

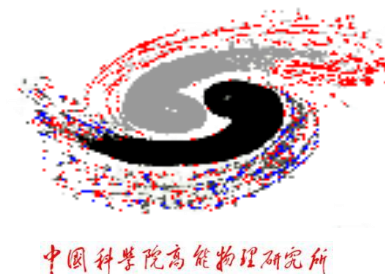
第六届中国格点量子色动力学研讨会

中国格点QCD年度综述

陈莹



中国科学院高能物理研究所
香港中文大学（深圳），深圳，2026.10.8-11

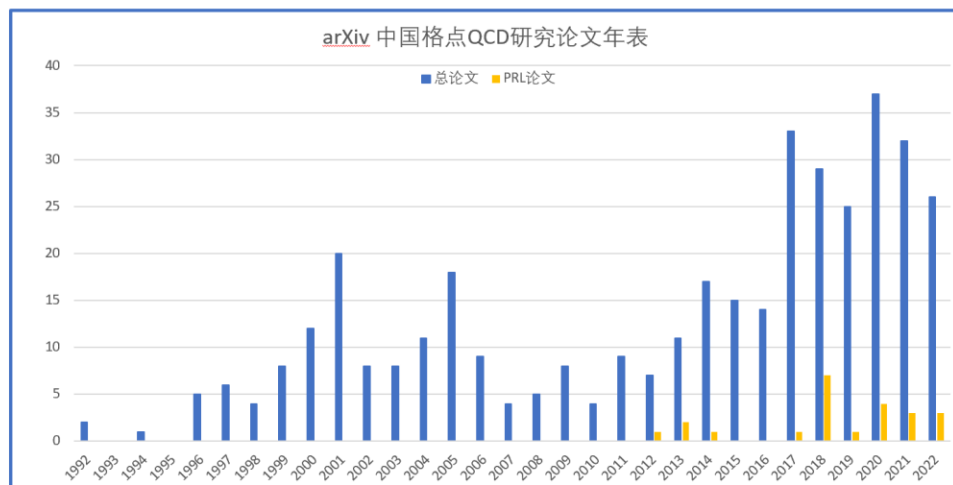


格点QCD在中国

陈莹

中国科学院高能物理研究所

“第二届中国格点QCD年会”
上海交通大学李政道研究所，2022年10月7-10日



国内网络
还不发达

筚路蓝缕

蓬勃发展

arXiv 的 hep-lat 每年文章数大致400-600篇

三、总结与展望

- 格点QCD 研究在中国有很长的历史
- 此前大部分时间都受到计算资源不足的制约
- 近些年来，发展迅速：
 - 人员队伍不断壮大
 - 计算资源逐渐增加
 - 物理成果在数量和质量上都有长足的进步
- 所以才开中国格点年会
 - 第一届 2021.10.30-11.02 华南师大承办
 - 第二届 2022.10.07-10.10 上海交大承办
 - 。 。 。 。 。
- 明天会更好！

- 十分成功的预言！
- 五年时间弹指一挥间！中国格点QCD (CLQCD)的进展已经不能用五年的周期来总结。
- 回顾2025.9-2026.9月，各方面都取得了丰硕的成果。

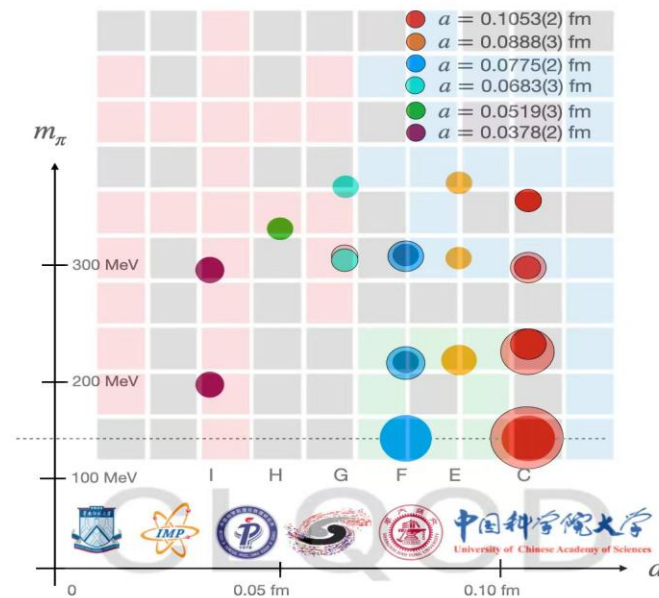
一、概览

1. 时空对称的 $N_f = 2 + 1$ 规范组态 (国际先进)

- ✓ 最小格距: $a = 0.038$ fm
- ✓ 最轻夸克: $m_\pi \approx 140$ MeV
- ✓ 最大格子: 6.7fm ($64^3 \times 128$)

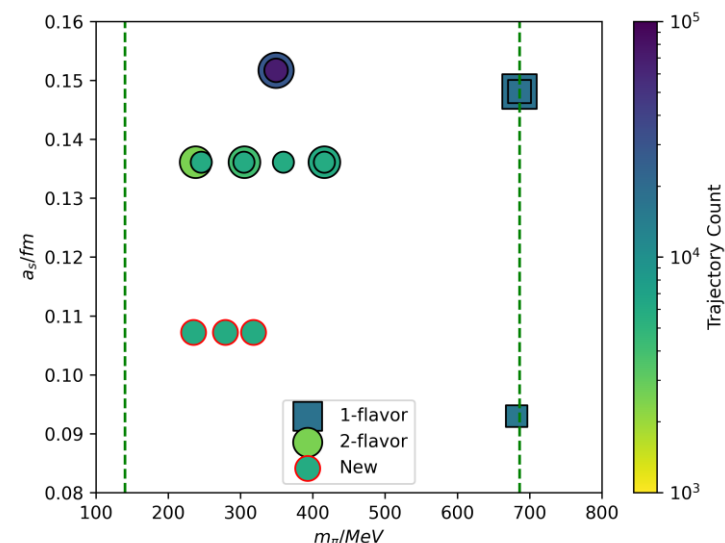
FLAG ★ 标准:

1. 手征外推: 至少三个 m_π , $m_\pi^{\min} < 200\text{MeV}$;
2. 连续极限: 至少三个格距 a , 至少两个满足 $a < 0.1\text{fm}$;
3. 有限体积: 至少三个体积, 或者 $m_\pi^{\min} > 4$;
4. 至少领头阶同位旋破坏效应;
5. 非微扰重整化 (如果需要)



2. 时空不对称的 $N_f = 2$ 和 $N_f = 1$ 规范组态

- ✓ 时空不对称: 适合强子谱学研究
- ✓ 大统计量: 为BESIII相关胶球、混杂态等奇特强子态的研究量身定做 (国际特有)
- ✓ $N_f = 1$ 组态: 简化物理问题, 主要胶子-夸克动力学研究

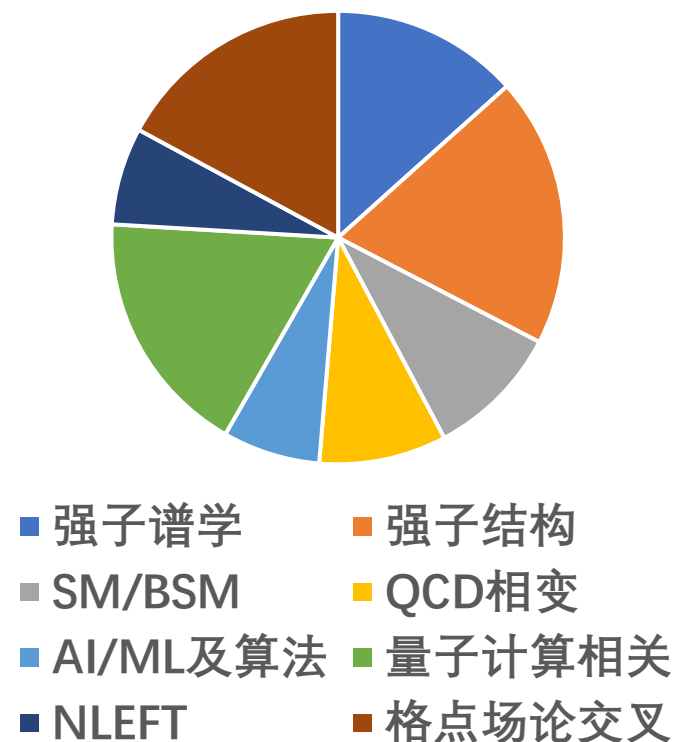


一、概览

通过AI搜索arXiv预印本库，有中国人（大陆、港澳台、海外华人）参与的格点相关文章180篇左右（不含博士论文），分论如下：

- 强子谱学相关 (hadron spectroscopy) 25篇
- 强子结构相关 (hadron structure) 35 篇
- 标准模型精确检验与新物理寻找相关
(SM&BSM) 强子矩阵元计算 18 篇
- 有限温度有限密度QCD相关17篇
- 量子算法、量子模拟及张量网络 33 篇
- 核格点有效场论及多体应用 13 篇
- 一般格点场论及交叉扩展 32 篇

论文数分布



二、强子谱学相关 (hadron spectroscopy)

（一）强子-强子散射的格点QCD研究

1. State-of-art Approach——Lüscher's formalism

(see R. Briceno et al., Rev. Mod. Phys. 90 (2018) 025001 for a review).

$$\det \left[F^{-1} \left(\vec{P}, E, L \right) + \mathcal{M}(E) \right] = 0$$

$E_n(L)$: Eigen-energies of lattice Hamiltonian.

