粒子物理前沿卓越创新中心

2017年考评报告

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报告内容
1. 研究工作介绍
2. 会议、论文等

研究工作介绍

研究方向	格点量子色动力学 (Lattice QCD)

用蒙特卡洛数值模拟的方法，非微扰地求解描写强相互作用的量子色动力学理论

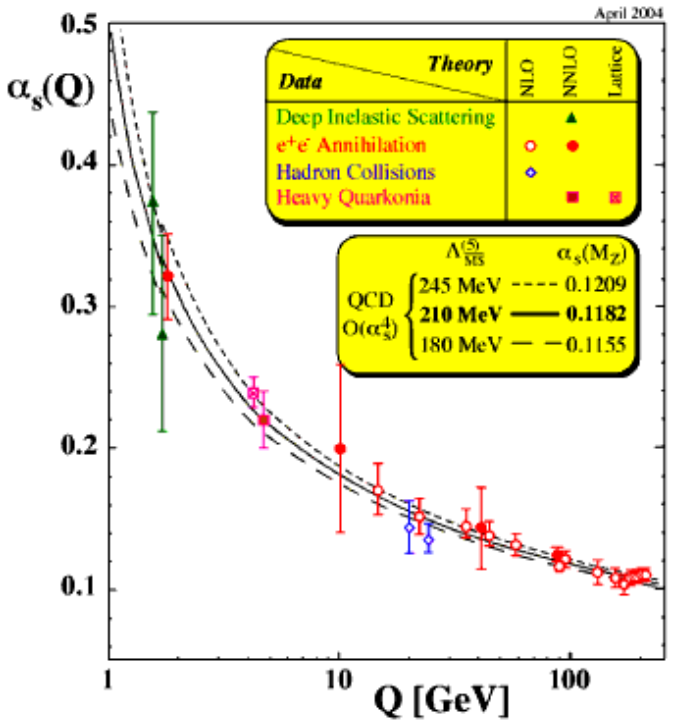


FIG. 1: QCD running coupling constant

- 提高QCD理论计算的精度
- 新强子态相关研究

- ✓ 夸克手征凝聚
- ✓ 胶球相关研究
- ✓ 重整化常数(服务性工作)
- ✓ 粲及轻介子衰变常数

夸克手征凝聚

- $\langle\bar{\psi}\psi\rangle$是手征对称性自发破缺的序参量
- 最低阶手征微扰论拉氏量的两个低能常数之一, $B = -\langle\bar{\psi}\psi\rangle/f^2$

$$\mathcal{L}_2 = \frac{f^2}{4}\mathrm{Tr}(\partial_\mu U \partial_\mu U^\dagger) + B\frac{f^2}{2}\mathrm{Tr}[M(U+U^\dagger)]$$

