

Collaborative research center CRC 110

“Symmetries and the emergence of structure in QCD”



**The Sino-German CRC
from the Chinese Perspective**

Bing-Song Zou

Deutsche
Forschungsgemeinschaft

DFG



NSFC

National Natural Science Foundation of China



Chinese members in CRC110

- **Institute of Theoretical Physics (ITP), CAS**

Feng-Kun Guo , Shan-Gui Zhou, Bing-Song Zou

- NSFC outstanding young scientists

- **Institute of High Energy Physics (IHEP), CAS**

Yu Jia, Cai-Dian Lü , Qiang Zhao - NSFC outstanding young scientists

Ying Chen, Yu-Bing Dong, Qian Wang (asso. IHEP)

Mei Huang, Jian-Xiong Wang & Ping Wang (former PI)

- **Peking University (PKU)**

Xu Feng, Jie Meng , Shi-Lin Zhu - NSFC outstanding young scientists

Chuan Liu

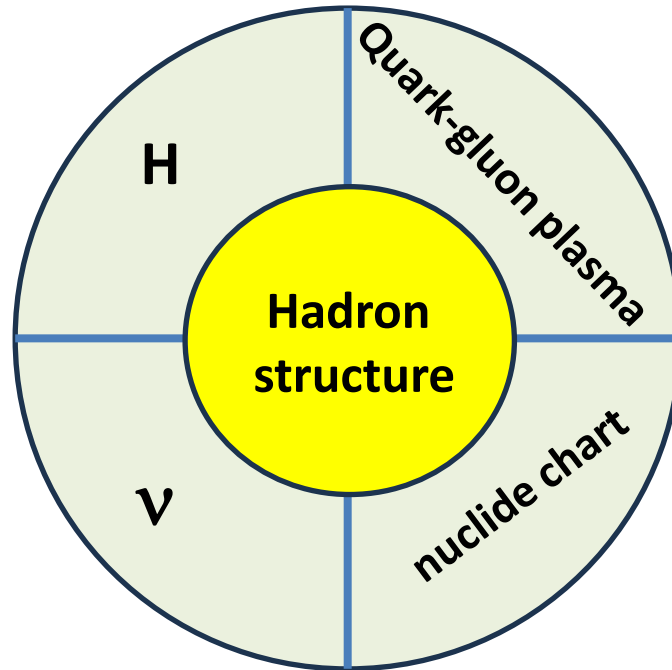
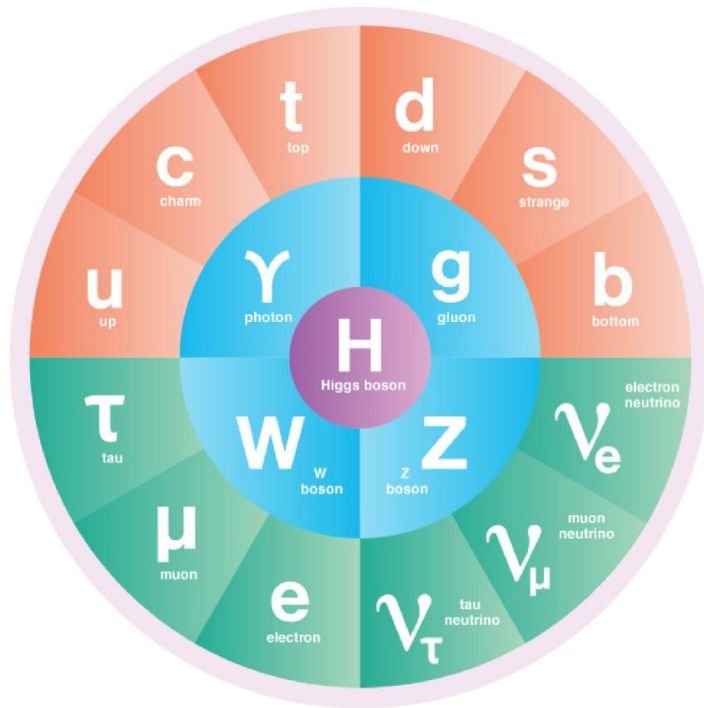
16 PLs + 3 professors & 36+ postdocs & 118+ PhD & 18+ Ms students

CONTENT

- **Original intention of the CRC110**
- **Major scientific achievements**
- **Talent cultivation achievements**
- **Synergy effects of collaboration**
- **Perspectives**

Why CRC110 ?

Structures of QCD : forefront of exploring microscopic structure of matter



Hadron structure : forefront of both particle and nuclear physics

Why CRC110 ?

Large Chinese investment (1 Billion RMB) in QCD relevant facilities



and international experiment collaborations

PANDA/FAIR (IHEP&IMP)

STAR/RHIC (SINAP&HNU&USTC)

Experiments need theoretical guidance and support

Shortage of relevant experienced theorists in China

2006	CERN	KEK	BNL	IHEP	IMP
Theorists with Ph.D	133	56	59	17	4

2007 CAS → TPCSF



↓
36

- 1) fix-term Research Associates (4-6), postdocs (8-12)
(France, Italy, USA, Japan, India, Hungary, China)
- 2) visitors (4-6 person x year)
- 3) workshops and summer school

Still short of high level visiting collaborators like German PIs and reviewers of the CRC110

CRC110 – 2012-2024

➤ Sino-German Joint Interdisciplinary Research Program by NSFC&DFG

CRC110	Term-1 (2012-15)	Term-2 (2016-19)	Term-3 (2020-24)
NSFC	8M RMB	12M RMB	15M RMB
DFG	5M Euro	8M Euro	11M Euro

➤ German partners: Spokesman – U.-G. Meißner (Bonn/Juelich)

UB: H. Dreiner, H. W. Hammer, B. Kubis, B. Metsch, F. M. Steffens, M. Petschlies, A. Rusetsky, U. Thoma, C. Urbach

FZJ: J. Haidenbauer, C. Hanhart, S. Kreward, A. Nogga, T. Luu, D. Rönchen

TUM: M. Beneke, N. Brambilla, N. Kaiser, S. Paul, A. Vairo, D. van Dyk, W. Weise

RUB: E. Epelbaum, H. Krebs, M. Polyakov, U. Wiedner

Major scientific achievements

INSPIRE HEP

literature fulltext 11261130311 or 11621131001 or 12070131001

Literature Authors Jobs Seminars Conferences More...