- **Interpolation field operator set** for a given J^{PC}
 $\mathcal{O}_i: \bar{q}_1 \Gamma q_2 \quad [\bar{q}_1 \Gamma_1 q] [\bar{q} \Gamma_2 q_2] \quad [q_1^T \Gamma_1 q] [\bar{q} \Gamma_2 \bar{q}_2^T], \dots$
- **Correlation function matrix** —— **Observables**

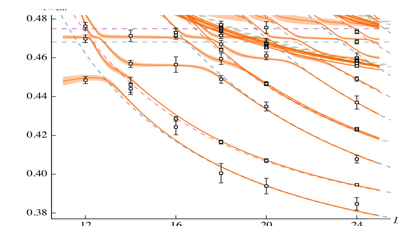
$$C_{ij}(t) = \langle \Omega | \mathcal{O}_i(t) \mathcal{O}_j^\dagger(0) | \Omega \rangle$$

$$= \sum_n \langle \Omega | \mathcal{O}_i | n \rangle \langle n | \mathcal{O}_j^\dagger | \Omega \rangle e^{-E_n t}$$

All the energy levels $E_n(L)$ are discretized.

$F(\vec{P}, E, L)$: Mathematically known function matrix in the channel space (the explicit expression omitted)

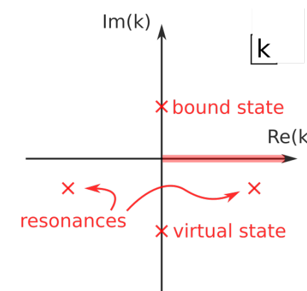
$$\begin{array}{c} \bullet \\ \circlearrowleft \mathcal{L} \quad \vee \quad \mathcal{R}^\dagger \circlearrowright \\ \bullet \end{array} - \begin{array}{c} \bullet \\ \circlearrowleft \mathcal{L} \quad \infty \quad \mathcal{R}^\dagger \circlearrowright \\ \bullet \end{array} = \begin{array}{c} \vdots \\ \circlearrowleft \mathcal{L} \quad \vee \quad \mathcal{R}^\dagger \circlearrowright \\ \vdots \end{array} \equiv -\mathcal{L}(P) F(P, L) \mathcal{R}^\dagger(P)$$



$\mathcal{M}(E)$: Scattering matrix.

- Unitarity requires

$$\mathcal{M}_{ab}^{-1} = (\mathcal{K}^{-1})_{ab} - i\delta_{ab} \frac{2q_a^*}{E_{cm}}$$
- $\mathcal{K}$ is a real function of s for real energies above kinematic threshold.
- The **pole singularities** of $\mathcal{M}(s)$ in the complex s -plane correspond to bound states, virtual states, resonances, etc.



$$k = \frac{1}{2}\sqrt{s - 4m^2}$$

2. 课题 (2025.9-2026.9)

直接格点QCD计算——

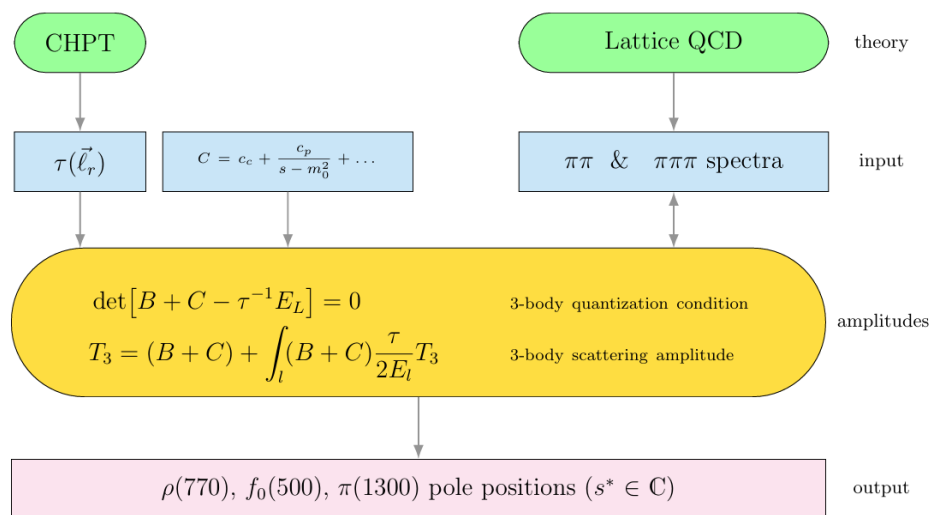
- Λ 激发态相关赝标量介子-重子散射 (2605.28447)、 $E_{cc}K$ 相互作用(2511.12611)
- 核子-核子散射(2605.16977)、 $p\Lambda$ 散射(2603.05854)、 $N\Omega_{ccc}$ 散射(2603.01566)、 H 双重子(2603.05880)、双粲重子之间的相互作用(2509.24649)
- $B^{(*)}\bar{D}^{(*)}$ 散射及浅束缚态 T_{bc} (2602.02176)
- 最轻的正宇称粲介子的内部结构 (2604.00743)
- $K^*(892)$ 和 ρ 共振态性质 (2603.16266, 2602.23044)、 $\pi K(I = 3/2)$ S-波散射(2601.01205)
- $\pi(1300)$ 相关 3π 散射(2510.09476)

基于格点QCD数据的唯象分析——

- 基于手征有效理论 (格点QCD约束) 轻介子-双粲重子散射 (2606.30211)
- 基于格点能谱研究 $D_0^*(2300)$ 双极点结构 (2606.03826, 2604.18286)
- 基于实验和格点数据确定 $Z_c(3900)$ 和 $Z_{cs}(3985)$ 的性质(2604.25607)
- 基于近期格点相移细致研究 $\pi\pi$ 散射(PoS Hadran2025(2026) 095)
- 考虑左手割线的修正的Leuscher公式的截断依赖性(DOI:10.1016/j.nuclphysa.2026.123337)
- 在N体有限体积广义哈密顿体系下通过格点能级抽取 ω 共振态(2603.07205)
- . . .

3. $\pi(1300)$ 相关 3π 散射 (H. Yan et al., Phys. Rev. Lett. 136 (2026) 141901 [2510.09476])

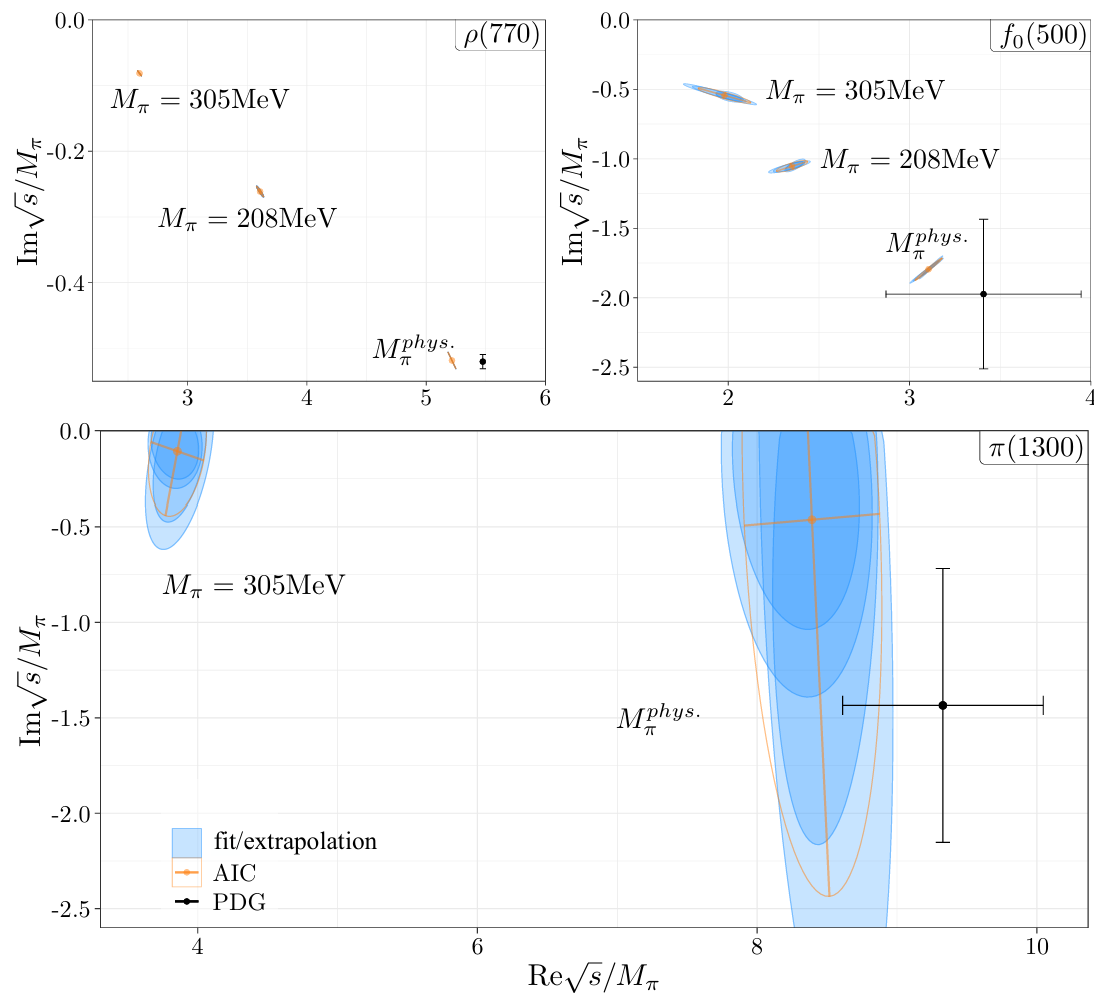
3π 散射的格点QCD计算表明, **QCD允许 $\pi(1300)$ 共振态的存在。**



