CRC110: Symmetrien und Strukturbildung in QCD

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KHuK, Bad Honnef, November 2019

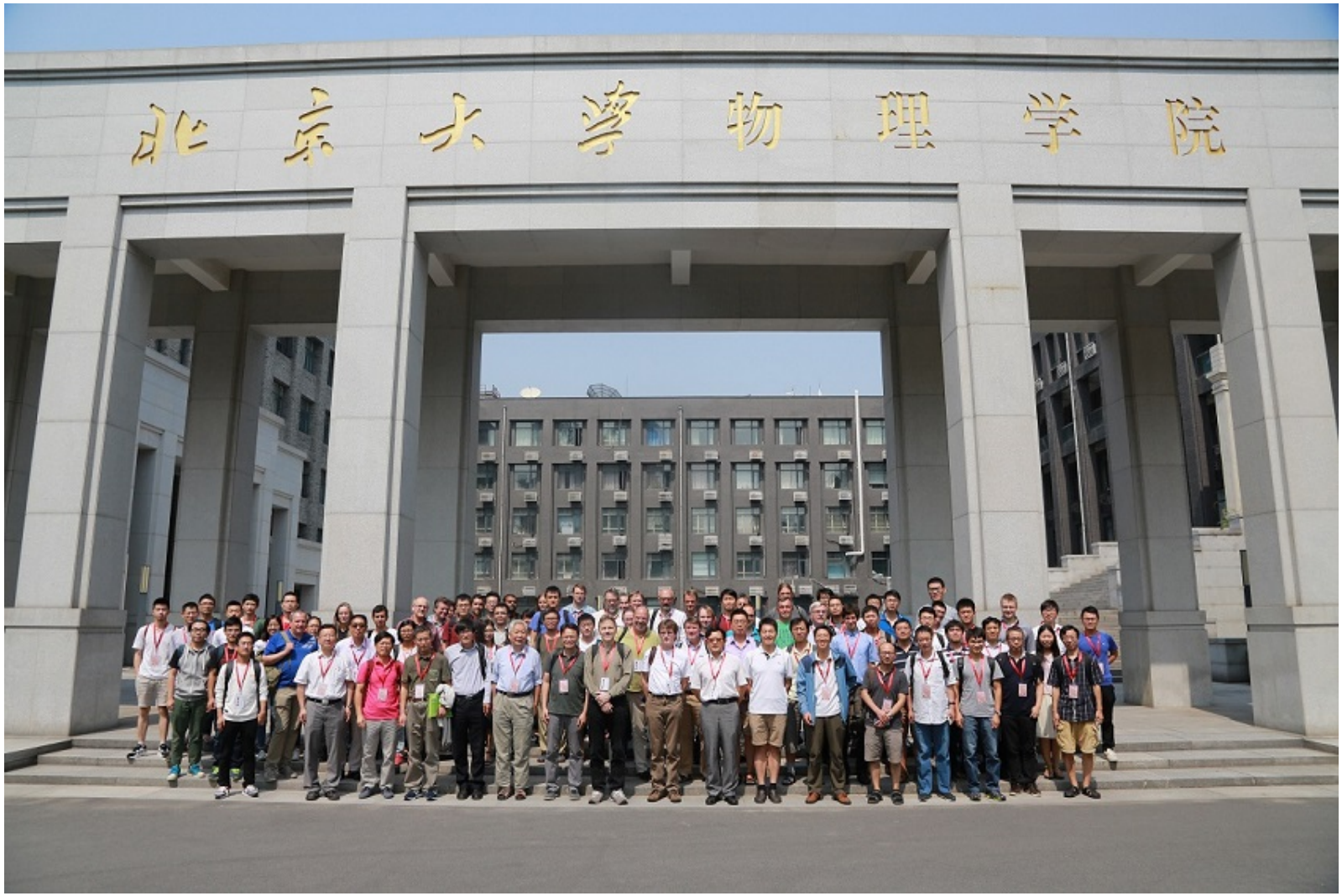
A Unique Endeavour in 2012

- form a CRC combining German nodes Bonn, Munich with Chinese node Beijing

$\Rightarrow$ with purely theoretical focus on QCD!

- participating institutions first funding period (2012):
  - Rheinische Friedrich-Wilhelms-Universität Bonn
  - Peking University, Beijing
  - Technische Universität München
  - Forschungszentrum Jülich
  - Institute of High Energy Physics, Beijing
  - Theoretical Physics Center for Science Facilities, Beijing

- additional since second funding period (2016):
  - Ruhr-Universität Bochum
  - Institute of Theoretical Physics, Beijing
  - experimental component: PW analyses

