

RA1 „Bound states of light and heavy quarks“

Program:

⇔ Discussion of the overall work program in RA1

- Current and future projects

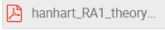















→
13 talks

Interesting talks and fruitful discussions!

Discussion on cross-functional research teams:

- Idea to collect project proposals and discuss based on those the formation of cross functional research teams.

Agenda

10:00	→ 10:20	Introduction Speakers: Christoph Hanhart (uni-bonn), Ulrike Thoma (uni-bonn) 	⌚ 20m	
10:20	→ 10:40	Light baryon resonances at INSIGHT Speaker: Ulrike Thoma (uni-bonn)	⌚ 20m	
10:40	→ 11:00	Light and heavy baryon resonances from the JüBo model Speaker: Deborah Rönchen (Forschungszentrum Jülich)	⌚ 20m	
11:00	→ 11:20	Recent results of BGOOD and outlook to insight Speaker: Hartmut Schmieden (uni-bonn)	⌚ 20m	
11:20	→ 11:40	Strange hadron spectroscopy Speaker: Peter Hurck (Helmholtz-Institut für Strahlen- und Kernphysik)	⌚ 20m	
11:40	→ 12:00	Two-pole structures in QCD Speaker: Ulf-G. Meißner (Helmholtz-Institut für Strahlen- und Kernphysik)	⌚ 20m	
12:00	→ 12:20	Baryons at ELSA meet LHCb via PWA (e.g. $\Lambda_b \rightarrow K p \gamma$) Speaker: Ulrike Thoma (uni-bonn)	⌚ 20m	
12:20	→ 12:40	Light and strange meson resonances Speaker: Bernhard Ketzer (Helmholtz-Institut für Strahlen- und Kernphysik)	⌚ 20m	
12:40	→ 13:00	Short discussion of our resonance results and future plans Speaker: Carsten Urbach (HISKP, Uni Bonn)	⌚ 20m	
13:00	→ 13:20	Advanced parametrisations for hadronic form factors Speaker: Bastian Kubis (HISKP, Bonn University)	⌚ 20m	
13:20	→ 14:30	Lunch Break	⌚ 1h 10m	
14:30	→ 14:50	Between Color and Flavor: Understanding the D^{**} Mesons Speaker: Markus Prim	⌚ 20m	
14:50	→ 15:10	Model independent analyses of doubly heavy exotic states Speaker: Vadim Baru	⌚ 20m	
15:10	→ 15:30	Heavy quark exotics and charm loops at LHCb Speaker: Sebastian Neubert (Helmholtz-Institut für Strahlen- und Kernphysik)	⌚ 20m	
15:30	→ 15:50	Connecting Color and Flavor Speaker: Mick Mulder	⌚ 20m	
15:50	→ 16:30	Closing Discussion Speakers: Christoph Hanhart (uni-bonn), Ulrike Thoma (uni-bonn)	⌚ 40m	

Objectives / main research areas:

- **Understand the spectrum, properties, and inner structure of hadrons.** (Mesons, Baryons – light and heavy)
- **Clarify the nature of exotic hadrons and what they tell us about QCD.**
- **Operate the new experiment INSIGHT @ ELSA and investigate the non-strange and strange baryon spectrum, search for multi-quark and molecular states.**
- **Understand occurrence of two-pole structures in meson and baryon sectors.**
- **Investigate final-state interactions in hadronic decays.**

⇔ From the light to the heavy quarks

⇔ Connecting to the other RA's, especially RA2

Projects received – a quick summary

- 1) Ulf, Carsten: **Ab initio** calculation of hadronic three-particle decays in QCD
- 2) Stefan, Christoph: **Lattice Quantum Chromodynamics** study of exotic hadrons
- 3) Christoph, Bastian, Thomas: **B-decays with multi-hadron final states** (= project applied for inRA2)
- 4) Christoph, Thomas: **Spectroscopic analyses of exotic states and their spin and flavor partners: data driven insights and implications for CP violation**
- 5) Christoph: **Light-quark mass dependence of doubly heavy tetraquark**
- 6) Christoph: **From LHCb to Lattice QCD: an extended chiral EFT approach to P_c Pentaquarks and $\Lambda_c \bar{D}^{(*)}$ -dynamics**
- 7) Bastian: **Conformal maps for hadronic form factors**
- 8) Peter: **P_s pentaquark-search at INSIGHT**
- 9) Tom: **Study of exotic states with INSIGHT**
- 10) Ulrike for INSIGHT et al.: **Software developments for INSIGHT**
- 11) Bernhard, Peter: **Light and strange exotic mesons – Advanced fitting methods**
- 12) Ulrike, Sebastian, Johannes, Deborah: **PWA to understand the light (u,d) and (u,d,s) baryon sector / Combining light baryon spectroscopy data (from ELSA) with LHCb-data in a PWA**