$$M_{\pi(1300)} = (1169 \pm 46) - i(62 \pm 169) \text{ MeV}$$

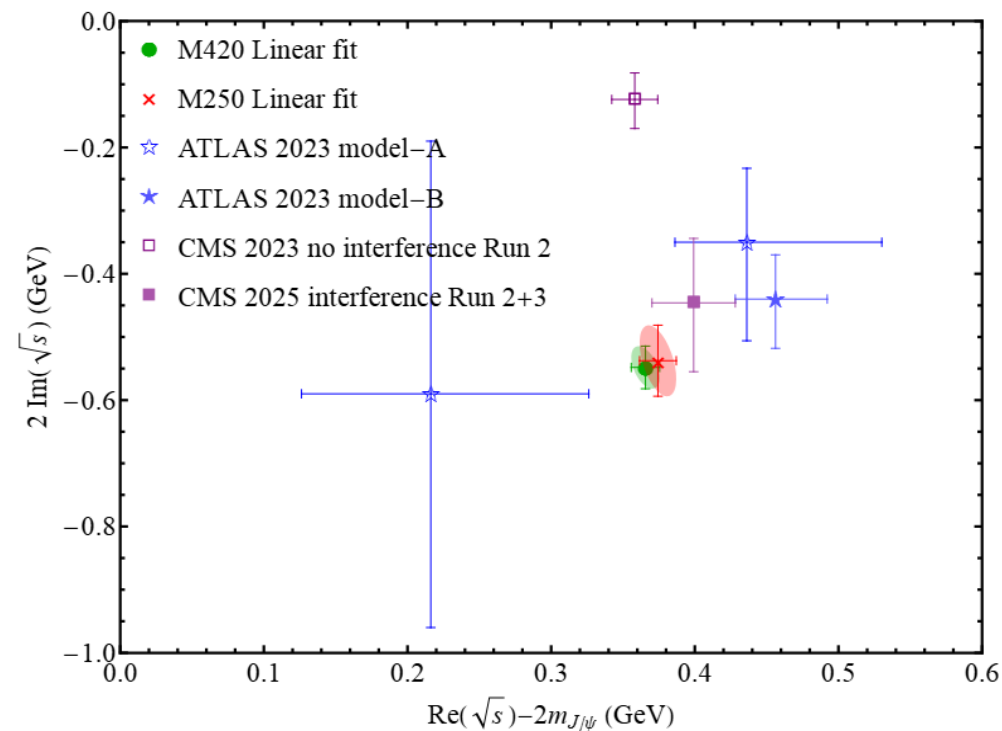
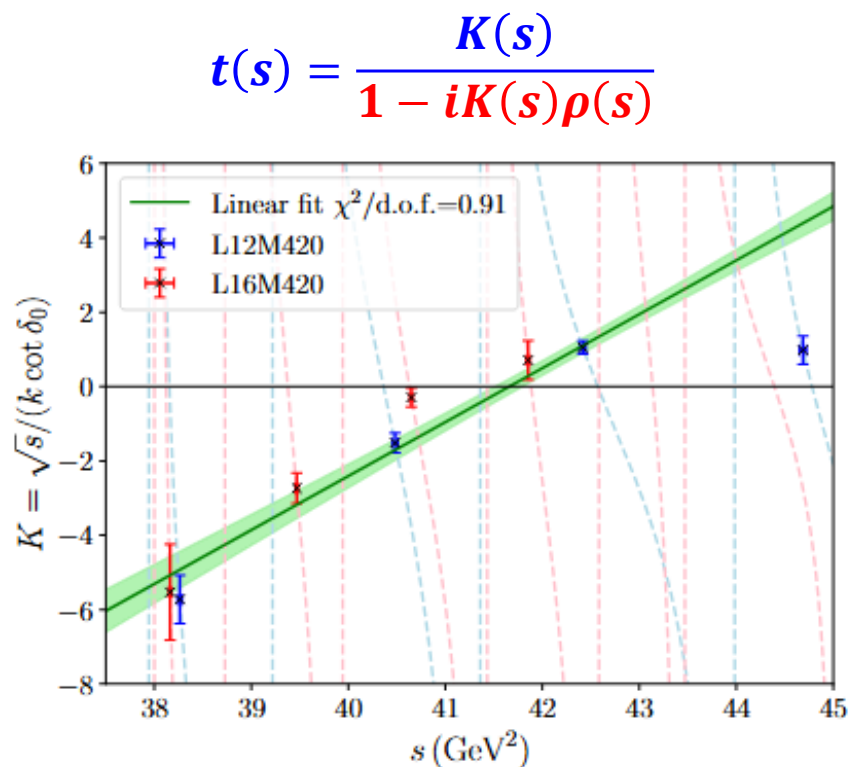
$$M_{\rho(770)} = (727 \pm 3) - i(72 \pm 1) \text{ MeV},$$

$$M_{f_0(500)} = (433 \pm 7) - i(250 \pm 7) \text{ MeV}.$$



4. $J/\psi J/\psi$ 散射中的 2^{++} 共振态 (G. Li et al., Phys. Rev. D 114 (2026) 3, L031506)

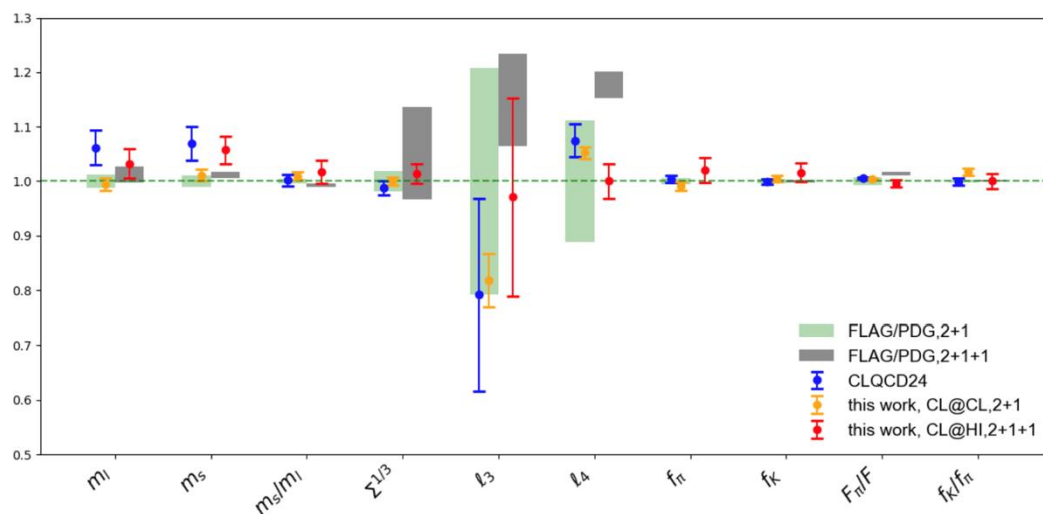
- $X(6600)$, $X(6900)$ 和 $X(7200)$ 被LHCb, ATLAS, CMS 在 $J/\psi J/\psi$ 不变质量谱中陆续发现。
- CMS将它们归为 2^{++} 的全粲四夸克态家族 (CMS Collab. Nature 648 (2025) 8092, 58-63) 。
- 该结果和CMS新结果一致并几乎同时发布, 这在有关奇特态研究方面尚属首次。