1,107 results | cite all Citation Summary Most Cited

Date of paper

Number of authors

Single author 57

10 authors or less 1,107

Exclude RPP

Exclude Review of Particle Physics 1,107

Document Type

article 979

published 891

conference paper 122

review 12

proceedings 3

book chapter 2

thesis 1

Citation Summary

Exclude self-citations

	Citeable	Published
Papers	1,102	891
Citations	29,963	29,118
h-index	73	73
Citations/paper (avg)	27.2	32.7

Citations per paper (avg)

Citations	Citeable	Published
0	91	24
1-9	374	249
10-49	488	470
50-99	104	103
100-249	35	35
250-499	6	6
500+	4	4

Hadronic molecules

#1

Feng-Kun Guo (Beijing, Inst. Theor. Phys.), Christoph Hanhart (Julich, Forschungszentrum), Ulf-G. Meißner (Bonn U., ITKP and U. Bonn, Phys. Inst., BCTP and IAS, Julich and JCHP, Julich), Qian Wang (Bonn U., ITKP), Qiang Zhao (Beijing, Inst. High Energy Phys. and CAS, Beijing and TPCSF, Beijing) et al. (Apr 29, 2017)

Published in: *Rev.Mod.Phys.* 90 (2018) 1, 015004, *Rev.Mod.Phys.* 94 (2022) 2, 029901 (erratum) • e-Print: 1705.00141 [hep-ph]

"CRC 110 "Symmetries and the Emergence of Structure in QCD" (NSFC Grant No. 11621131001, DFG GrantNo. TRR110), by NSFC (Grant Nos.11425525, 11521505 and11647601) ..."

pdf DOI cite claim reference search 1,132 citations

The top cited subject in QCD physics since 2012

Multiquark states – crucial for hadron structure !

Pc states → top cited paper for LHCb (2015) 1751 cites

Zc(3900) → top cited paper for BES3 (2013) 1101 cites

F.K.Guo, C.Hanhart, U.-G.Meißner, Q.Wang, Q.Zhao, B.S.Zou,
Rev.Mod.Phys. 90 (2018)015004: “Hadronic molecules” 1132 cites

H.X.Chen, W.Chen, X.Liu, S.L.Zhu, Phys.Rept. 639 (2016) 1:
“The hidden-charm pentaquark and tetraquark states” 1093 cites

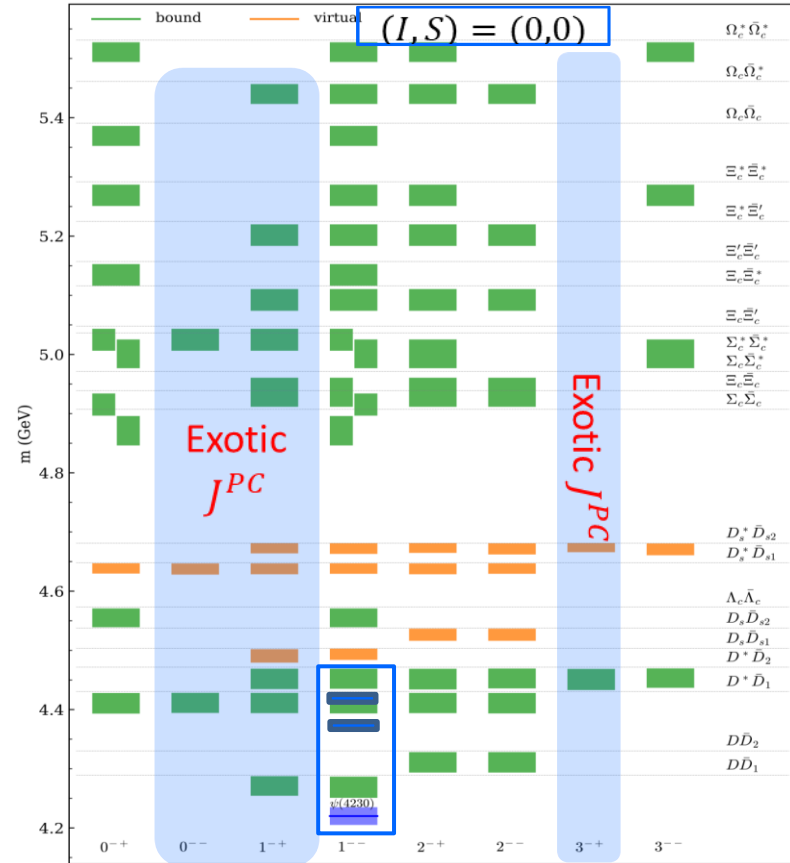
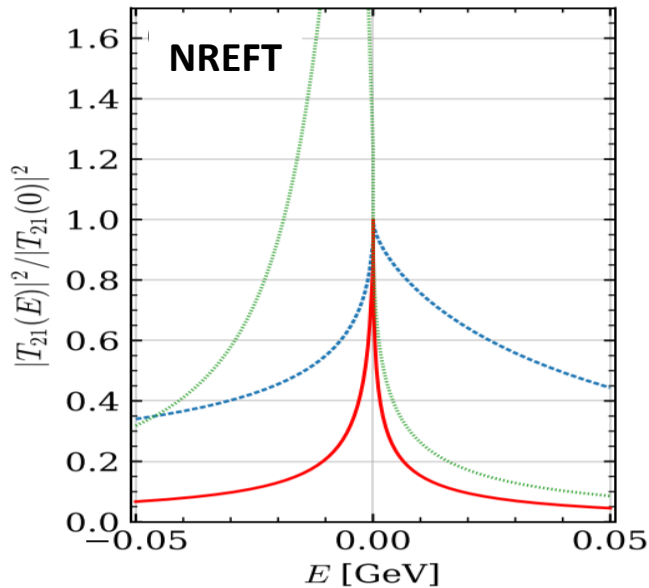
N.Brambilla, S.Eidelman, C.Hanhart, A.Nefediev, C.P.Shen,
C.E.Thomas, A.Vario, C.Z.Yuan, Phys.Rept. 873 (2020) 1: 713 cites
“The XYZ states: Expt. & theor. status and perspectives

CRC PIs played a leading role for predictions & explanations

Highlight #1 :

General explanation of near-threshold structures & systematic prediction for hadron molecule spectra