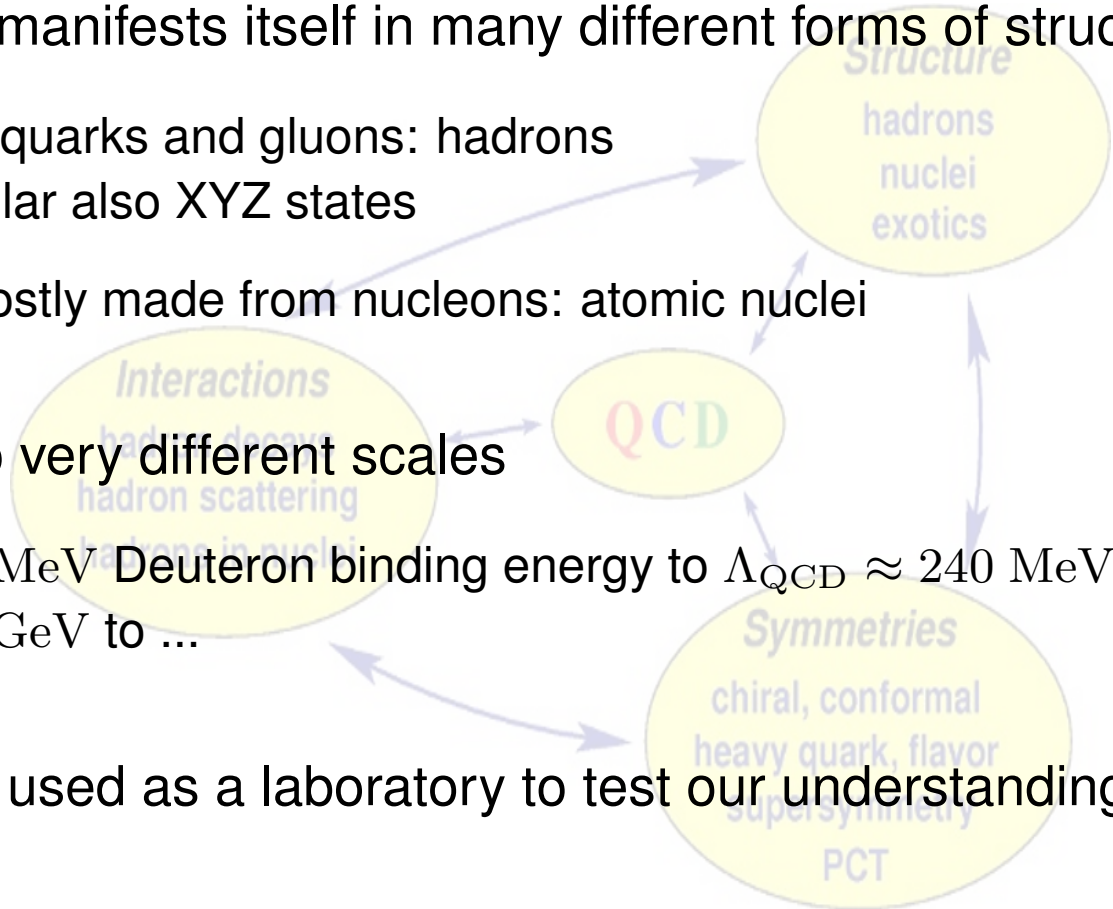


@ CRC110 general meeting at PKU 2017

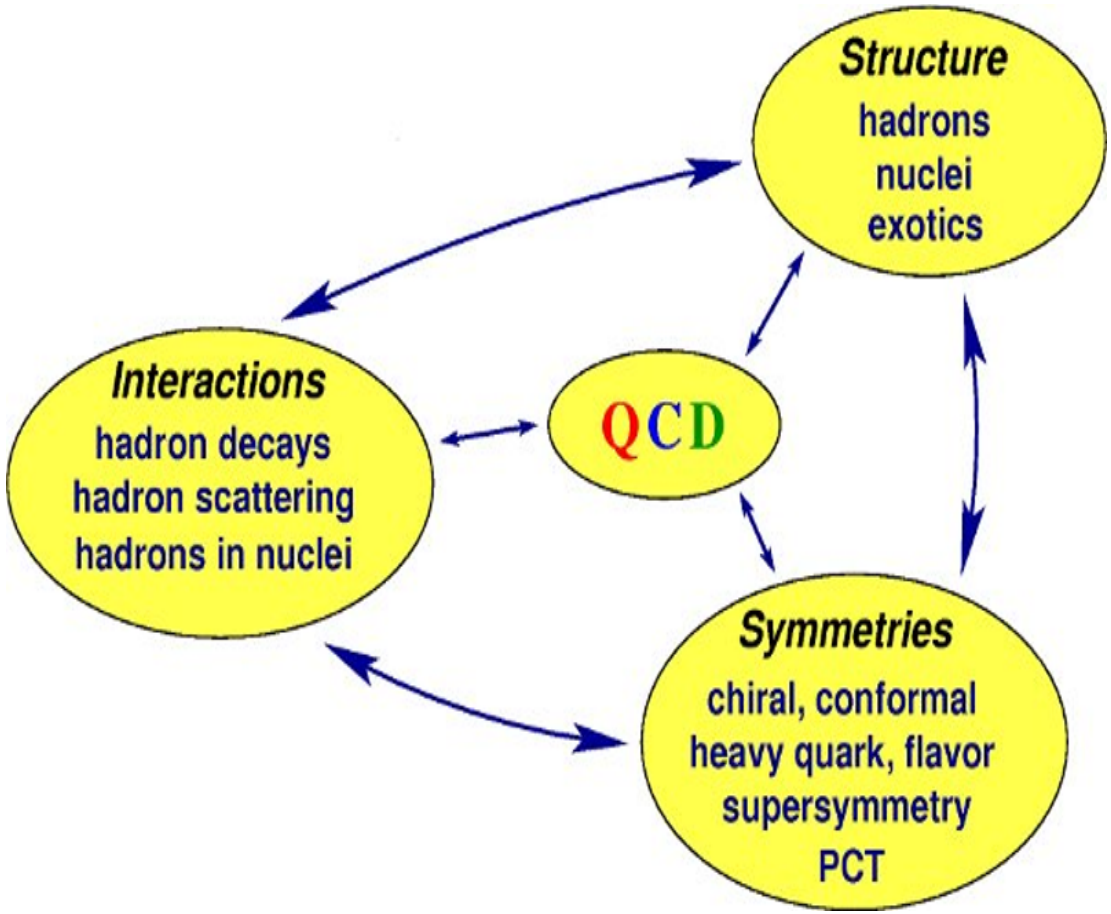
Ambition

$\Rightarrow$ deepen our understanding of strong QCD and the SM

- strong QCD manifests itself in many different forms of structures
  - states of quarks and gluons: hadrons
    in particular also XYZ states
  - states mostly made from nucleons: atomic nuclei
- connected to very different scales
  - from $2.2\ \mathrm{MeV}$ Deuteron binding energy to $\Lambda_{\mathrm{QCD}} \approx 240\ \mathrm{MeV}$ to $m_N \approx 1\ \mathrm{GeV}$ to ...
- QCD can be used as a laboratory to test our understanding of symmetries
  - CPT
  - chiral symmetry

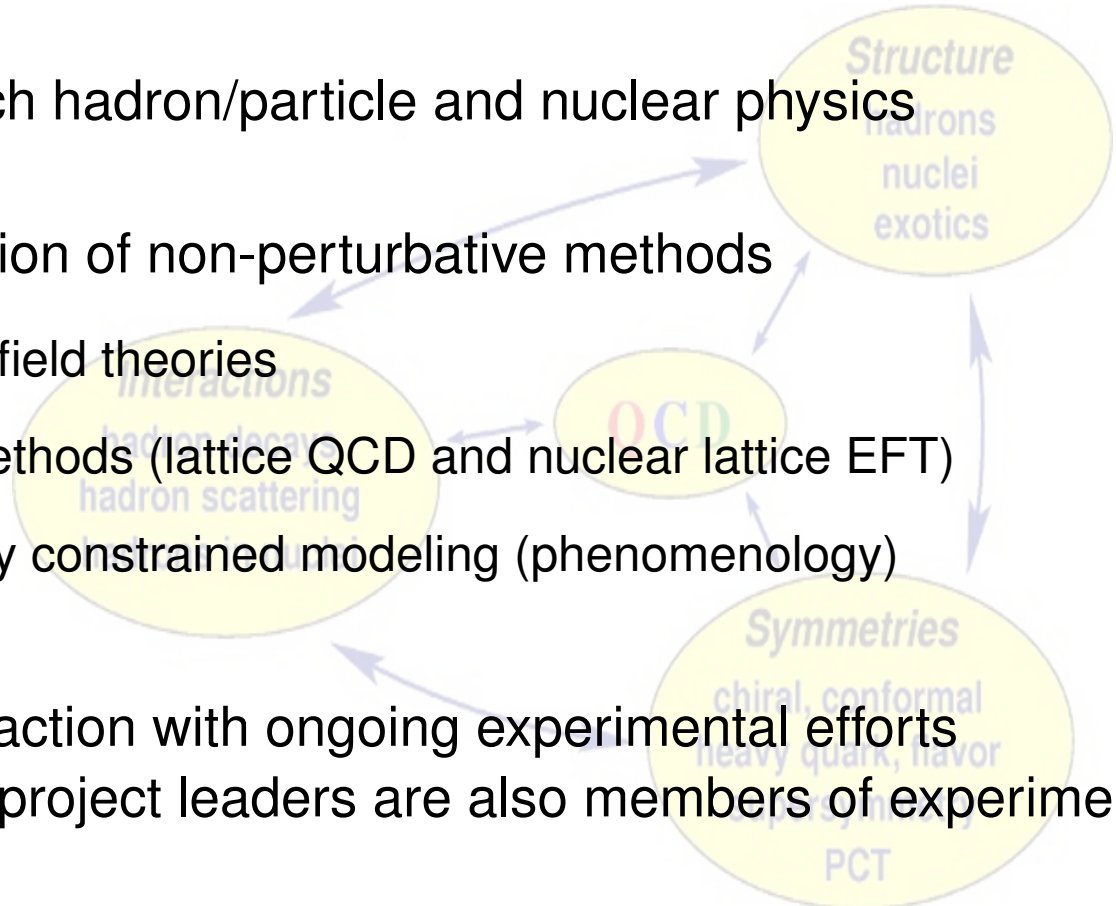


Ambition


Structure
hadrons
nuclei
exotics
Interactions
hadron decays
hadron scattering
hadrons in nuclei
QCD
Symmetries
chiral, conformal
heavy quark, flavor
supersymmetry
PCT

Ambition

- joint approach hadron/particle and nuclear physics
- joint application of non-perturbative methods
  - effective field theories
  - lattice methods (lattice QCD and nuclear lattice EFT)
  - symmetry constrained modeling (phenomenology)
- intense interaction with ongoing experimental efforts
  some of our project leaders are also members of experiments



Structure and Collaboration

- by enlarge, projects are led by at least one Chinese and one German PI
- now 20 projects with 35 project leaders
- longer term student exchanges and shared postdocs
- dual doctorates from Chinese and German institutions
- longer visits by Chinese and German PIs to Germany or China
- co-organised workshops and conferences (20 by now)

Assembling Collaborations

- before 2012: selected collaborations among single persons
- 2012: CRC110 starts
  MoU for common graduate education (UBonn, PKU, ITP)
- 2012–: many workshops CRC organised or co-organised
- 2014: MoU for common graduate education (UBonn, IHEP)
- 2016: “Physik Show” travels to China
- 2018: RMP on “Hadronic Molecules” written by 3 Chinese and 3 German project leaders
- 2019: common Postdoc between ITP and Bonn