➢ 我们计算$\langle\bar{\psi}\psi\rangle$的方法:
比较夸克传播子的算符乘积展开表达式与格点QCD的数值结果

	Collaboration	Ref.	N_f	publication status	chiral extrapolation	continuum extrapolation	finite volume	renormalization	$\Sigma^{1/3}$
	ETM 13	[33]	2+1+1	A	○	★	★	★	280(8)(15)
	RBC/UKQCD 15E	[334]	2+1	P	★	★	★	★	274.2(2.8)(4.0)
✱	RBC/UKQCD 14B	[10]	2+1	A	★	★	★	★	275.9(1.9)(1.0)
✱	BMW 13	[35]	2+1	A	★	★	★	★	271(4)(1)
✱	Borsanyi 12	[34]	2+1	A	★	★	★	★	272.3(1.2)(1.4)
✱	MILC 10A	[13]	2+1	C	○	★	★	★	$281.5(3.4)(^{+2.0}_{-5.9})(4.0)$
	JLQCD/TWQCD 10A	[337]	2+1	A	★	■	○	★	234(4)(17)
	RBC/UKQCD 10A	[144]	2+1	A	○	○	○	★	256(5)(2)(2)
	JLQCD 09	[336]	2+1	A	★	■	○	★	$242(4)(^{+19}_{-18})$
	MILC 09A, $SU(3)$-fit	[6]	2+1	C	○	★	★	★	279(1)(2)(4)
	MILC 09A, $SU(2)$-fit	[6]	2+1	C	○	★	★	★	$280(2)(^{+4}_{-8})(4)$
	MILC 09	[89]	2+1	A	○	★	★	★	$278(1)(^{+2}_{-3})(5)$
	TWQCD 08	[339]	2+1	A	■	■	■	★	259(6)(9)
	JLQCD/TWQCD 08B	[340]	2+1	C	○	■	■	★	249(4)(2)
	PACS-CS 08, $SU(3)$-fit	[93]	2+1	A	★	■	■	■	312(10)
	PACS-CS 08, $SU(2)$-fit	[93]	2+1	A	★	■	■	■	309(7)
	RBC/UKQCD 08	[145]	2+1	A	○	■	○	★	255(8)(8)(13)
✱	Engel 14	[38]	2	A	★	★	★	★	263(3)(4)
✱	Brandt 13	[37]	2	A	○	★	○	★	261(13)(1)
✱	ETM 13	[33]	2	A	○	★	○	★	283(7)(17)
	ETM 12	[341]	2	A	○	★	○	★	299(26)(29)
	Bernardoni 11	[342]	2	C	○	■	■	★	306(11)
	TWQCD 11	[248]	2	A	○	■	■	★	230(4)(6)
	TWQCD 11A	[343]	2	A	○	■	■	★	259(6)(7)
	JLQCD/TWQCD 10A	[337]	2	A	★	■	■	★	242(5)(20)
	Bernardoni 10	[344]	2	A	○	■	■	★	$262(^{+33}_{-34})(^{+4}_{-5})$
✱	ETM 09C	[36]	2	A	○	★	○	★	$270(5)(^{+3}_{-4})$
	ETM 09B	[345]	2	C	★	■	○	★	245(5)
	ETM 08	[41]	2	A	○	○	○	★	264(3)(5)
	CERN 08	[301]	2	A	○	■	○	★	276(3)(4)(5)
	Hasenfratz 08	[346]	2	A	○	■	★	★	248(6)
	JLQCD/TWQCD 08A	[138]	2	A	○	■	■	★	$235.7(5.0)(2.0)(^{+12.7}_{-0.0})$
	JLQCD/TWQCD 07	[347]	2	A	★	■	■	★	239.8(4.0)
	JLQCD/TWQCD 07A	[348]	2	A	★	■	■	★	252(5)(10)

FLAG2016 review, EPJC(2017) no. 2, 112 [arXiv:1607.00299]

夸克手征凝聚

- 夸克传播子: $S_q(p) \equiv \int \mathrm{d}^4x \mathrm{e}^{-\mathrm{i}p\cdot x}\langle T\psi(x)\bar{\psi}(0)\rangle = \frac{-\mathrm{i}\not{p}V(p^2)}{p^2} + \frac{S(p^2)}{p^2}$
- $\langle\bar{\psi}\psi\rangle$ from $S(p^2)/V(p^2)$

  $\langle\bar{\psi}\psi\rangle^{\overline{\mathrm{MS}}}(2\ \mathrm{GeV}) = (-304(15)\ \mathrm{MeV})^3$
- $\langle\bar{\psi}\psi\rangle$ from $S(p^2)$

  $\langle\bar{\psi}\psi\rangle^{\overline{\mathrm{MS}}}(2\ \mathrm{GeV}) = (-284(13)\ \mathrm{MeV})^3$
- 两中心值的差作为系统误差(离散误差):

  $\langle\bar{\psi}\psi\rangle^{\overline{\mathrm{MS}}}(2\ \mathrm{GeV}) = (-304(15)(20)\ \mathrm{MeV})^3$

✓ 统计误差
✓ 格距误差
✓ 拟合区间
✓ 截断误差

- Chao Wang* (王超, 博士生), Yujiang Bi, Hao Cai, Ying Chen, Ming Gong, Zhaofeng Liu*, "Quark chiral condensate from the overlap quark propagator", Chin. Phys. C41 (2017) 053102 [arXiv:1612.04579], 5月份期刊亮点(highlights)之一

胶球相关研究

- **2-味非对称格子组态(两个π质量点; 大统计量: 4800/10400个组态)**
- **使用24个由胶子场构造的算符; 变分法(优化算符)**
- **张量2^{++}, 赝标量, 标量道的基态质量**

	m_π (MeV)	$m_{0^{++}}$ (MeV)	$m_{2^{++}}$ (MeV)	$m_{0^{-+}}$ (MeV)
$N_f = 2$	938	1397(25)	2367(35)	2559(50)
	650	1480(52)	2380(61)	2605(52)
$N_f = 2 + 1$ [6]	360	1795(60)	2620(50)	—
quenched [1]	—	1710(50)(80)	2390(30)(120)	2560(35)(120)
quenched [2]	—	1730(50)(80)	2400(25)(120)	2590(40)(130)