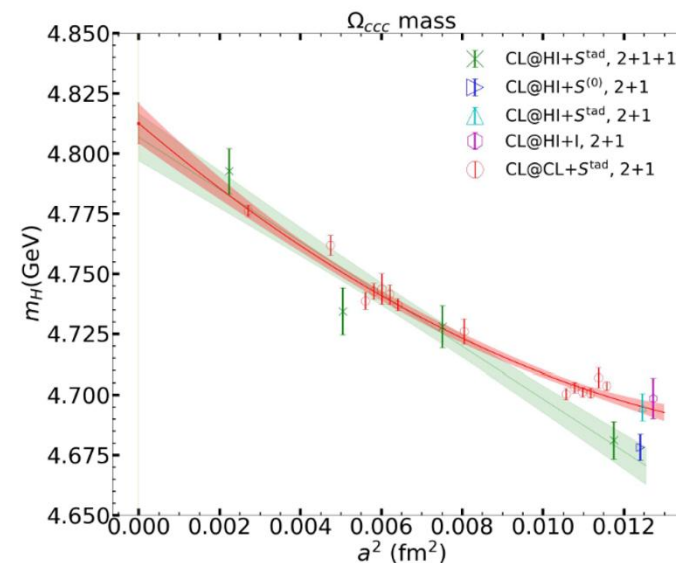
(二) 其它强子谱学研究

1. 基于CLQCD新一代 $N_f = 2 + 1 + 1$ 规范组态研究B介子及底偶素性质 (Courtesy to Yi-Bo)

CLQCD ensembles



Charm sea effects

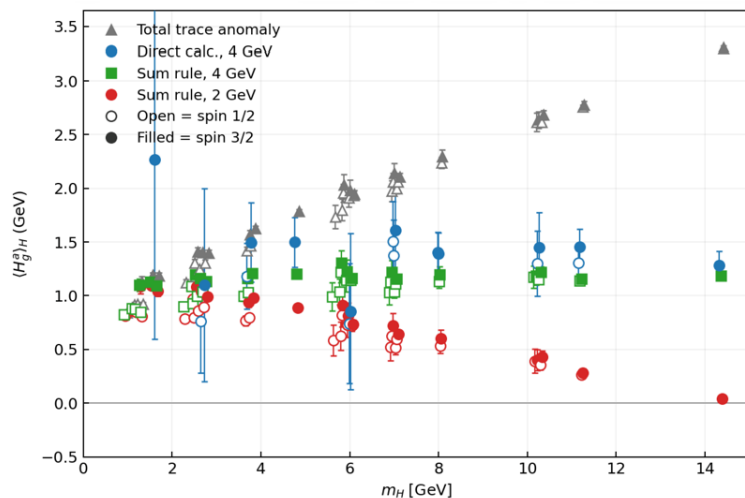
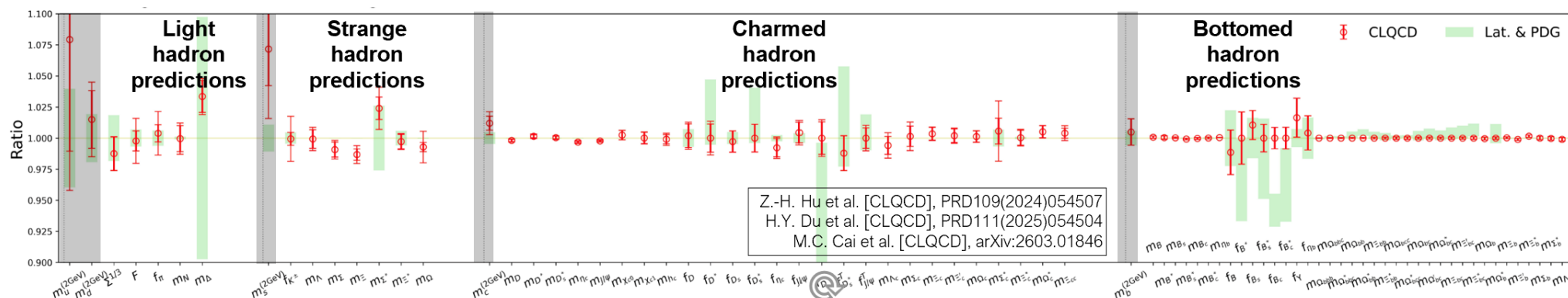


- The second generation of the CLQCD ensembles uses $N_f=2(\text{light})+1(\text{strange})+1(\text{charm})$ setup and turner suppresses the discretization errors;
- Good consistency between the 2+1 and 2+1+1 results for the light quark physics, using the same clover fermion action.
- Also good agreement for $m_{\Omega_{ccc}}$ within 0.2% uncertainty.

2. 强子质量、QCD迹反常贡献及电磁修正 (Courtesy to Yi-Bo)

Hadron mass

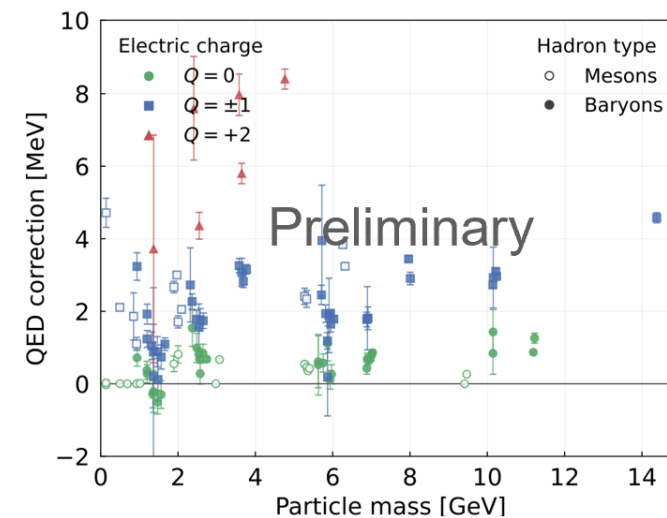
From different sources



B.-L. Hu, et. al., CLQCD, arXiv: 2411.18402

C.Y. Zhang, H.Y Du et al. [CLQCD], in preparation

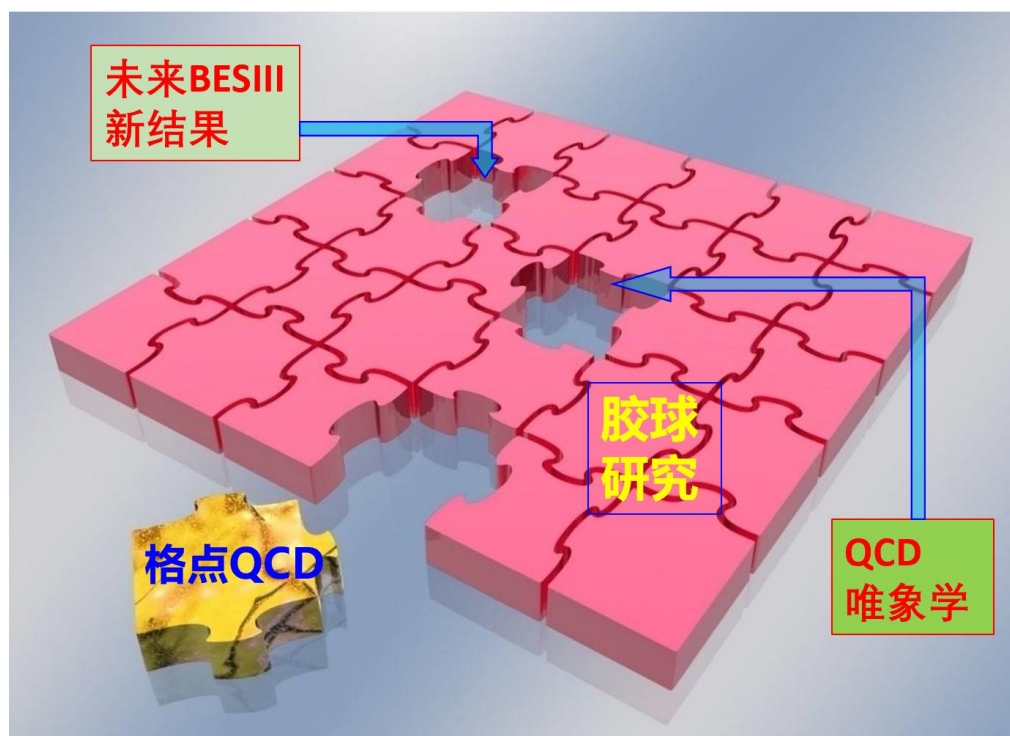
- The total trace anomaly contribution increase linearly on the baryon mass based on the sum rule;
- QED correction of the hadron mass can be much smaller than the naive $\mathcal{O}(\alpha_s)$ power counting in the Dashen's scheme.