Indicators of Success

- more than 600 peer reviewed papers, 150 with both Chinese and German authors
  among others in PRL, RMP, PR, Nature, PRD, JHEP, EPJC, EPJA, ...
- among those: a number of review articles
- more than 100 invited talks at conferences and workshops
- career booster: > 15 former postdocs now permanent in academia (professor or staff)
- CRC110 postdocs and students successful in the Chinese 1000 Talents Project
- more than 100 finished or ongoing dissertations

Example: Connecting EFT with Lattice QCD

- traditionally: use chiral perturbation theory (ChPT) for meson masses and decay constants computed in lattice QCD
- however, lattice QCD nowadays able to compute many more observables, e.g.
  - phase shifts, pole positions
  - three particle couplings
  - transition matrix elements
- guidance beyond ChPT needed for extrapolations and analysis
- strength of the CRC110: expertise in both fields

Outreach Activities

- “Physik Show”
  - various places in Germany and Europe
  - in 2016 first time in Beijing
  - EPS outreach prize

- academies for high school students: “Schülerakademien Teilchenphysik”
- school teacher training: “Lehrerfortbildung Teilchenphysik”

Fundamental Research Questions

Fundamental questions:

- which forms of strongly interacting particles and matter are generated by QCD?

- how do the underlying symmetries manifest themselves in the spectrum and interaction of QCD?

$\Rightarrow$ two project groups

- A – symmetries
- B – emergence of structure

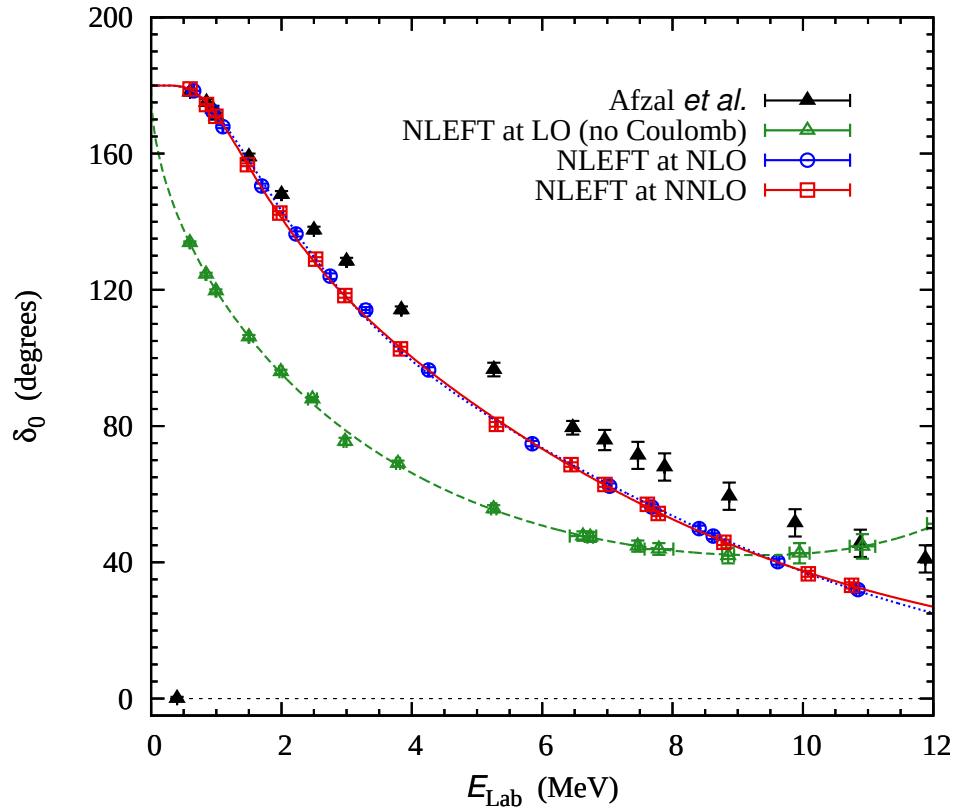
Three examples in the following

$\alpha - \alpha$ Scattering from Nuclear Lattice Simulations

- Nuclear Lattice Simulations: very successful combination of lattice and EFT methods
- allowed for the first “at initio” calculation of the Hoyle state

  [Epelbaum et al., PRL 109 (2012)]
- newly developed adiabatic projection method for reactions: Algorithmic scaling $\propto (A_1 + A_2)^2$
- good description of $\alpha - \alpha$ scattering

  [Elhatisari et al., Nature 528 (2015)]