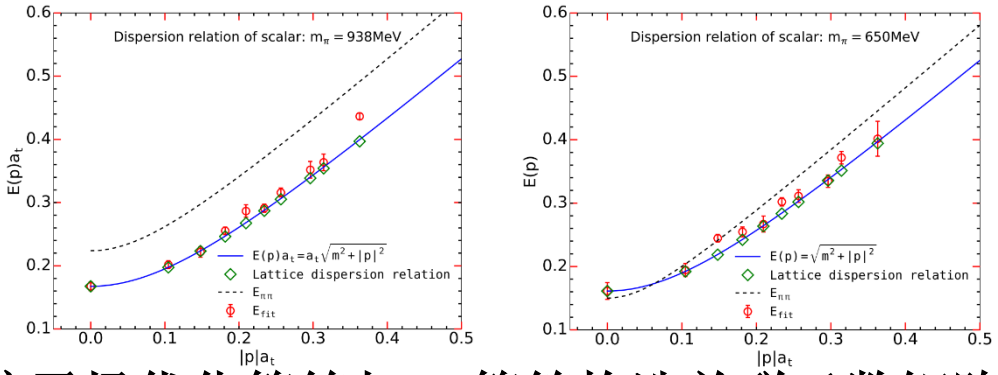
我们的结果
W. Sun et al.,
arXiv:1702.08174

[1] Morningstar, Peardon, PRD60,034509(1999)
[2] Chen et al., PRD73,014516(2006)
[6] Gregory et al., JHEP10,170(2012)

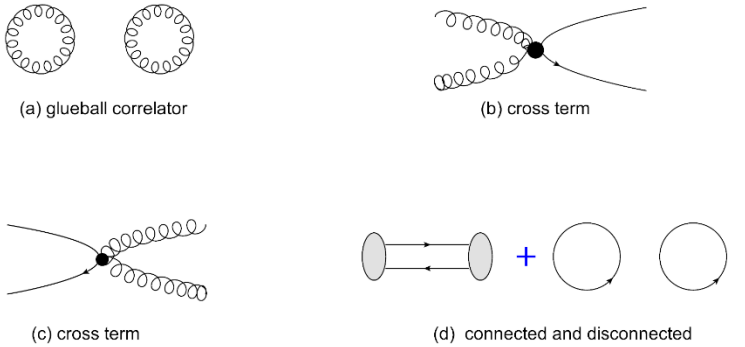
- $2^{++}, 0^{-+}$:
  - 和淬火近似下的结果一致
  - 对π质量不敏感
- 0^{++}: 与$q\bar{q}$态的混合?

标量道的进一步研究

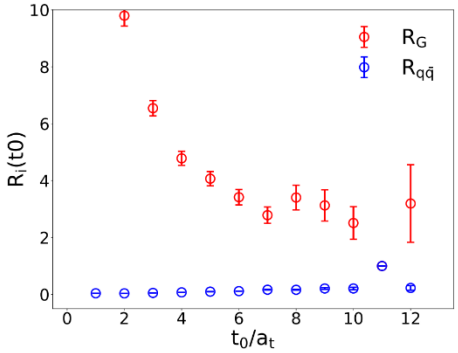
- 通过色散关系确认标量道的基态是一个单粒子态



- 从胶子场优化算符与$q\bar{q}$算符构造关联函数矩阵, 研究可能的混合



$$R_i(t_0) = \frac{\langle 0|O_i|1^{st}(t_0)\rangle}{\langle 0|O_i|2^{nd}(t_0)\rangle}$$



- **Wei Sun, Long-Cheng Gui, Ying Chen, Ming Gong, Zhaofeng Liu, "Glueball relevant study on isoscalar from $N_f = 2$ lattice QCD", Lattice2017, EPJ Web Conf., [arXiv:1711.00711]**

重整化常数、衰变常数

计算框架：

- 价夸克: 重叠费米子 (overlap fermion)
- 2+1-味 (domain wall fermion) 全QCD模拟组态 (RBC-UKQCD合作组) [T. Blum et al., PRD93, no.7, 074505 (2016)]
- 物理的轻夸克(u, d)质量: $M_{\pi}^{(\mathrm{sea})} = 139.2(4)$ MeV