X.-K. Dong, F.-K. Guo, B.-S. Zou,
 Phys.Rev.Lett. 126 (2021) 152001 [100 cites]
*Explaining the Many Threshold Structures
 in the Heavy-Quark Hadron Spectrum*



X.-K. Dong, F.-K. Guo, B.-S. Zou, *A Survey of Heavy-(Anti)heavy Hadronic Molecules*,
 Prog. Phys. 41 (2021) 65 [138 cites]; Commu. Theor. Phys. 73 (2021) 125201 [149 cites]



Feng-Kun's talk

Highlight #2 :

Universal chiral dynamics for heavy hadron molecules and deuteron

L.Meng, B.Wang, G.J.Wang, S.L.Zhu, *Phys. Rept.* **1019** (2023) 1-149 [105 cites]
Chiral perturbation theory for heavy hadrons and chiral effective field theory for heavy hadronic molecules

Spectrum of the strange hidden charm molecular pentaquarks
in chiral effective field theory

[84 cites]

BO WANG, LU MENG, and SHI-LIN ZHU

PHYS. REV. D **101**, 034018 (2020)

TABLE III. The predicted binding energies ΔE and masses M for the $[\Xi'_c \bar{D}^{(*)}]_J$, $[\Xi_c^* \bar{D}^{(*)}]_J$, and $[\Xi_c \bar{D}^{(*)}]_J$ systems in $I = 0$ channel, where the subscript “ J ” denotes the total spin of the system. We correspondingly use the thresholds of $\Xi'_c + \bar{D}^{(*)0}$, $\Xi_c^* + \bar{D}^{(*)0}$, and $\Xi_c + \bar{D}^{(*)0}$ as the benchmarks to calculate the values in this table (in units of MeV). The state that denoted by “ $\#$ ” means which may be nonexistent at the upper limit.

System	$[\Xi'_c \bar{D}]_{\frac{1}{2}}$	$[\Xi'_c \bar{D}^*]_{\frac{1}{2}}$	$[\Xi'_c \bar{D}^*]_{\frac{3}{2}}$	$[\Xi_c^* \bar{D}]_{\frac{3}{2}}$	$[\Xi_c^* \bar{D}^*]_{\frac{1}{2}}$	$[\Xi_c^* \bar{D}^*]_{\frac{3}{2}}$	$[\Xi_c^* \bar{D}^*]_{\frac{5}{2}}^{\#}$	$[\Xi_c \bar{D}]_{\frac{1}{2}}$	$[\Xi_c \bar{D}^*]_{\frac{1}{2}}$	$[\Xi_c \bar{D}^*]_{\frac{3}{2}}$
ΔE	$-18.5_{-6.8}^{+6.4}$	$-15.6_{-7.2}^{+6.4}$	$-2.0_{-3.3}^{+1.8}$	$-7.5_{-5.3}^{+4.2}$	$-17.0_{-7.5}^{+6.7}$	$-8.0_{-5.6}^{+4.5}$	$-0.7_{-2.2}^{+0.7}$	$-13.3_{-3.0}^{+2.8}$	$-17.8_{-3.3}^{+3.2}$	$-11.8_{-3.0}^{+2.8}$
M	$4423.7_{-6.8}^{+6.4}$	$4568.7_{-7.2}^{+6.4}$	$4582.3_{-3.3}^{+1.8}$	$4502.9_{-5.3}^{+4.2}$	$4635.4_{-7.5}^{+6.7}$	$4644.4_{-5.6}^{+4.5}$	$4651.7_{-2.2}^{+0.7}$	$4319.4_{-3.0}^{+2.8}$	$4456.9_{-3.3}^{+3.2}$	$4463.0_{-3.0}^{+2.8}$

- Later, LHCb reported evidence of $P_{cs}(4459)$ in 2020, $P_{cs}(4338)$ in 2022

H.X.Chen, W.Chen, X.Liu, Y.R.Liu, S.L.Zhu, *Rept. Prog. Phys.* **86** (2023) 026201

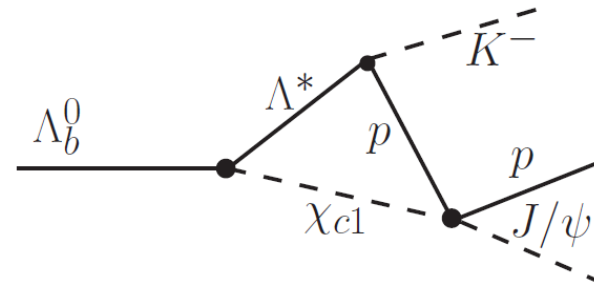
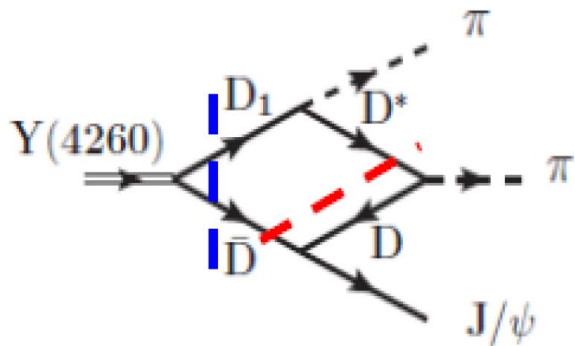
An updated review of the new hadron states

[317 cites]

Highlight #3 : Importance of triangle singularities

Q.Wang, C.Hanhart, Q.Zhao , Phys.Rev.Lett. 111 (2013) 132003 [318 cites]
Decoding the riddle of $Y(4260)$ and $Z_c(3900)$

F.K.Guo, U.-G.Meißner, W.Wang, Z.Yang, Phys.Rev.D 92 (2015) 071502R [309 cites]
How to reveal the exotic nature of the $P_c(4450)$



F.K.Guo, X.H.Liu, S.Sakai, Prog.Part.Nucl.Phys. 112 (2020) 103757 [222 cites]
Threshold cusps and triangle singularities in hadronic reactions

➡ Qiang's talk

Highlight #4 : Lattice QCD calculations of various hadronic form factors

X.Feng, M.Gorchtein, L.C.Jin, P.X.Ma, C.Y.Seng, Phys.Rev.Lett. 124 (2020) 192002
First-principles calculation of electroweak box diagrams from lattice QCD [67 cites]