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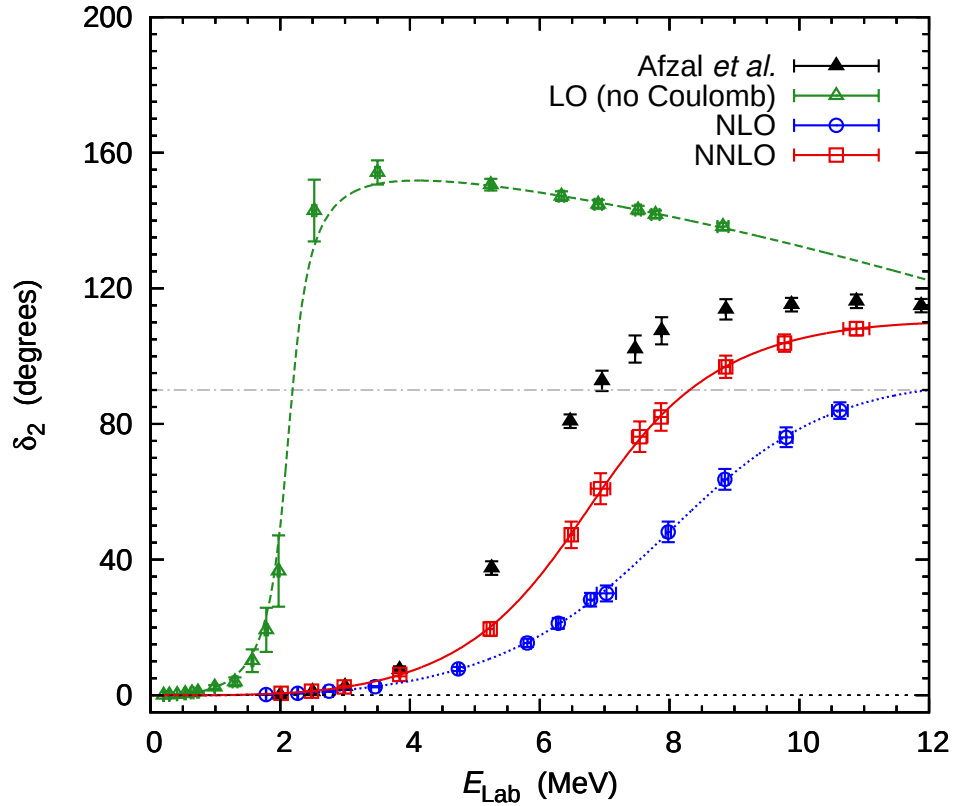


NLEFT outlook

- this seminal result on $\alpha - \alpha$ scattering paves the way towards

$$\alpha + {}^{12}C \quad \rightarrow \quad {}^{16}O + \gamma$$

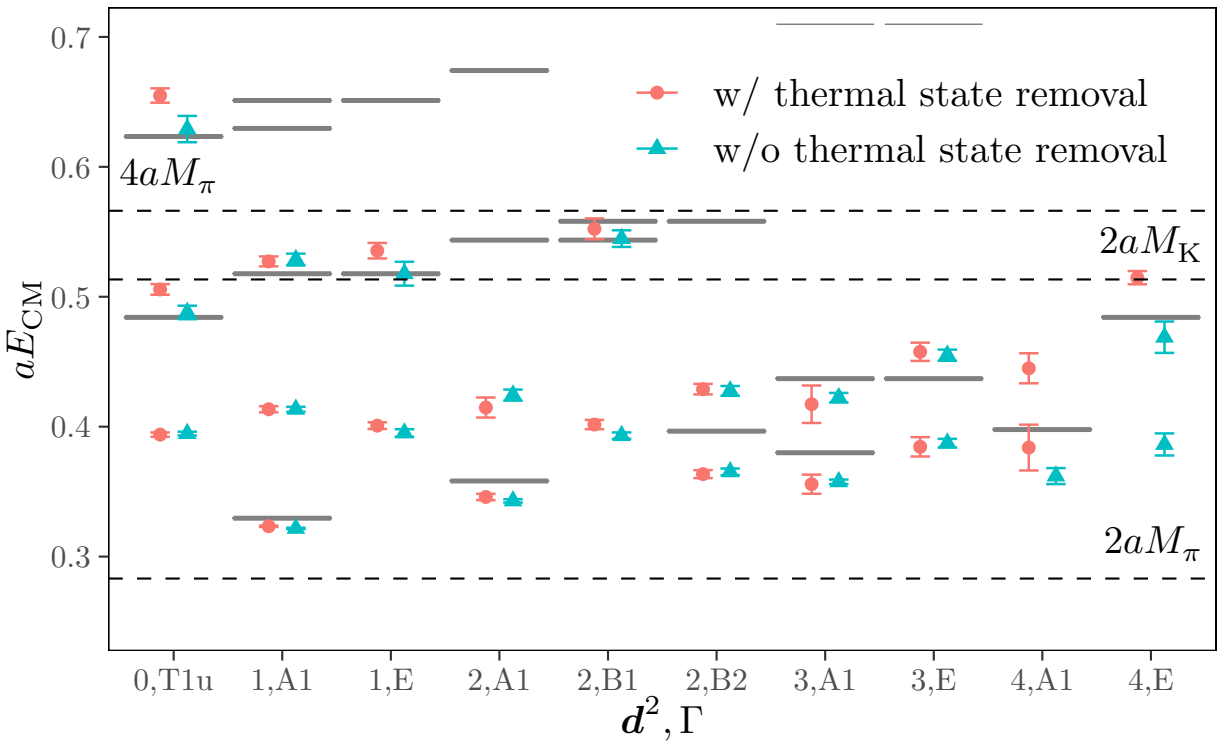
  holy grail of nuclear astrophysics

- long term goal: connect lattice QCD and NLEFT

$\Rightarrow$ compute low energy constants from lattice QCD as input for NLEFT calculations

Hadron-Hadron Interactions from Lattice QCD: ρ-resonance

- very successful combination of lattice and EFT methods



- lattice interacting versus free energy levels

[ETMC: Werner et al., arxiv:1907.01237]

Hadron-Hadron Interactions from Lattice QCD: ρ-resonance

- Lüscher method relates energy shifts to phase shifts
- lattice results at un-physically large pion mass values
- extrapolation using EFT

  [Djukanovic et al., Phys. Lett. B680, 235]
- good agreement to experiment for the ρ-mass, slight miss-match for the width