➢双线性算符重整化: $\bar{\psi}\Gamma\psi, \Gamma = I, \gamma_5, \gamma_\mu, \gamma_\mu\gamma_5, \sigma_{\mu\nu}$

➢介子衰变常数: $f_{D^{(*)}}, f_{D_s^{(*)}}, f_V^T/f_V$等

重整化常数

$$O(\mu) = Z(\mu, a)O(a)$$

- 联系格点QCD(裸)结果与实验、唯象的桥梁: 夸克流质量, 强子矩阵元 (形状因子、衰变常数), ……
- 与精确测量相关的格点QCD计算与实验测量相互推动提高精度
- 重整化常数的统计误差已可以小于系统误差
  - 例如: $Z_S^{\overline{\rm MS}}$(2 GeV)=1.127(9)(19), [ZL et al. (χQCD Collab.), PRD90, 2014]

TABLE V. Error budget of $Z_S^{\overline{\rm MS}}(2\ {\rm GeV})$ in the chiral limit.

Source	Error (%, L=24)	Error (%, L=32)
Statistical	0.8	0.6
Truncation (RI to $\overline{\rm MS}$)	1.5	1.4
Coupling constant	0.3	0.3
Perturbative running	<0.02	<0.02
Lattice spacing	0.5	0.4
Fit range of a^2p^2	0.4	0.1
Extrapolation in m_l^R	0.2	1.8
Total systematic uncertainty	1.7	2.3

- 新计算: 用两种动量减除方案过渡, 最终给出匹配到$\overline{\rm MS}$方案的结果
- 进一步缩小统计误差与系统误差

数值结果

Matching factors to the $\overline{\text{MS}}$ scheme for the quark field and bilinear quark operators

Z_A	$Z_q(2\text{ GeV})$	$Z_T(2\text{ GeV})$	$Z_S(2\text{ GeV})$	$Z_P(2\text{ GeV})$
1.1025(9)	1.2157(54)	1.1631(24)	1.118(18)	1.123(19)

- $Z_S^{\overline{\text{MS}}}$(2 GeV)的精度从2%提高到1.6%
- $Z_T^{\overline{\text{MS}}}$(2 GeV)的精度达到0.3%
- $Z_T^{\overline{\text{MS}}}$(2 GeV)/$Z_V$的精度达到0.2%
- Yujiang Bi* (毕玉江, 联培博士生), Hao Cai*, Ying Chen, Ming Gong, Keh-Fei Liu, Zhaofeng Liu*, Yi-Bo Yang, "RI/MOM and RI/SMOM renormalization of overlap quark bilinears on domain wall fermion configurations", [arXiv:1710.08678], submitted to Phys. Rev. D

介子衰变常数$f_{D^{(*)}}, f_{D_s^{(*)}}, f_V^T/f_V$

- 定义: $\langle 0|\bar{s}\gamma_\mu\gamma_5 c|D_s\rangle = f_{D_s} p_\mu$

$$\langle 0|\bar{q}(0)\gamma^\mu q'(0)|V(p,\lambda)\rangle = f_V m_V e_\lambda^\mu$$

$$\langle 0|\left(\bar{q}(0)\sigma^{\mu\nu}q'(0)\right)(\mu)|V(p,\lambda)\rangle = i f_V^T(\mu)\left(e_\lambda^\mu p^\nu - e_\lambda^\nu p^\mu\right)$$

- 从纯轻衰变抽取CKM矩阵元, 例如从$D_s^{(*)}$的衰变得$|V_{cs}|$

$$\Gamma(P\to \ell\nu) = \frac{G_F^2|V_{q_1q_2}|^2}{8\pi} f_P^2 m_\ell^2 M_P (1-\frac{m_\ell^2}{M_P^2})^2$$

$$\Gamma_{(D_s^*\to\ell\nu)} = \frac{G_F^2}{12\pi}|V_{cs}|^2 f_{D_s^*}^2 M_{D_s^*}^3\left(1-\frac{m_\ell^2}{M_{D_s^*}^2}\right)^2\left(1+\frac{m_\ell^2}{2M_{D_s^*}^2}\right)$$

