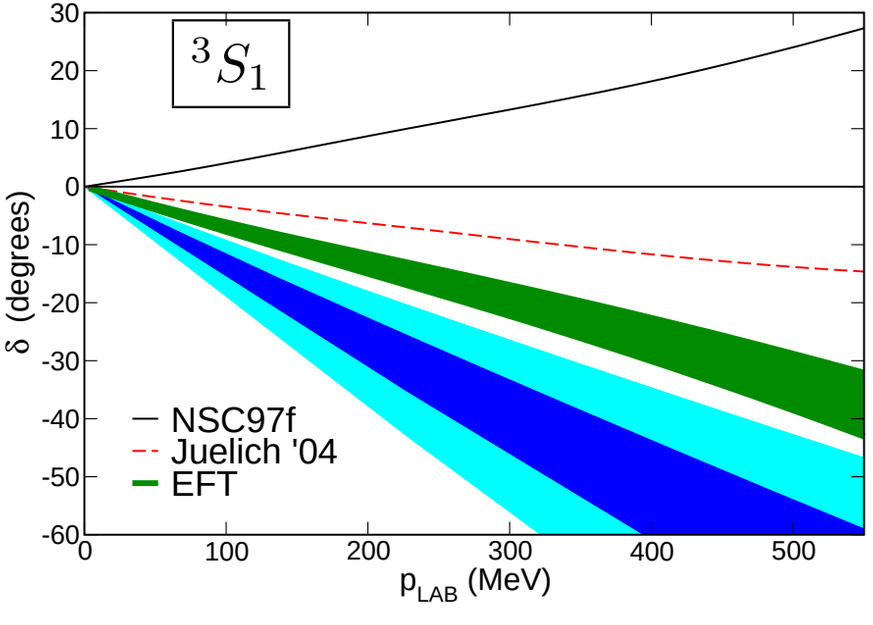


A FEW SELECTED HI-LITES VIII

• "Hyperon-Nucleon Interactions and the Composition of Dense Nuclear Matter from Quantum Chromodynamics," S.R. Beane et al., Phys. Rev. Lett. **109** (2012) 172001.

The low-energy $n - \Sigma^-$ interactions determine, in part, the role of the strange quark in dense matter, such as that found in astrophysical environments. The scattering phase shifts for this system are obtained from a numerical evaluation in Lattice QCD.

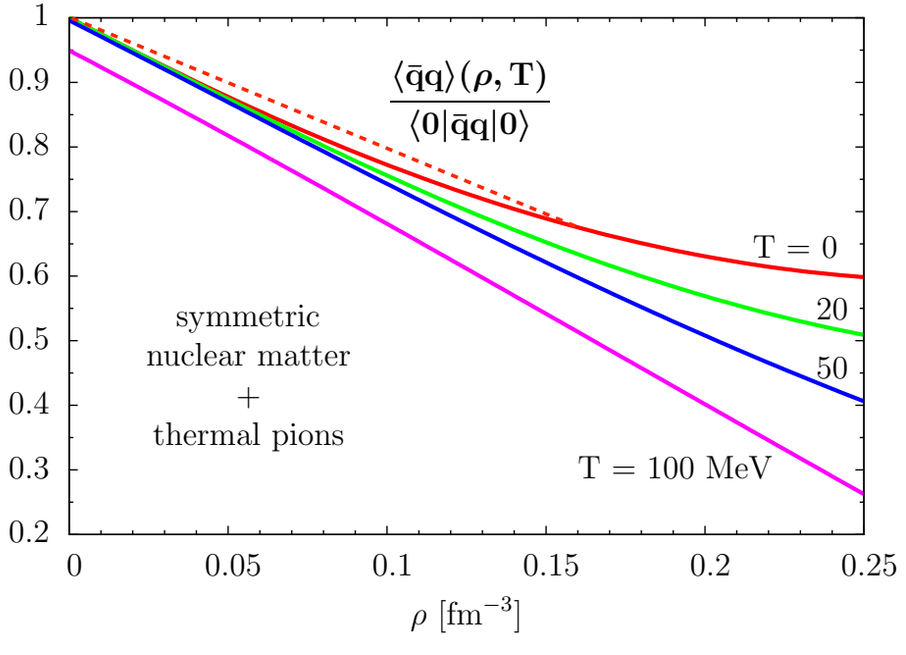




A FEW SELECTED HI-LITES IX

"Nuclear thermodynamics and the in-medium chiral condensate,"
S. Fiorilla, N. Kaiser, W. Weise, Phys. Lett. B **714** (2012) 251.

The temperature dependence of the chiral condensate in isospin-symmetric nuclear matter at varying baryon density is investigated using thermal in-medium chiral effective field theory.



⇒ *much more to come . . .*

SUMMARY & OUTLOOK

- EPOS is a large assembly of active hadron physics theoreticians
- Many intriguing results obtained in **all** project areas
- EPOS theoreticians highly visible internationally
- Still many challenges remain:
  - ⋆ precision calculations
  - ⋆ the spectrum of QCD
  - ⋆ methods for lattice QCD
  - ⋆ phases of QCD

$\Rightarrow$ **significant progress, but work not finished**