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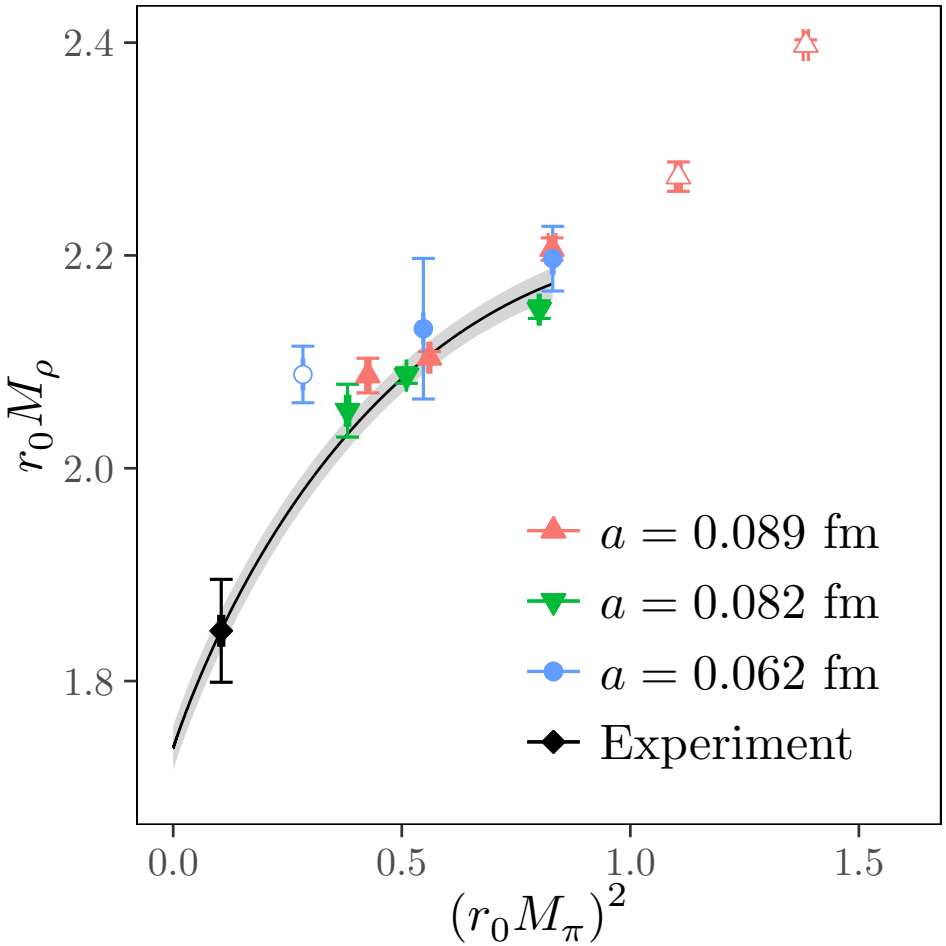

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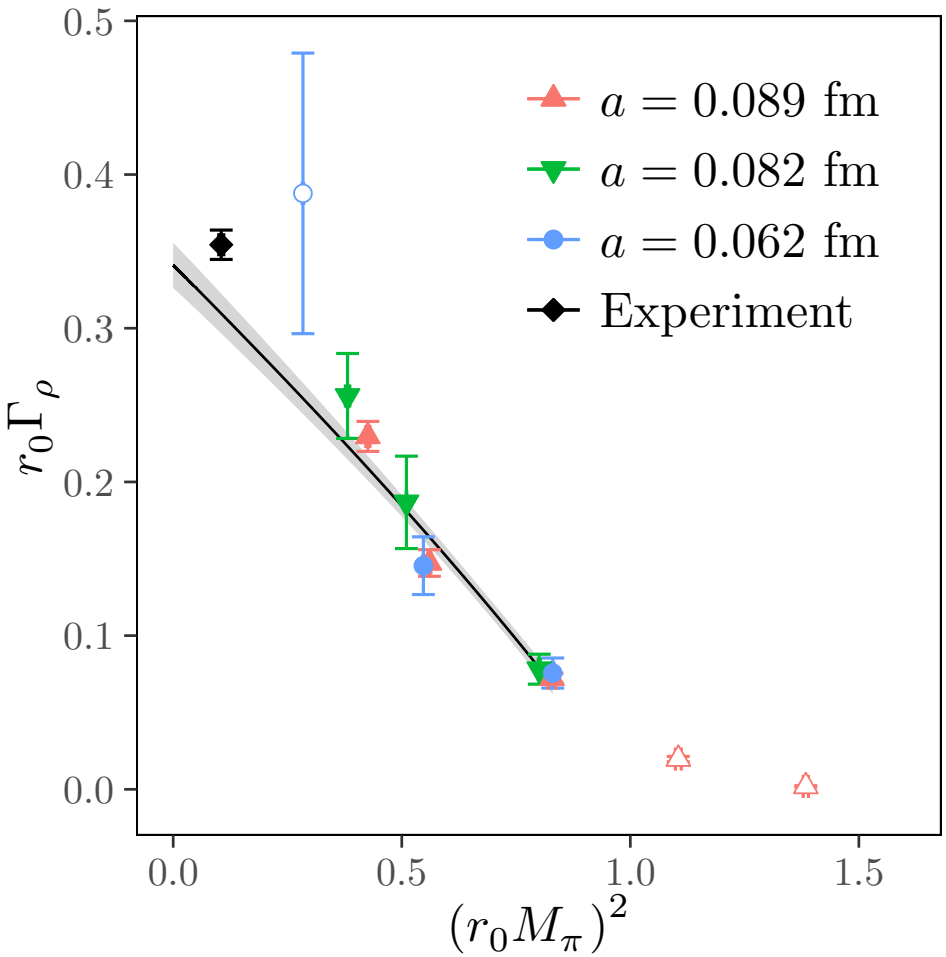