尚无实验测量

- 用因子化方法研究 B 介子非轻衰变时需要输入衰变常数 (e.g., f_{D^*} for $B\to D^{(*)}M$)

介子衰变常数

- 用光锥求和规则计算$B \to \rho, B \to K^*$等过程中的形状因子时，f_V^T/f_V是一个重要的输入参数
- 例如f_ρ^T/f_ρ的值如果改变25%, 会影响形状因子$A_1^{B\to\rho}(q^2)$的值改变15-20%
- f_V^T目前不能从实验来, 需用理论计算
- 初步结果 (统计误差 + 重整化常数误差)

	D	D^*	D_s	D_s^*
f_M/MeV	213(1)	235(3)	248(2)	275(5)

$f_{D^*}/f_D = 1.10(3)$ $\quad$ $f_{D_s^*}/f_{D_s} = 1.11(2)$

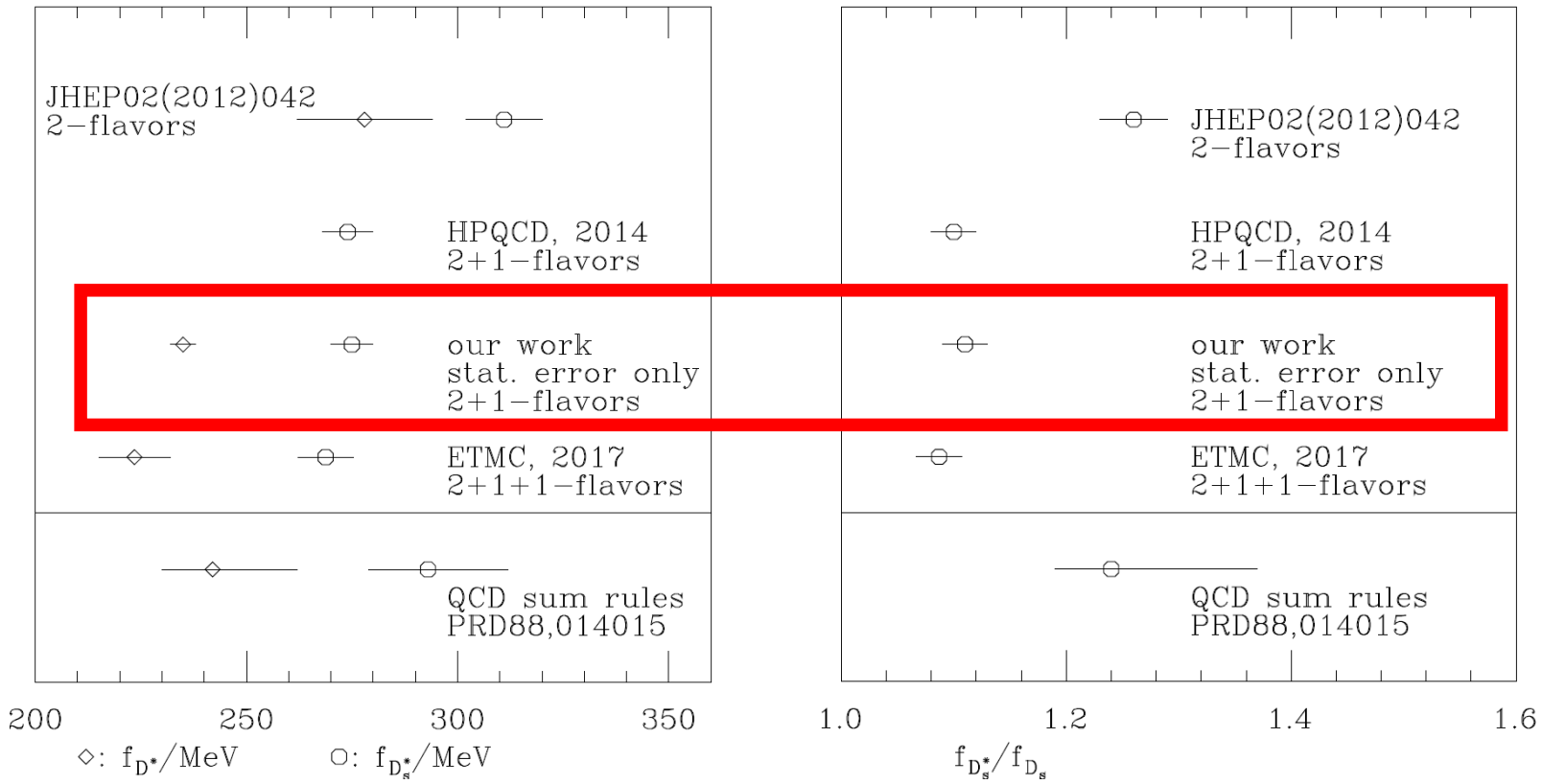
$\overline{\text{MS}}$(2 GeV)	K^*	ϕ	D^*	D_s^*
f_V^T/f_V	0.737(2)	0.762(2)	0.912(2)	0.917(2)