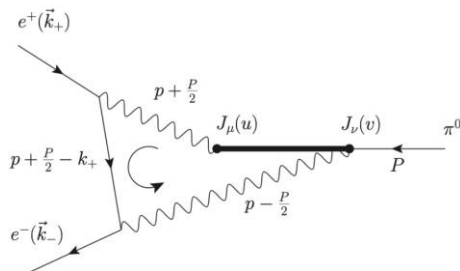
Y.Li, S.C.Xia, ..., X.Feng, ..., C.Liu, ..., F.Steffens, ..., Phys.Rev.Lett. 128 (2022) 062002
Lattice QCD Study of Transverse-Momentum Dependent Soft Function [59 cites]

X.Feng, L.Jin, M.Riberdy, Phys.Rev.Lett. 128 (2022) 052003
Lattice QCD Calculation of the Pion Mass Splitting [24 cites]

Y.Fu, X.Feng, L.Jin, C.Lu, Phys.Rev.Lett. 128 (2022) 172002, *Lattice QCD Calculation of the Two-Photon Exchange Contribution to the Muonic-Hydrogen Lamb Shift* [14 cites]

N.Christ, X.Feng, L.Jin, C.Tu, Y.Zhao, Phys.Rev.Lett. 130 (2023) 191901
Lattice QCD Calculation of $\pi \rightarrow ee$ Decay [16 cites]

P.X.Ma, X.Feng, et al., Phys.Rev.Lett. 132 (2024) 191901, *Lattice QCD Calculation of Electroweak Box Contributions to Superaligned Nuclear and Neutron Beta Decays* [13 cites]

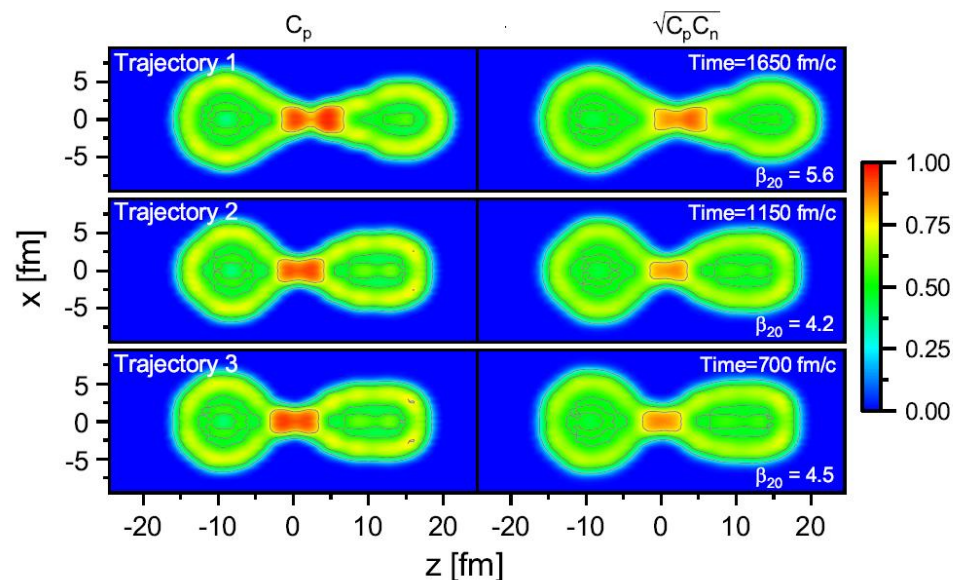


Xu's talk

Highlight #5 : ab initio covariant DFT for nuclear structure

S.H.Shen, H.Z.Liang, W.H.Long, J.Meng, P.Ring, Prog. Part. Nucl. Phys. 109 (2019) 103713
Towards an ab initio covariant density functional theory for nuclear structure [83 cites]

J.M.Yao, J.Meng, Y.F.Niu, P.Ring, Prog. Part. Nucl. Phys. 126 (2022) 103965 [33 cites]
Beyond-mean-field approaches for nuclear $0\nu 2\beta$ decay in the standard mechanism



Z.X.Ren, D.Vretenar, T.Nikšić, P.W.Zhao, J.Zhao, J.Meng, Phys.Rev.Lett. 128 (2022) 172501
Dynamical Synthesis of ^4He in the Scission Phase of Nuclear Fission [29 cites]

➡ Jie's talk

An excellent platform for fostering young talents

- **6 winners of NSFC outstanding young scientists**

Q.Zhao (2014), M.Huang (2017), Y.Jia (2019), F.K.Guo, W.Wang, X.Feng (2021)

- **10 winners of national young talent program:**

W.Wang, F.K.Guo, J.J.Wu, Q.Wang, B.N.Lü, M.L.Du, L.Y.Dai (UB/FZJ);

W.Chen, Y.B.Yang, J.Liang (Canada/USA)

- **13 full professors of other programs:**

L.M.Liu, D.L.Yao, X.N.Xiong, C.W.Xiao, Q.B.Chen (UB/FZJ/TUM);

Z.W.Liu, D.N.Li, W.L.Sang, N.Li, B.Wang, R.Chen, C.J.Xia, A.Guevara

- **37 associate professors or lecturers:**

X.H.Liu, Y.H.Chen, N.Li, X.W.Kang, Z.Yang, L.P.He, S.H.Shen, J.Y.Pang, L.Ma, Y.J.Shi (UB/FZJ)

G.J.Wang, Q.Qin, Q.A.Zhang, L.Y.Xiao, Q.F.Lü, J.P.Dai, L.C.Gui, S.H.Zhou, Z.Y.Lu, K.Chen,

Y.B.We, X.H.Wu, J.B.Chen, B.L.Huang, Y.Meng, C.J.Xiao, M.J.Yan, N.Yalikun, H.J.Jing,

H.Liu, W.Qin, M.N.Tang, Y.Y.Wang, Y.T.Rong, Q.Wu, Y.Kamiya, S.Gonzalez-Solis

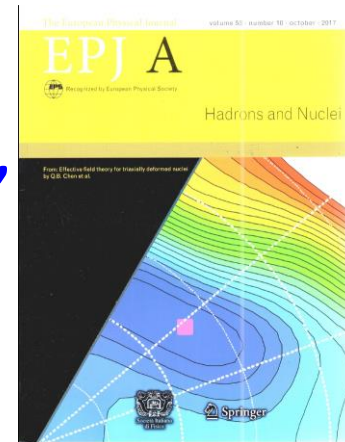
An excellent platform for fostering young talents