Y.Y. Liu et al. [CLQCD], in preparation

2. 其它强子谱学研究

- 海粲夸克、混合作用量等效应对强子质量的影响(2603.04230, 2512.19265) K^* (892) 和 ρ 共振态
- 标量胶球- $s\bar{s}$ 介子混合的格点QCD研究 (2607.17294) (桂龙成报告)
- 赝标量胶球- $c\bar{c}$ 混合机制及X(2370)在 J/ψ 辐射衰变中的产率(2605.01757) (桂龙成报告)



三、强子结构相关 (hadron structure)

- 核子和介子的 **PDF**、**GPD**、**TMD**，重子与重介子分布振幅，核子荷、自旋、质量分解及引力形状因子
- LaMET理论和再分析 (见季向东老师的报告)

(一) 直接格点QCD计算

1. Computability of **GPDs** near $x = \pm\xi$ in Lattice QCD, [arXiv:2609.20545](#)
2. Lattice QCD Calculations of **Transverse-Momentum-Dependent Distributions**, [PoS SPIN2025 \(2026\) 024](#)
3. Probing **Meson Structure** via Lattice QCD: Electromagnetic Form Factor at High Momentum Transfer and Generalized Parton Distribution, [PoS SPIN2025 \(2026\) 086](#)
4. **Pion Transition Form Factor** in Lattice QCD, [arXiv:2607.27868](#)
5. Baryon **Light-Cone Distribution Amplitudes** from Lattice QCD: Formalism, Renormalization, Extrapolation, and Matching, [2606.30387](#), [2606.29597](#)
6. Hybrid renormalization in lattice calculation of **baryon LCDAs**, [arXiv:2606.18777](#)
7. Continuum-Limit HQET LCDAs from Lattice QCD for Tightening B Decay Uncertainties, [arXiv:2605.10946](#), [2604.25802](#)
8. Hybrid Renormalization for **Baryon Distribution Amplitudes** from Lattice QCD in LaMET, [arXiv:2604.12419](#)
9. Proton isovector **helicity PDF** at NNLO and the twist-3 moment $\tilde{d}_2$ from lattice QCD at physical quark2 masses, [arXiv:2604.00143](#)
10. Lattice extraction of the **Collins-Soper kernel** using the auxiliary field representation of the Wilson line [arXiv:2603.03814](#)

1. The **hadronic tensor** from four-point functions on the lattice, [arXiv:2602.22379](#)
2. Factorization formula connecting the Λ_Q **LCDA** in QCD and boosted HQET, [arXiv:2602.14187](#)
3. Lattice-QCD validation of hadron mass and trace-anomaly decomposition sum rules, [2601.13070](#)
4. Total **Gluon Helicity** Contribution to the Proton Spin from Lattice QCD, [arXiv:2512.24315](#)
5. Lattice QCD calculation of **charmed baryon decay constants** at continuum limit and physical mass, [arXiv:2512.20372](#)
6. Lattice QCD Determination of the **Collins-Soper Kernel** in the Continuum and Physical Mass Limits, [arXiv:2511.22547](#)
7. Precision determination of nucleon **iso-vector scalar and tensor charges** at the physical point, [arXiv:2511.02326](#)
8. **Moments** of parton distributions functions of the pion from lattice QCD using gradient flow, [arXiv:2510.26738](#)
9. **Unpolarized gluon PDF** of the nucleon from lattice QCD at physical point in the continuum limit, [arXiv:2510.26425](#)
10. The **axion-photon coupling** from lattice Quantum Chromodynamics, [arXiv:2603.29153](#)
11. Flowed quark field renormalization in lattice QCD: A Ward-identity approach and its validation using quark bilinears, [arXiv:2609.23379](#)

(二) 与格点QCD计算相关的理论研究

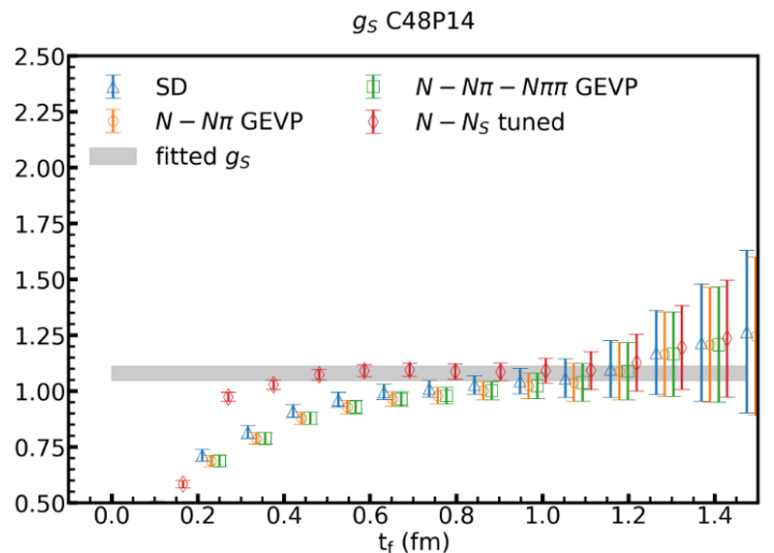
1. **Generalized parton distributions**: Theory meets experiment, [arXiv:2609.19544](#)
2. Towards power corrections in the **factorization of baryon quasi-distribution** amplitudes in LaMET, [arXiv:2608.29042](#)
3. Revisiting **Quark Confinement in the Proton** through the Force on Quarks, [arXiv:2607.21952](#)
4. Heavy quark mass dependence of the Λ_Q **light-cone distribution amplitude** in QCD, [arXiv:2607.17471](#)
5. Proton's **isovector PDF** with updated analysis of large-momentum lattice data, [arXiv:2606.22224](#)
6. The **Collins-Soper kernel** from a vacuum soft function, [arXiv:2606.19221](#)
7. Constraining **DVCS** Compton Form Factors Using Lattice QCD informed Neural Network, [2606.09152](#)
8. Parton Distribution Functions from Large Momentum Expansion of Current-Current Correlators, [arXiv:2605.03234](#)
9. Evidence for Quark Confinement in the Proton, [2605.00339](#)
10. Asymptotic **Long-Distance Expansion of Euclidean Correlators** in Lattice Parton Applications, [arXiv:2601.12189](#)
11. **Three-dimensional imaging of hadrons** with hard exclusive reactions: advances in experiment, theory, phenomenology, and lattice QCD, [arXiv:2512.15064](#)
12. Extracting **Mellin moments** of double parton distributions from lattice data, [arXiv:2511.15546](#)
13. One-Loop Renormalization of the **Improved Energy-Momentum Tensor** in Lattice QCD, [arXiv:2606.24222](#)

例一. 多强子态对强子矩阵元的抽取的影响 (Courtesy to Yi-Bo)

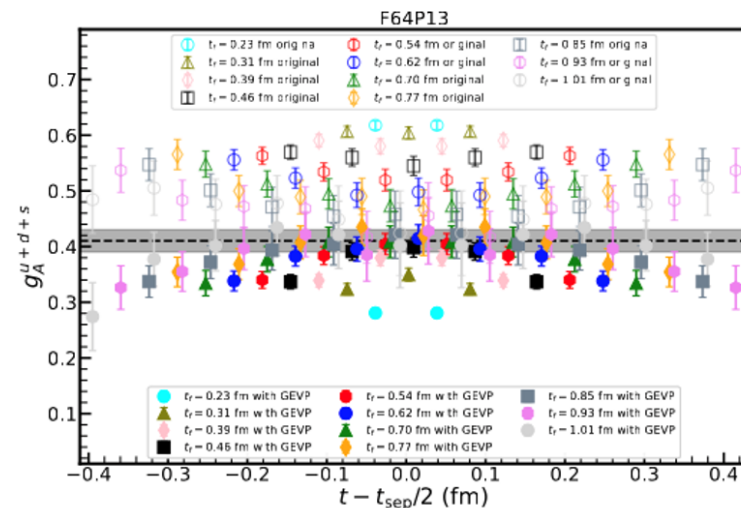
Nucleon matrix elements

Contaminations from
Multi-hadron state

- Further application of the blending method on the multi-hadron state contamination on the nucleon matrix element;
 - The current-involved state turns out to be much more important than the low lying $N\pi$ and $N\pi\pi$ states, for iso-vector scalar and tensor charges;
- So far the most precise determination of the total quark spin contribution in the nucleon, directly at the physical pion mass.