首个格点QCD计算

Wei-Feng Chiu et al., in preparation

f_{D^*} and $f_{D_s^*}$

Wei-Feng Chiu et al., in preparation



- **HPQCD, PRL112, 212002 (2014)** — **2 lattice spacings, 2+1-flavors**
- **ETMC, PRD96, 034524 (2017)** — **3 a's, 2+1+1-flavors**
- **Becirevic et al., JHEP02 (2012) 042** — **4 a's, 2-flavors**
- **奇异夸克的海夸克效应? 2-味结果与2+1-味, 2+1+1-味结果有所不同**

会议和报告

- 第十届计算物理国际会议，2017.1.16-20，澳门，组织格点QCD分会(mini-symposium)
- 第17届全国中高能核物理大会暨第11届全国中高能核物理专题研讨会, 2017.5.5-9, 宜昌, “Lattice QCD and heavy flavor physics”, 大会报告
- 第三十五届国际格点场论年会，2017.6.18-24，西班牙格拉纳达, “Renormalization of overlap quark bilinear operators in RI/MOM and RI/SMOM schemes”, 毕玉江
- BESIII-BELLE-LHCb粲强子物理联合研讨会，2017.9.22-24, 南开大学, “Charm physics in lattice QCD”
- The 3rd Sino-Americas workshop and school on the bound-state problem in continuum QCD, 2017.10.16-20, Nankai University, “Quark chiral condensate from overlap quark propagators”

- 论文
  - **"Quark chiral condensate from the overlap quark propagator", Chao Wang, Yujiang Bi, Hao Cai, Ying Chen, Ming Gong, Zhaofeng Liu, CPC41, no. 5, 053102 (2017) , one of the highlights of the May issue**
  - **"Glueball spectrum from $N_f = 2$ lattice QCD study on anisotropic lattices", Wei Sun, Long-Cheng Gui, Ying Chen, Ming Gong, Chuan Liu, Yu-Bin Liu, Zhaofeng Liu, Jian-Ping Ma, Jian-Bo Zhang, [arXiv:1702.08174], submitted to Phys. Rev. D**
  - **"RI/MOM and RI/SMOM renormalization of overlap quark bilinears on domain wall fermion configurations", Yujiang Bi, Hao Cai, Ying Chen, Ming Gong, Keh-Fei Liu, Zhaofeng Liu, Yi-Bo Yang, [arXiv:1710.08678], submitted to Phys. Rev. D**
- 会议论文
  - **"Flavour anomalies in $b \to s l^+ l^-$ processes – a round table discussion", T. Blake, M. Gersabeck, L. Hofer, S. Jager, Z. Liu, R. Zwicky, XIIth Quark Confinement and the Hadron Spectrum, EPJ Web Conf., 137, 01001 (2017) [arXiv:1703.10005]**
  - **"Glueball relevant study on isoscalar from $N_f = 2$ lattice QCD", Wei Sun, Long-Cheng Gui, Ying Chen, Ming Gong, Zhaofeng Liu, The 35th International Symposium on Lattice Field Theory, EPJ Web Conf., [arXiv:1711.00711]**

- 正在执行的经费情况
  - 主要成员，科技部国家重点研发计划，课题二“高能物理高性能计算应用软件研发”，297万/794万，2017.7-2020.6
  - 负责人, 基金委面上项目, 74万, 2016.01-2019.12
  - 主要成员, 基金委重点项目, 260万, 2014.01-2018.12
- 其它
  - 国科大助教: 粒子物理基础, 量子场论, 规范场理论
  - 交流: 邀请MSU的Andrea Shindler
  - 国科大、南京大学本科生暑期实习
  - 科普翻译《量子时刻》获评2017年院优秀科普图书、2017年全国优秀科普作品

谢谢！