- **9 Award/Prizes:** Humboldt Research Award: J.Meng (2022), B.S.Zou (2023)
The 17th China Youth Science & Technology Award: Xu Feng (2022)
Wu YX / Wang GC Prize: Q.Zhao, S.L.Zhu (2019); S.G.Zhou, J.X.Wang (2021)
Hu JM Prize: F.K.Guo (2019), X.K.Dong (2023)

Synergy effects of collaboration - examples

- 1) Chen, Kaiser, Meißner, Meng, EPJA 53 (2017) 204
“Effective field theory for triaxially deformed nuclei”
- 2) Elhatisari, Epelbaum, Krebs, Lähde, Lee, N.Li, B.Lü, Meißner, Rupak, PRL 119 (2017) 222505: “Ab initio calculations of the isotopic dependence of nuclear clustering”
- 3) Shen, Rönchen, Meißner, Zou, CPC 42 (2018) 023106
“Exploratory study of possible resonances in the heavy meson - heavy baryon coupled-channel interactions”



CRC110-3rd will surely bring more such successful synergy examples

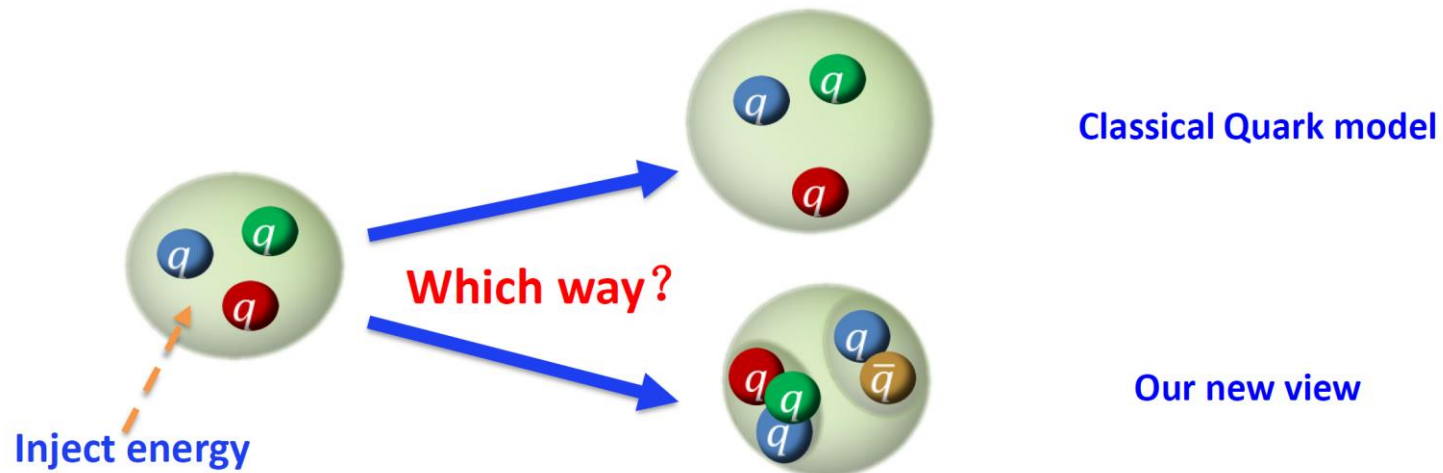
Synergy effects of collaboration - more examples in CRC110-3rd

- **X.K.Dong, V.Baru, F.K.Guo, C.Hanhart, A.Nefediev**, PRL126 (2021) 132001
Coupled-channel interpretation of the LHCb double- J/ψ spectrum and hints of a new state near the $J/\psi J/\psi$ threshold" . [91 cites]
- **Y.Li, S.Xia, ..., X.Feng, ..., C.Liu, ... F.Steffens et.al.**, PRL128 (2022) 062002
Lattice QCD Study of TMD Soft Function, [59 cites]
- **M.L.Du, A.Filin, V.Baru, X.K.Dong, E.Epelbaum, F.K.Guo, C.Hanhart, A. Nefediev, J. Nieves, Q.Wang**, PRL131 (2023) 131903 *Role of left-hand cut contributions on pole extractions from lattice data: Case study for $T_{cc}^+(3875)$.* [31 cites]
- **Y.H.Lin, H.W.Hammer, U.-G.Meißner**, PRL128 (2022) 052002
New Insights into the Nucleon's Electromagnetic Structure. [64 cites]
- **S.Shen, S.Elhatisari, T.Lahde, D.Lee, B.N.Lu, U.-G.Meißner**, Nature Commun. 14 (2023) 2777 *Emergent geometry and duality in the carbon nucleus.* [19 cites]

Totally there are 100+ Sino-German joint papers

Perspectives

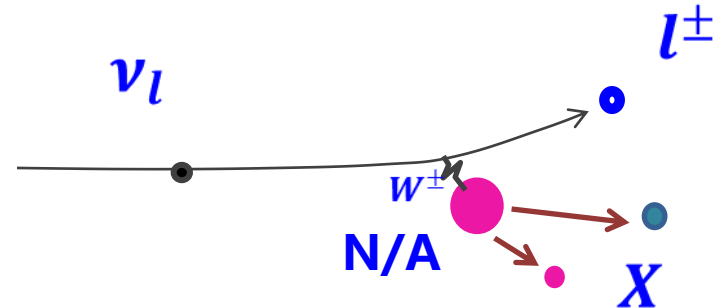
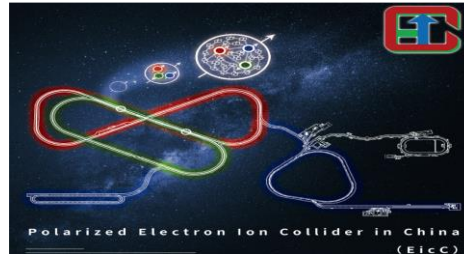
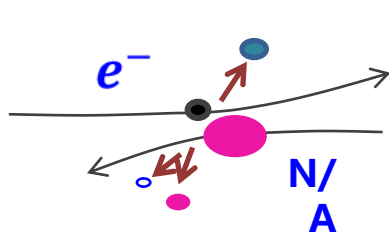
- last 12 years' CRC110 is very successful
- our knowledge on hadron structure is much improved