J-H. Wang et al. [CLQCD], arXiv:2511.02326v3



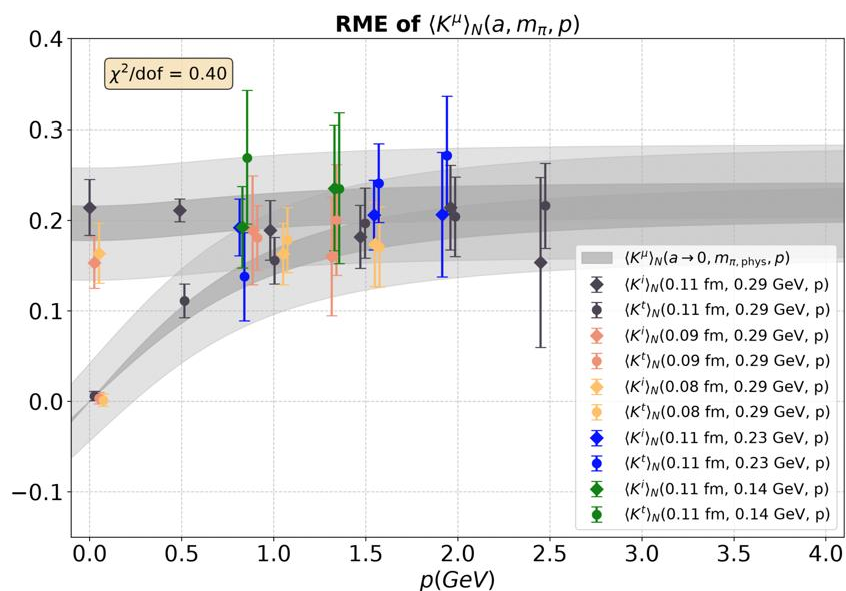
Z.-H. Hu et al., [CLQCD], arXiv:2505.01719v3

Nucleon matrix elements

Gluon spin and PDF

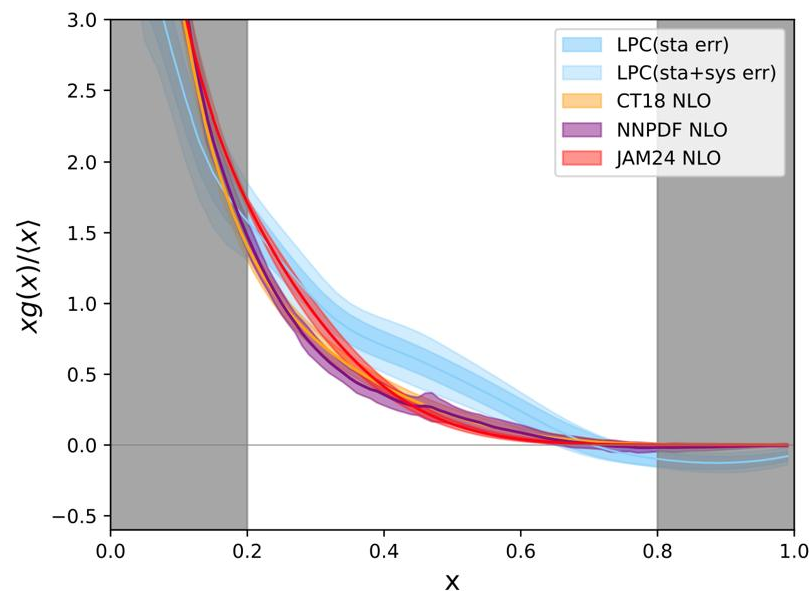
- Gluon spin and PDF calculation at the physical pion mass with continuum extrapolation:

- Gluon spin using the topological current with non-perturbative renormalization;



D.-J. Zhao et al., [CLQCD&LPC], arXiv:2512.24315

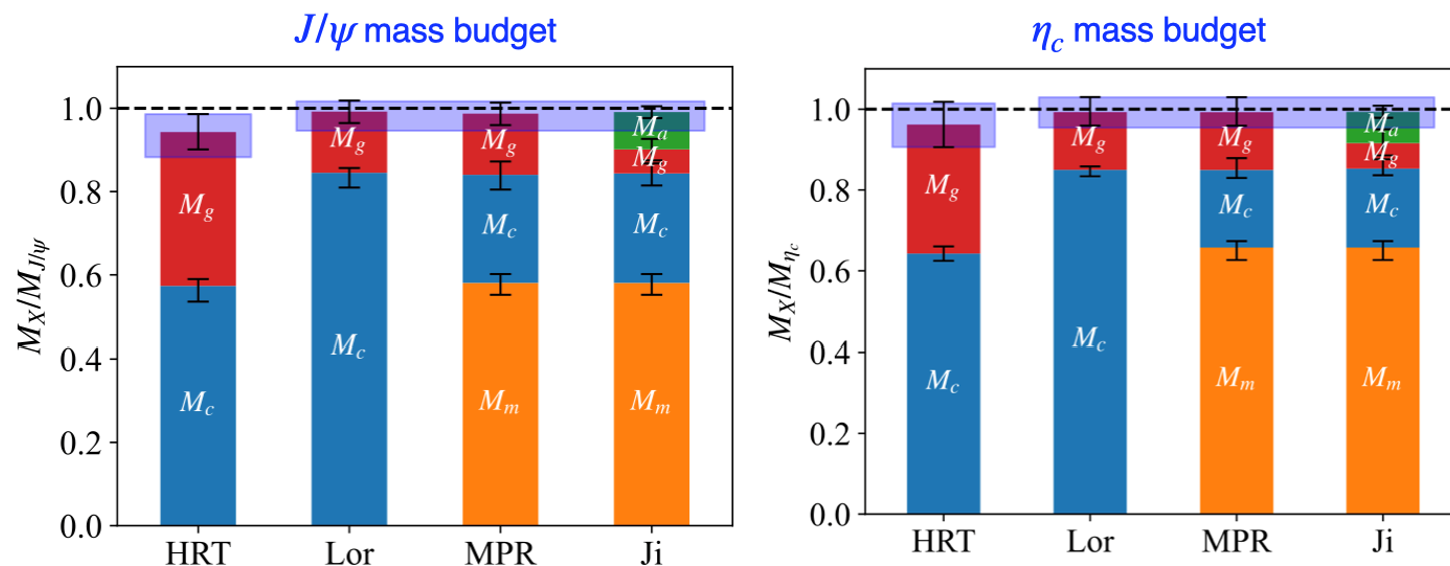
- Gluon unpolarized PDF with the maximum momentum $\sim 3 \text{ GeV}$ and finest lattice spacing $a \sim 0.05 \text{ fm}$.



C. C and C.-H. Zeng et al., [CLQCD&LPC], arXiv:2510.26425

例三. 粲偶素质量构成 (Courtesy to Heng-Tong)

以粲夸克偶素为例，核对了四类QCD sum rule



M_c : charm energy ; M_g : gluon; M_m : explicit charm-mass term; M_a : trace-anomaly

D. Bollweg, 丁亨通, 高翔, 罗冉, S. Mukherjee, Phys.Rev.Lett. 137 (2026) 6, 061901

四、标准模型精确检验及新物理寻找 (SM/BSM)相关的强子矩阵元)

(一) 课题 (2025.9-2026.9)

1. First-Principles Determination of the QCD Contribution to the **Axion-Photon Coupling** Using Domain-Wall Fermions, [arXiv:2609.22698](#)
2. First-principles determination of **anomaly-induced pion decay** beyond the chiral limit, [arXiv:2608.31024](#)
3. Direct lattice QCD calculation of the **θ -included CP-violating pion-nucleon coupling**, [arXiv:2608.23685](#)
4. **Δ resonance contribution** to QED radiative corrections in neutron and **inverse β decay**, [arXiv:2608.22845](#)
5. First Lattice QCD Determination of **Lepton-Flavor-Universality Ratios in Light-Meson Leptonic Decays**, [arXiv:2607.22358](#)
6. **Neutrinoless double- β decay** of the Δ resonance, [arXiv:2604.12535](#)
7. First-Principles Determination of the **Proton-Proton Fusion Matrix Element** from Lattice QCD, [arXiv:2603.09554](#)
8. **Radiative corrections to the nucleon isovector g_V and g_A** , [arXiv:2603.08596](#)
9. Lattice QCD constraints on **pion electroproduction off a nucleon**, [arXiv:2603.06055](#)
10. **Neutrinoless double β decays of hyperons** in covariant chiral perturbation theory, [arXiv:2602.08453](#)
11. Radiative decay of heavy-light mesons from lattice QCD, [arXiv:2602.07829](#)
12. Lattice determination of the neutrino background for **$J/\psi \rightarrow \gamma + \text{invisible}$** , [arXiv:2601.18209](#)
13. Lattice QCD determination of the **γZ box contribution to the proton weak charge**, [arXiv:2601.06582](#)
14. Form factors of the **$D_s \rightarrow \phi l \bar{\nu}$ semileptonic decay** with (2 + 1)-flavor lattice QCD, [arXiv:2512.21607](#), [arXiv:2510.14478](#)
15. Lattice Calculation of **Light Meson Radiative Leptonic Decays**, [arXiv:2510.26993](#)