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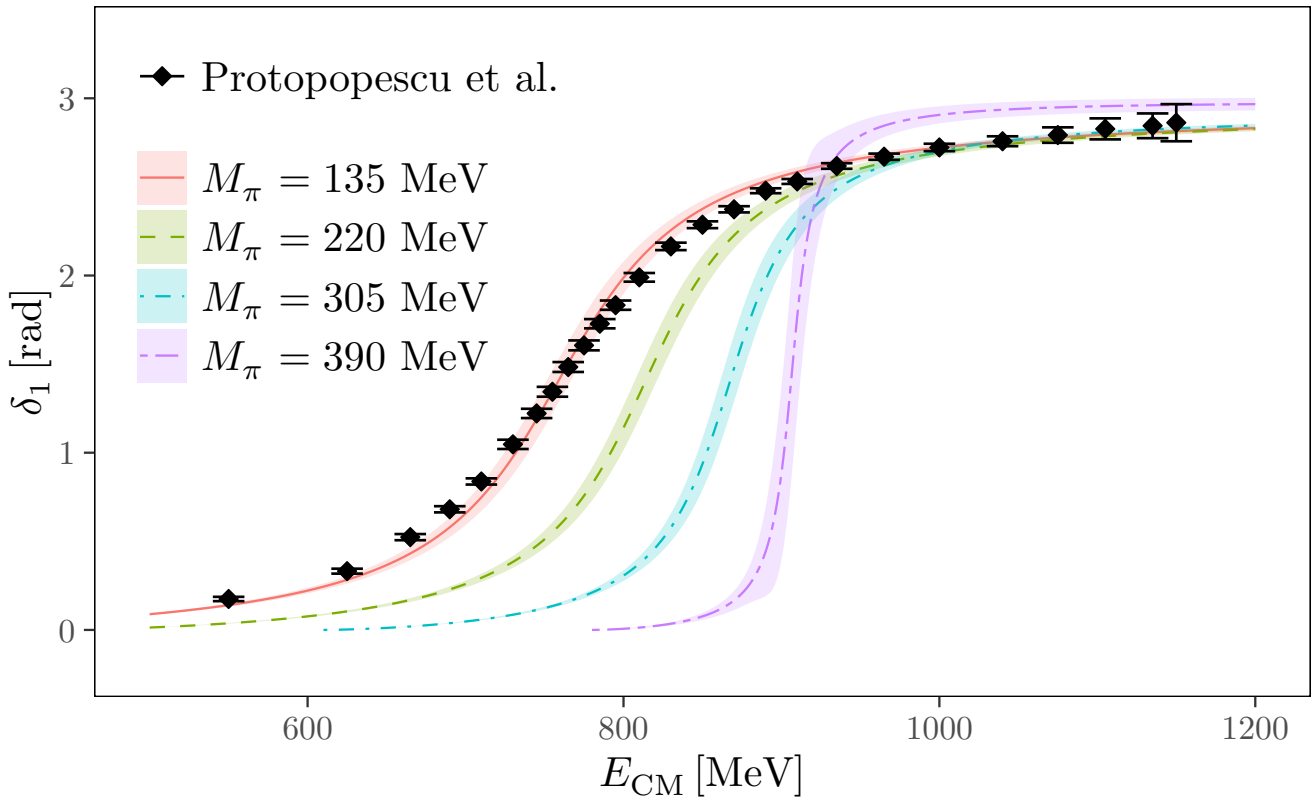
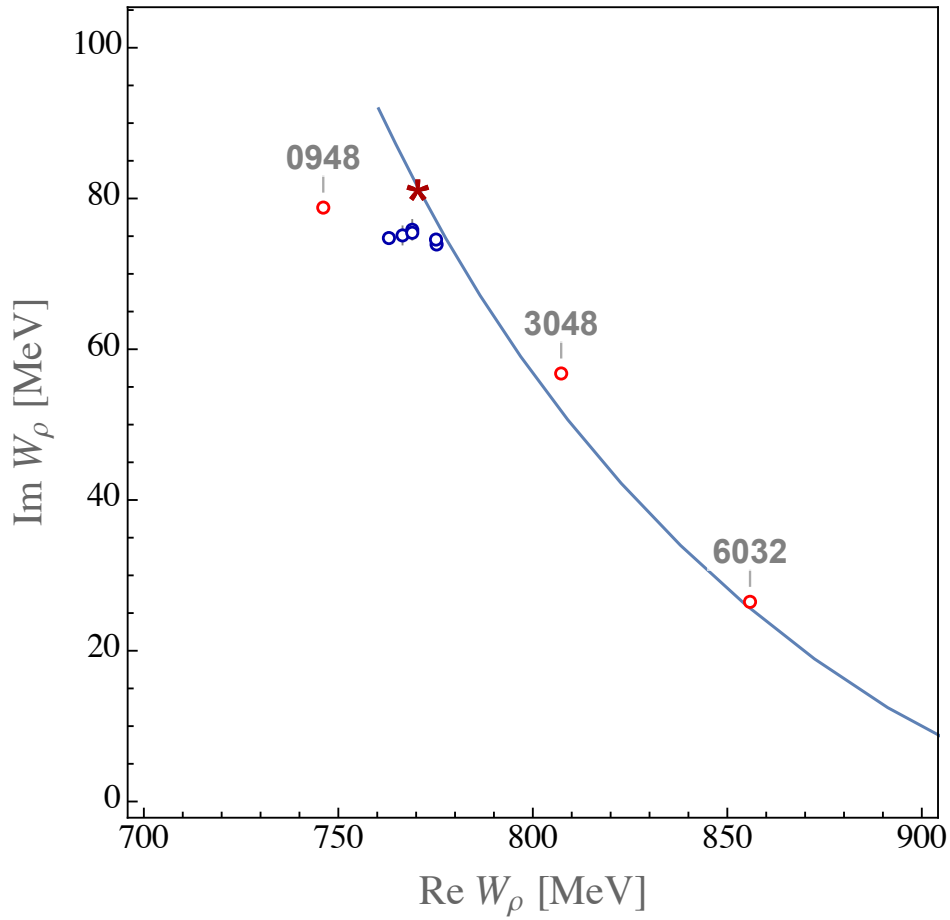