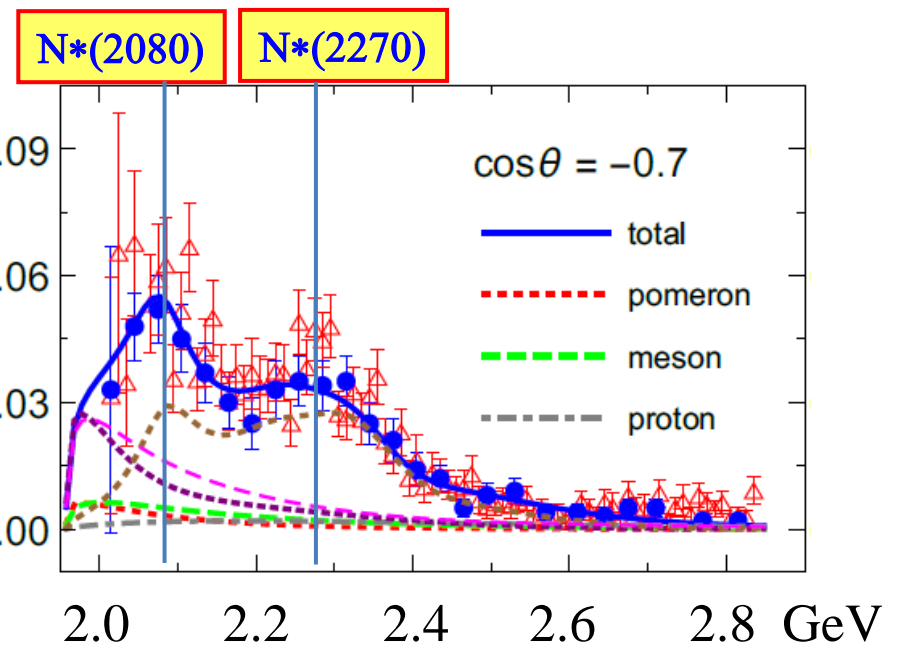
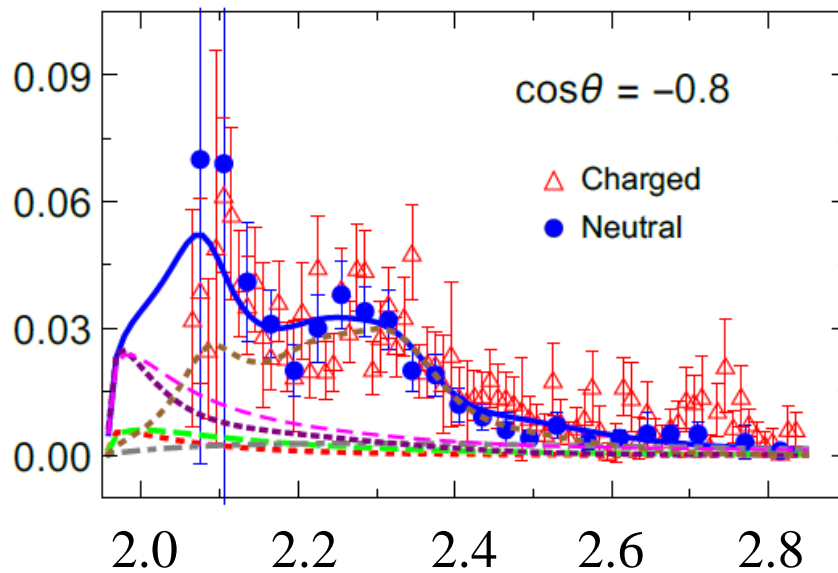
- nuclear lattice EFT is well developed for nuclear clusters
- hadron and nuclear structures with mixture of various cluster configurations to be further explored by joint efforts from EFT, models, lattice & expts

Perspectives

- Promising relevant facilities: CEBAF12, ELSA, Belle2, BEPC2', EicC, EIC, Faser...



$$\gamma p \rightarrow \phi p$$



Perspectives

- Many new platforms led by our CRC PLs are ready for our further collaboration

Shan-Gui Zhou, Feng-Kun Guo: ITP@CAS, Peng-Center@ITP

Qiang Zhao, Cai-Dian Lü : IHEP theory division

Shi-Lin Zhu: ITP@PKU; Chuan Liu & Xu Feng: NSFC major project on LQCD

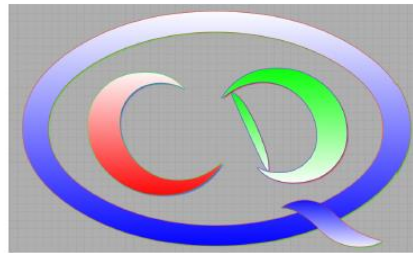
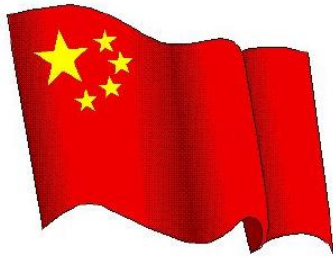
Jie Meng: NPT-Center @ CIAE

Bing-Song Zou : SCNT@HIAF, HEP-Center@Tsinghua-U

- All our CRC German PLs are warmly welcome to visit these institutions !

Conclusion

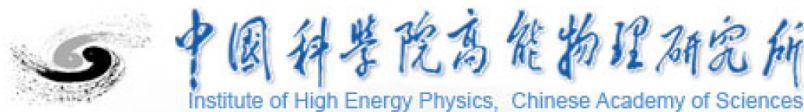
The successful CRC110 comes to an end,
our friendship & collaboration should be continued!





Thank you for your attention !

Thank you all for making this a success !