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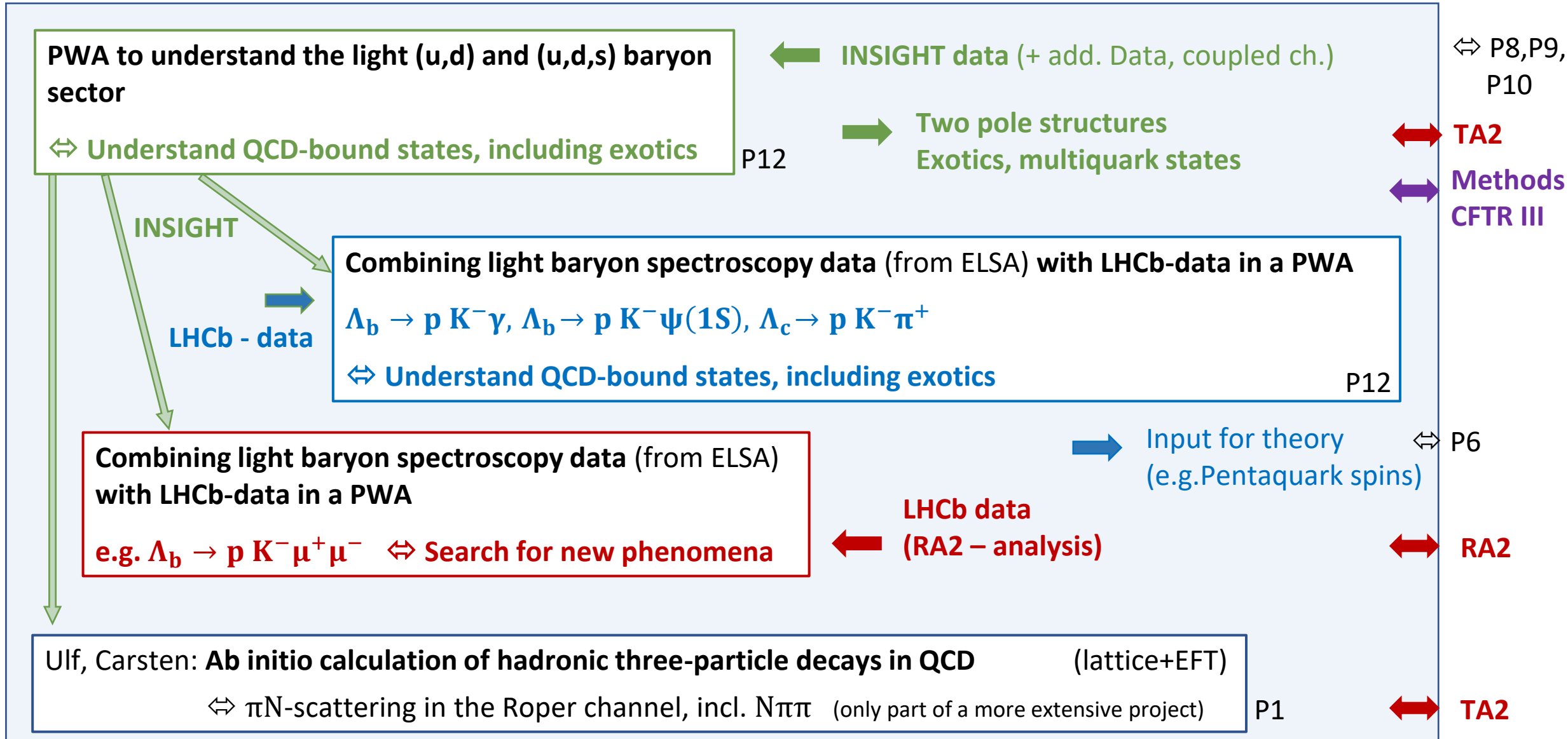
- 1) Ulf, Carsten: **Ab initio** calculation of hadronic three-particle decays in QCD
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**Christoph and myself did so far mostly discuss the projects not yet the CFRTs,
+ additional discussions with RA1 members needed**
⇔ aspects missing
⇔ only projects received for which funding is needed