Hadron-Hadron Interactions from Lattice QCD: Outlook

- many simulations in Lattice QCD now at the physical point!
- **preliminary** result for the ρ with $N_f = 2$
- three pion mass values including one at $M_\pi = 135\ \mathrm{MeV}$.
- line an IAM fit to all three ensembles
- move towards three particle interactions



Exotic states: the $D_0^\star$ scalar meson

- the $D_0^\star(2300)$ (former $D_0^\star(2400)$) scalar $I = 1/2$ meson
- lot of attention: mass very different from the quark model prediction
- $D_0^\star$ properties also influence the form factor $f_+ \quad \rightarrow \quad |V_{cd}|$
- a first lattice study with $D\pi$, $D\eta$ and $D_s\bar{K}$ coupled channels

  [Moir et al, JHEP 1610, 011 (2016)]

$\Rightarrow$ find a (single pole) bound state identified as $D_0^\star(2300)$
based on a parametrization of the t-matrix

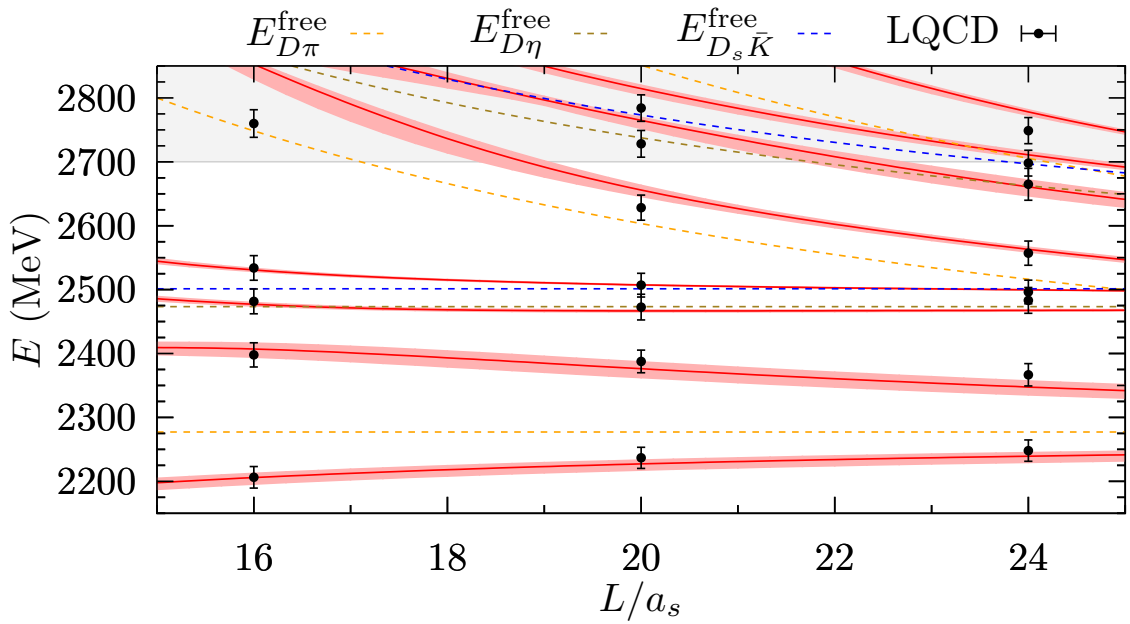
- however, situation might be different

  [Albalabejo et al., Phys.Lett. B767 (2017)]

Exotic states: the $D_0^\star$ scalar meson

- post diction of the lattice energy levels with LEC input

  [Liu et al., Phys. Rev. D 87, 014508 (2013)]



- this analysis reveals a two pole structure!

Exotic states: the $D_0^\star$ scalar meson

- two pole structure can be understood from group theory
- two poles $(M, \Gamma/2)$ for $D_0^\star$ in MeV

$$(2105(7), 102(11)) \, ; (2451(30), 134(8))$$

versus PDG in MeV

$$(2318 \pm 29, 134 \pm 20)$$

is there experimental evidence for this?

- more two-pole candidates:

$$D_1, B_0^\star, B_1$$

Summary

- CRC110: successful Sino-German endeavour with theory emphasis
- striving to improve our understanding of strong QCD and the SM
- strength in combining expertise in many different fields and methods
- foster Sino-German collaboration further
- working towards third funding period starting in July 2020