Direct collaboration with experiments

E.Grodner et al. (J.Meng), PRL 120 (2018) 022502: “First measurement of the g factor in the chiral band: The case of the ^{128}Cs isomeric state”

J.Timar et al. (J.Meng), PRL 122 (2019) 062501: “Experimental evidence for transverse wobbling in ^{105}Pd ”

Z.Y.Zhang et al. (S.G.Zhou), PRL 122 (2019) 192503: “New isotope ^{220}Np : Probing the robustness of the N=126 shell closure in Neptunium”

L.Ma et al. (S.G.Zhou), PRL 125 (2020) 032502: “Short-lived α -emitting isotope ^{222}Np and the stability of the N=126 magic shell”

BESIII (Zhao, Zou), PRL 121 (2018) 022001: “Observation of a_0 - $f_0(980)$ mixing”

BESIII (Zhao, Zou), PRL 122 (2019) 062001: “Observation of $D^+ \rightarrow f_0(500)e^+ \nu_e$ and improved measurements of $D^+ \rightarrow \rho e^+ \nu_e$ ”

The first observation of the doubly charmed baryon Ξ_{cc}

-- Top ten Chinese scientific advances in 2017

Weak Decays of Ξ_{cc}



Fu-Sheng Yu (于福升)

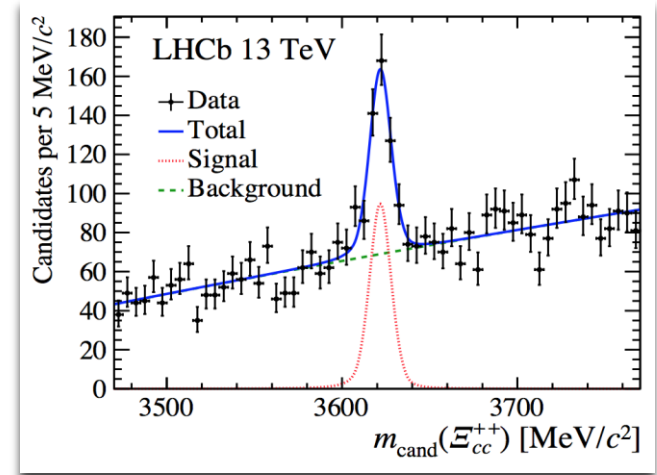
Lanzhou University

15.03.2017 @ LHCb Charm WG

Thank Ji-Bo and Andrea for invitation to give a talk!

Based on [arXiv:1703.09086]

In collaboration with Hua-Yu Jiang, Run-Hui Li, Ying Li, Cai-Dian Lü, Wei Wang, Zhen-Xing Zhao, Zhi-Tian Zou



Theory talks on decays

@ LHCb-China, Dec 2016

@ LHCb-Charm, Mar 2017

C.D.Lü's group, arXiv:1703.09086, CPC42(2018)051001

Observation reported

by LHCb, Jul 2017

LHCb, PRL 119 (2017) 112001

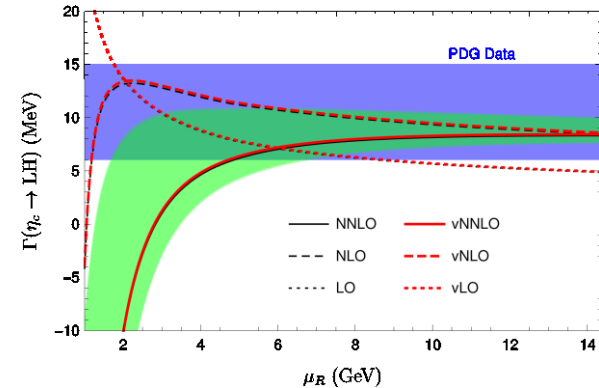
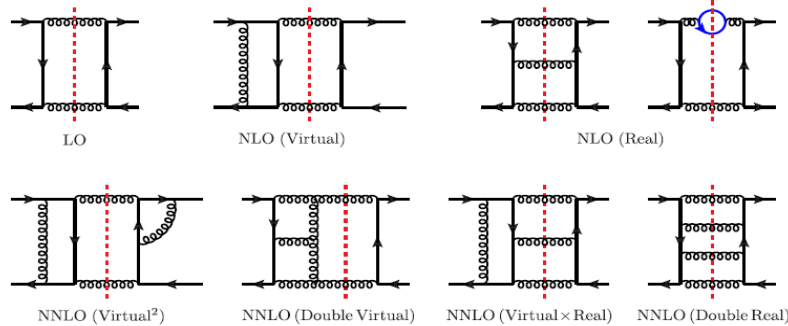
LHCb spokesperson Passaleva: "A group of Chinese theorists provided fundamental inputs to drive the analysis to the right direction and gave key suggestions to achieve this result."

Heavy meson production and decay from QCD EFT

- First time computing NNLO radiative correction of hadronic widths of η_c, η_b

Feng, Jia, Sang, PRL119 (2017) 252001

From NLO to NNLO, it takes about 40 years



- Propose a factorization theorem connecting B meson light-cone distribution amplitude, defined in QCD and HQET, respectively

Ishaq, Jia, Xiong, Yang, PRL125 (2020)

$$\Phi^{\text{QCD}}(x, \mu_Q) = \int_0^\infty d\omega Z(x, \omega, m_b; \mu_Q, \mu_H) \Phi_+^{\text{HQET}}(\omega, \mu_H),$$

Z factor can be computed in perturbation theory. This factorization theorem allows one to efficiently investigate heavy meson exclusive production.