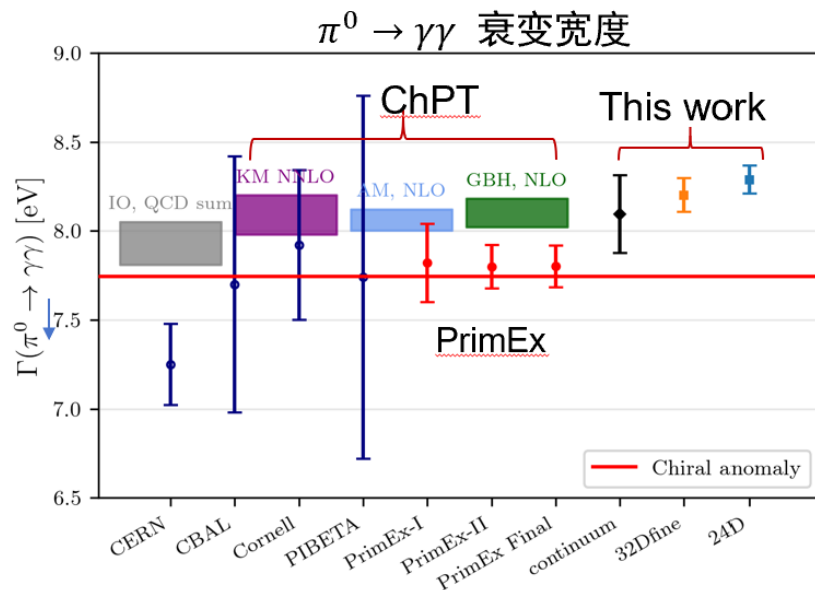
$\pi^0 \rightarrow \gamma\gamma$ 宽度，轴子-光子耦合

发展方法：

- 利用反常 Ward 恒等式将手征反常的贡献和夸克质量修正分离

物理应用：

- 首次给出含同位旋破缺效应的 $\pi^0 \rightarrow \gamma\gamma$ 宽度： $8.09(22)eV$
- 计算轴子-光子耦合的QCD贡献： $C_{QCD} = 1.965(35)$ ，厘清不同手征微扰论结果分歧的来源

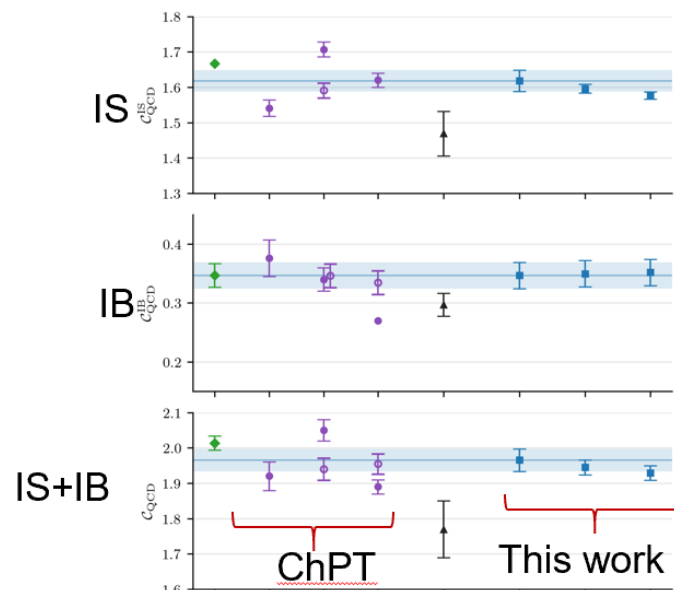


arXiv: 2608.31024

QCD 对轴子-光子耦合的贡献

QCD contribution to $C_{a\gamma}^{\text{eff}} = E/N - C_{QCD}$

Legend: $\blacklozenge$ LO χ PT, $\bullet$ NLO χ PT, $\blacktriangle$ Background field, $\blacksquare$ This work

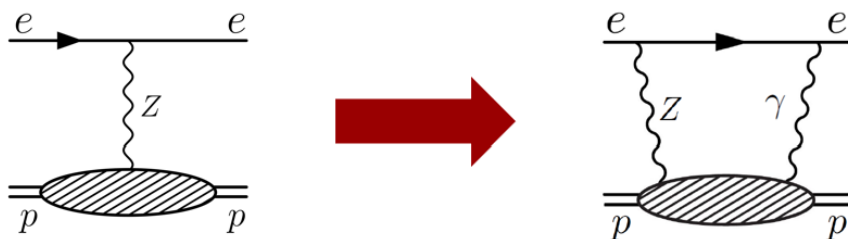


arXiv: 2609.22698

光子-Z玻色子圈图的首个格点计算 (2601.06582)



- 弱相互作用的温伯格角 $\sin^2 \theta_W$ 可从宇称破坏的e-p散射提取
- γZ 圈图是一圈修正中重要的理论误差来源

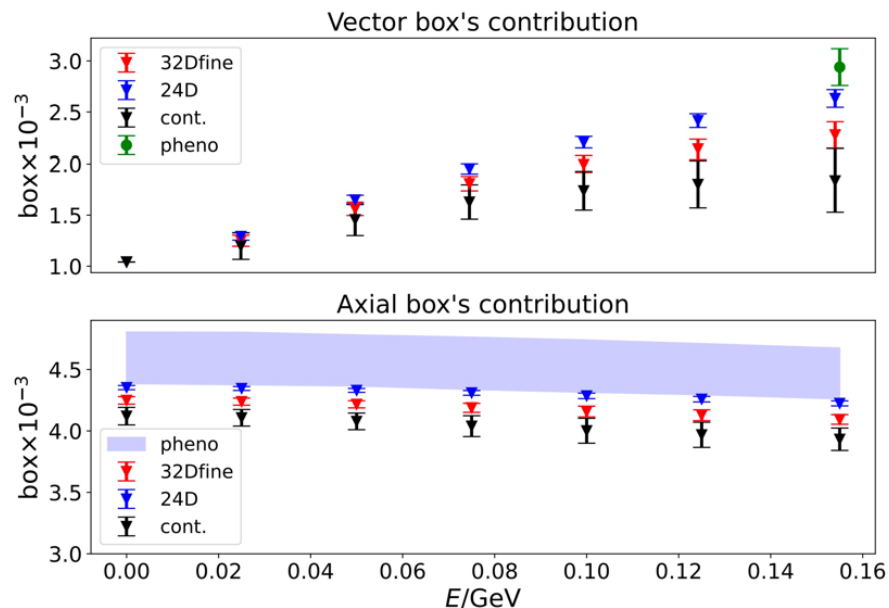


宇称破坏的电子-质子散射

 γZ 圈图修正
非微扰敏感

更新质子弱荷的标准模型理论预言

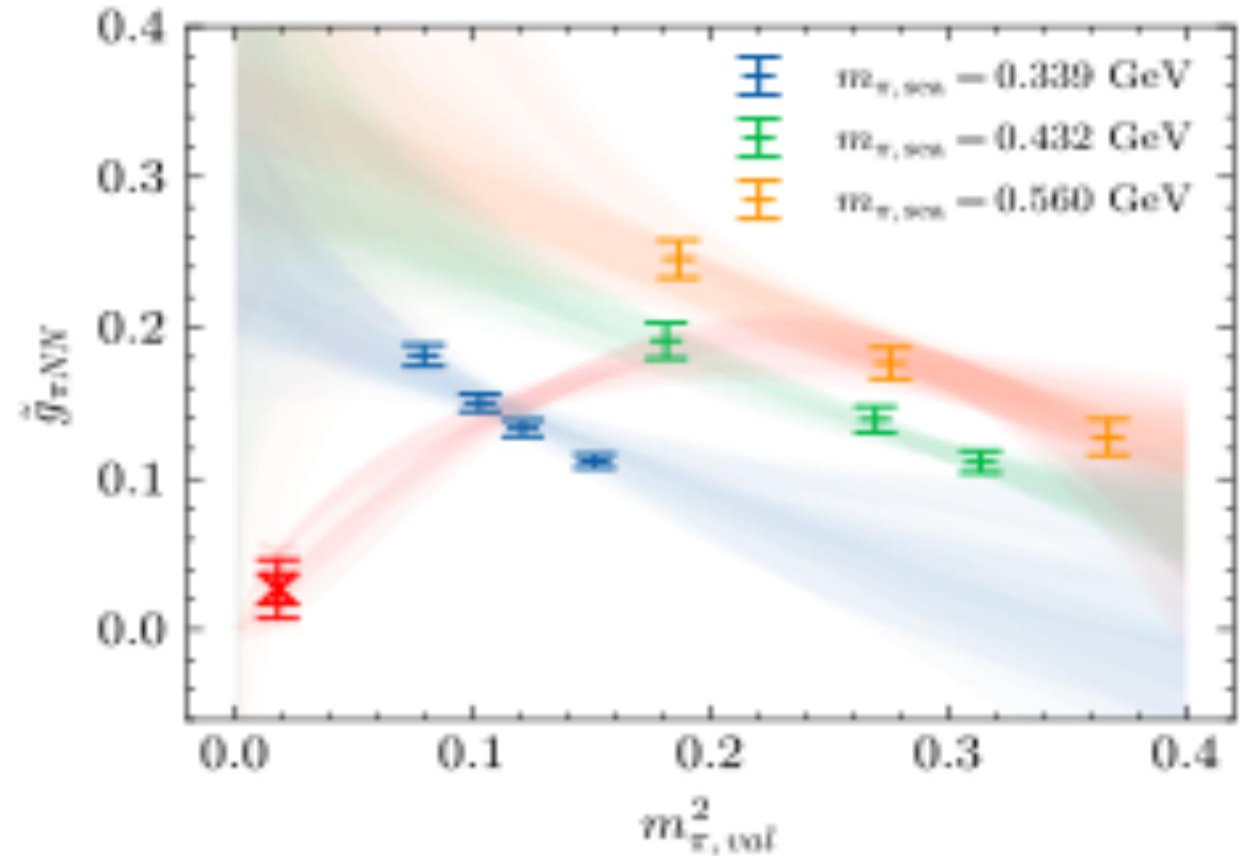
$$Q_W^p = 0.06987(20)_{s_W^2(10)_{WW}(9)_{\gamma Z(44)_{2\gamma}}$$

 γZ 修正随实验室系电子能量 E 的依赖

例三： The θ -included CP-violating pion-nucleon coupling (Courtesy to Liang Jian)

2608.23685

First direct lattice QCD determination of the θ -induced CP-violating pion-nucleon-nucleon. The cluster-decomposition error-reduction method is used to improve the statistical precision. A simultaneous extrapolation in the valence- and sea-pion masses, with model averaging over 7 forms based on the Akaike information criterion, gives $0.0306(56)(124)$ θ at the physical point.