RA1 „Bound states of light and heavy quarks“

Ulrike, Sebastian, Johannes, Deborah + Ulf, Carsten (Christoph, Bastian):

CFRT I



Peter, Tom, Ulrike + further INSIGHT-groups:

CFRT II

INSIGHT – Software and Analysis

Peter: **P_s pentaquark-search at INSIGHT (P8)**

$\gamma p \rightarrow \phi p \rightarrow p K^+ K^- \Leftrightarrow$ Search for exotic hadrons (strange pentaquark), INSIGHT@ELSA

- Software preparation / feasibility studies
- Data taking (2029), analysis

Tom: **Study of exotic states with INSIGHT (P9)**

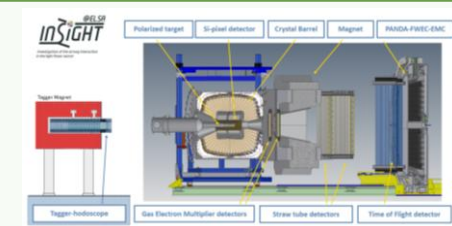
Search for exotic molecular states, pentaquarks (forward going K)

\Leftrightarrow driving BGOOD-physics into the future @INSIGHT, with target polarisation

- Software preparation / feasibility studies
- Data taking (2029), analysis (T: $\gamma p \rightarrow K^+ \Sigma^0$)

Ulrike for INSIGHT et al.: **Software developments for INSIGHT (P10)**

Software-developments for INSIGHT - from the hardware geometries to feasibility studies to exciting physics
= basis for an successful experiment (later (2029) data analysis)



TA1

➡ Two pole structures
Exotics, multiquark states

➡ Data provides also
basis for other projects

RA2

Bernhard, Peter + Christoph, Bastian, Thomas + Ulf, Carsten:

CFRT III

Bernhard, Peter: **Light and strange exotic mesons – Advanced fitting methods (P11)**

- **Tool developments:** unitary fit models, coupled channel analysis, inclusion of rescattering effects, extraction of branching ratios

- ⇔ analysis of COMPASS data / later AMBER (2031) data
 - $\pi_1(1600) \rightarrow \eta\pi, \eta'\pi$
 - development of unitary models for 3 particle states
 - analysis of $3\pi, K\pi\pi$

↔ **TA2**

← **From theory groups:**
unitary constraints,
analyticity

↔ **Methods also for**
CFTR I - PWA baryons

↔ **Understand QCD-bound states, including exotics**

↔ **RA2:** Excited meson spectrum for $B \rightarrow 3h$,
- final state interactions

- understand decay spectra, Dalitzplots (↔ „B-decays with multi-hadron final states“ handed in: RA2)
- amplitudes, strong phases ↔ **CP-violation**

Bastian: **Hadronic FF (P7)**

(Christoph, Bastian, Thomas)

Ulf, Carsten: **Ab initio calculation of hadronic three-particle decays in QCD (P1)**

↔ excited kaons from the lattice (only part of a more extensive project)

↔ **TA2**

Christoph, Stefan:

CFRT IV

Chiral EFT + LHCb-Data + lattice \Leftrightarrow Exotics

\longleftrightarrow TA2

Christoph: **From LHCb to Lattice QCD: an extended chiral EFT approach to P_c Pentaquarks and $\Lambda_c \bar{D}^{(*)}$ -dynamics (P2)**

- Include $\Lambda_c \bar{D}^{(*)}$ - LHCb –data into pentaquark analysis
- Extend analysis to finite volume \Rightarrow analysis of emerging lattice data
- Strange sector of pentaquarks



LHCb data

$$\begin{aligned}\Lambda_b^0 &\rightarrow \Lambda_c^+ \bar{D}^{(*)} K^- \\ \Lambda_b^0 &\rightarrow \Sigma_c^+ \bar{D}^{(*)} K^-\end{aligned}$$

Sebastian



JüBo – work on

$\Lambda_c \bar{D}^{(*)} - \Sigma_c^{(*)} \bar{D}^{(*)}$
interact.