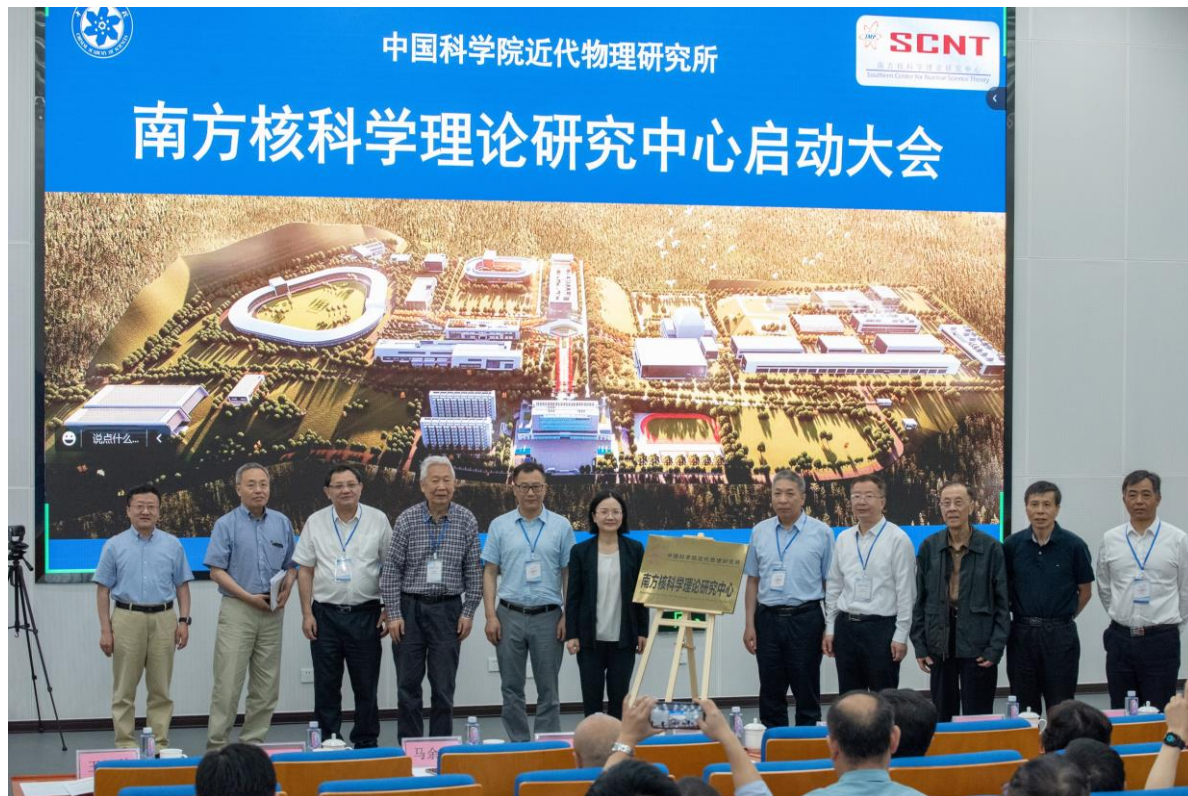
Future plan



SCNT

Southern Center for Nuclear-Science Theory

2023.05.04





- SCNT**
- 1) INT, Seattle, US
 - 2) ECT*, Trento, Italy
 - 3) FIAS, Frankfurt, Germany
 - 4) YITP, Kyoto, Japan
 - 5) ...

1 Nuclear Structure

- Super Heavy Element
- New Isotopes
- Collision Dynamics
- Nuclear-astrophysics

2 Nuclear Matter Structure

- QCD phase boundary, critical point
- Hyper-nuclear production
- EOS at high baryon density
- CEE, CBM, NICA, STAR

3 Nucleon Structure

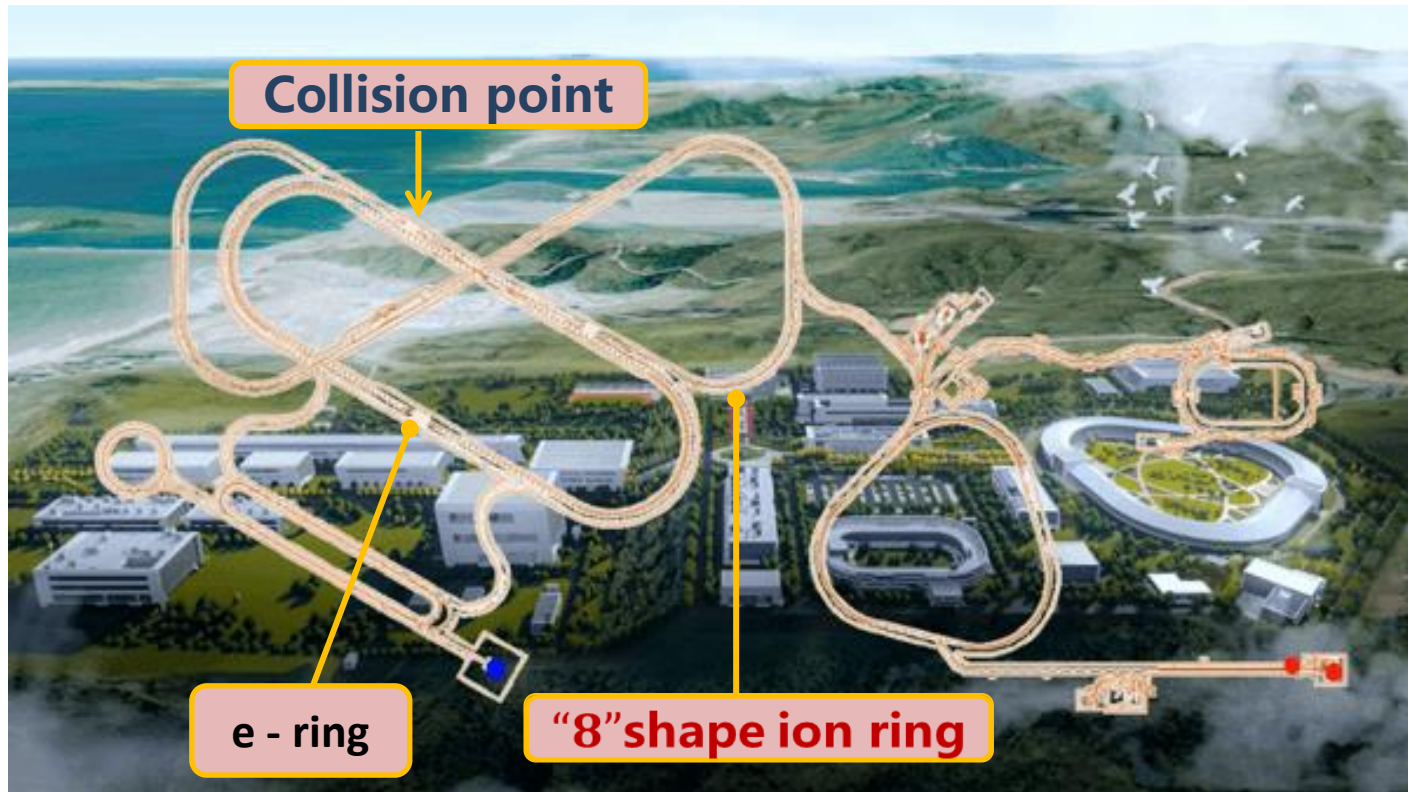
- Hadron spectroscopy
- 3D Imaging
- Origin of mass and spin
- EicC, EIC, BESIII, PANDA

4 Neutrino Weak interactions in Nucl. Phys.

- Dirac or Majorana?
- Beyond SM physics
- Nuclear structure with neutrino
- N ν DEx, NEXT

CRC members are welcome to SCNT to participate its activities!

EicC@HIAF



Complementary to CBM and PANDA at FAIR etc.