Deborah

Christoph: **Light-quark mass dependence of doubly heavy tetraquark (P5)**

- Analysis of lattice results for $T_{cc}^{(\prime)}$ and T_{bc} states, predictions for spin partners

Stefan, Christoph: **Lattice Quantum Chromodynamics study of exotic hadrons (P6)**

- Investigation of the structure of exotic charmed hadrons ($T_{cs}(2900)0^+$, $T_{cs}(2900)1^+$, $T_{cc}(3875)$, and $T_{c\bar{s}}(2900)^{++}$)
- lattice QCD simulations for $\bar{c}\bar{s}ud$, $c\bar{s}u\bar{d}$, $ccu\bar{d}$, and $c\bar{c}u\bar{d}$ with $N_f = 2 + 1$ dynamical quarks
- Extraction of scattering information and pole positions

Christoph, Thomas:

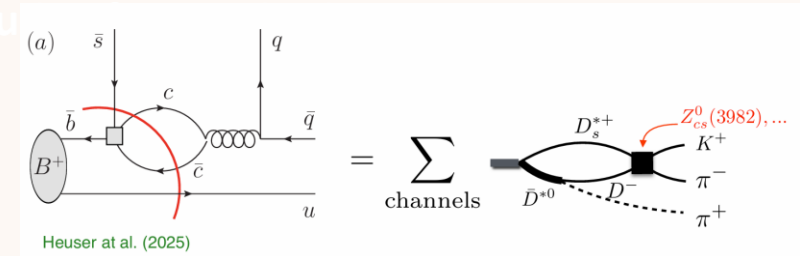
CFRT V

Christoph, Thomas: **Spectroscopic analyses of exotic states and their spin and flavor partners:
data driven insights and implications for CP violation**

- Combined analysis of BESIII $D_s^* \bar{D}, \bar{D}_s^* D, D^* \bar{D}, D^* \bar{D}^*$ final states to understand nature of exotic Z_{cs}, Z_c -states
 \Leftrightarrow B-decay data also of interest
- D-meson loops as key to better understand CP-conserving charm loop contribution observed in CP-asymmetry of $B \rightarrow K\pi\pi$

RA2

Stefan, Christoph: Lattice Quantum Chromodynamics studies



One could as well put the exotics part to CFTR IV
and the CP-part to CFTR III

Summary:

- **5 Cross-Functional Research Teams (CFTR)** (different size)
 - ⇔ maybe RA1+RA2-combinations missed?
 - ⇔ additional topics? (without project descriptions handed in so far)
- **Important: only first thoughts!**
 - your feedback = ?

Experiment

Light baryon spectrum: $N^*, \Delta^*, \Lambda^*, \Sigma^*$

Light hadrons

- 3q-states
- Pentaquarks? Two-pole structures / molecules

Polarized photoproduction of protons and neutrons

Non-strange and strange meson spectrum:

- $q\bar{q}$ -states
 - Exotica: hybrids, glueballs, multi-quark states, molecules
- π -,K-beams

↕ many connections

Heavy meson and baryon spectrum

Heavy hadrons

- $Qq\bar{q}$ -, $Q\bar{q}$ -, $Q\bar{Q}$ -states
 - Pentaquarks, Tetraquarks,
 - X, Y, Z-states, 2 pole-str./molecules
- e.g. B, Λ_b -decays

Connections:

- Light hadrons to understand heavy hadron decays
- Heavy hadrons as source of light hadrons to study

Similar phenomena

- 2-pole structures in the light ($\Lambda(1405)$) and heavy sector ($D_0^*(2300)$)
- Pentaquarks?
- Hybrids?

Techniques

- PWA needed in all sectors
- Multi-hadron final states in weak decays
- ↔ FSI

↔ RA2 : e.g. $D, B \rightarrow 0^- 0^- \ell \nu$ ↔ $D\pi, K\pi$ systems

$B \rightarrow D 0^- 0^-$

e.g. Flavor anomalies, $b \rightarrow c \ell \nu$, ($B \rightarrow D\pi \ell \nu$)

e.g. $\Lambda_b \rightarrow Kp \mu^+ \mu^-$ ↔ new phenomena

$b \rightarrow s \ell^+ \ell^-$