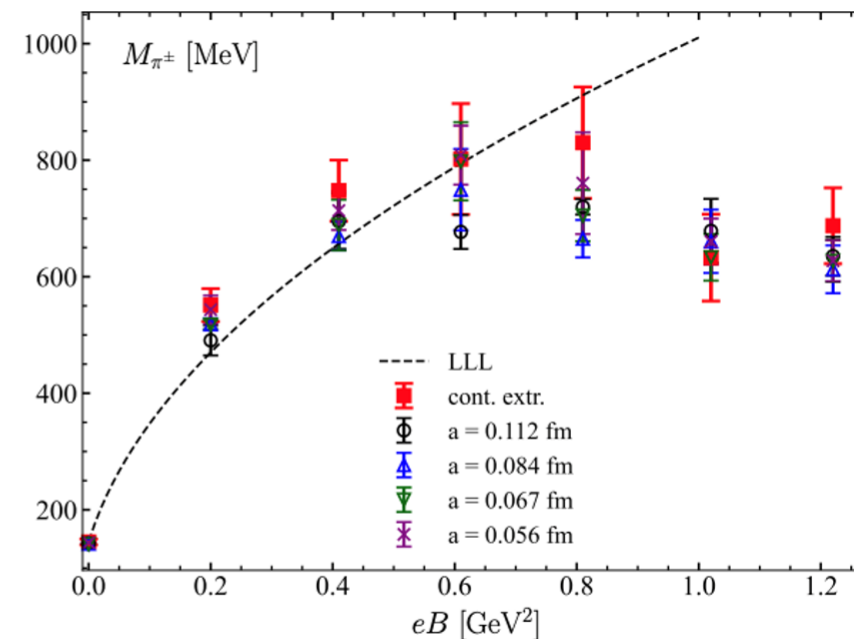
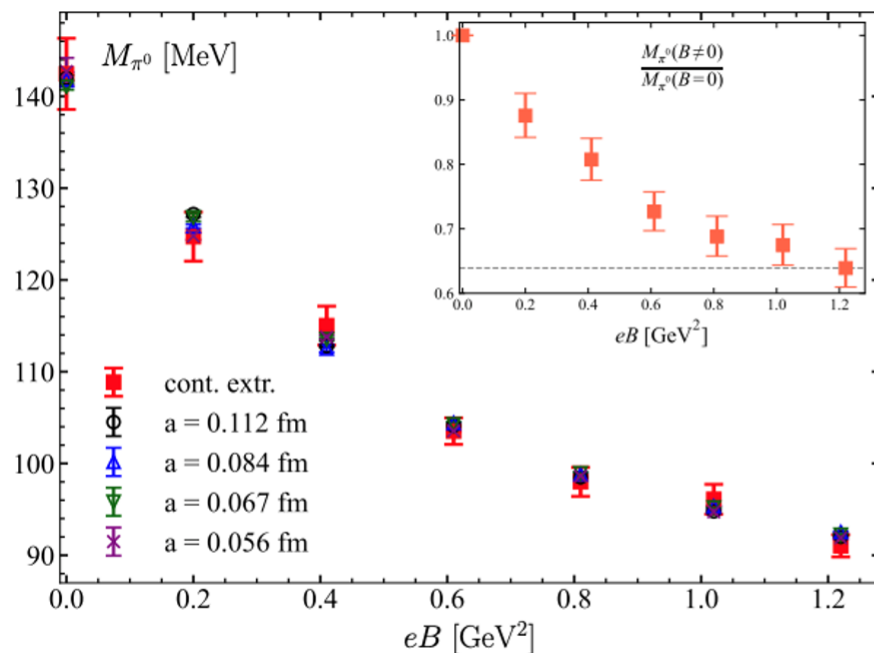
五、有限温度有限密度QCD相关

(一) 课题 (2025.9-2026.9)

1. Gradient Flow for the **Jet Transport Coefficient**: A Quenched Lattice Benchmark, [arXiv:2609.25089](#)
2. **Axial U(1) Symmetry Breaking in Hot QCD**: From Topology to the Chiral Phase Transition, [arXiv:2609.21907](#)
3. **QCD Chiral Crossover Line** from Lee-Yang Edge Singularities, [arXiv:2608.05752](#)
4. **Static Quark-Antiquark Interactions Under Rotation**, [arXiv:2607.26939](#)
5. **Chiral and $U_A(1)$ symmetries in background magnetic fields** from lattice QCD, [arXiv:2607.11625](#)
6. Isospin-Driven Splitting of **Chemical Potentials in Isobar Collisions** from Lattice QCD, [arXiv:2606.30164](#)
7. Temperature dependence of **heavy quark diffusion** from 2 + 1 lattice QCD, [DOI:10.1051/epjconf/202636408001](#)
8. **QCD in strong magnetic fields**: fluctuations of conserved charges and equation of state, [arXiv:2604.00370](#)
9. **Mesonic screening correlators** in an external imaginary electric field at finite temperature, [arXiv:2603.27620](#)
10. Lattice QCD at finite temperature and density, [arXiv:2603.16230](#)
11. Wilson loops with oppositely oriented plaquettes as a probe of center vortex structure, [arXiv:2603.13757](#)
12. RG-Invariant Symmetry Ratio for QCD: A Study of **$U_A(1)$ and Chiral Symmetry Restoration**, [arXiv:2602.14811](#)
13. **Chiral Properties of (2+1)-Flavor QCD in Magnetic Fields** at Zero Temperature, [arXiv:2601.18354](#)
14. **Shear and bulk viscosities of the gluon plasma** across the transition temperature from lattice QCD, [arXiv:2601.14967](#)
15. **QCD Crossover at Low Temperatures** from Lee-Yang Edge Singularity, [arXiv:2601.04782](#)
16. One-quark state near a boundary of the confinement phase of QCD, [arXiv:2510.24363](#)(北京雁栖湖应用数学研究院)
17. **QCD in strong magnetic fields**: fluctuations of conserved charges and EoS, [arXiv:2510.21731](#)

例一：零温强磁场下pion介子随磁场强度的变化 (Courtesy to Heng-Tong)

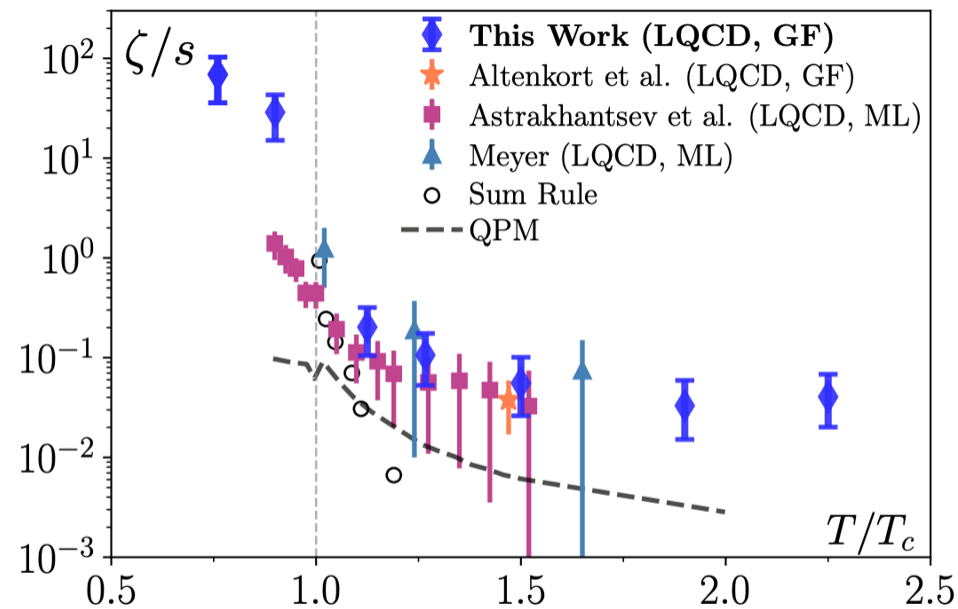
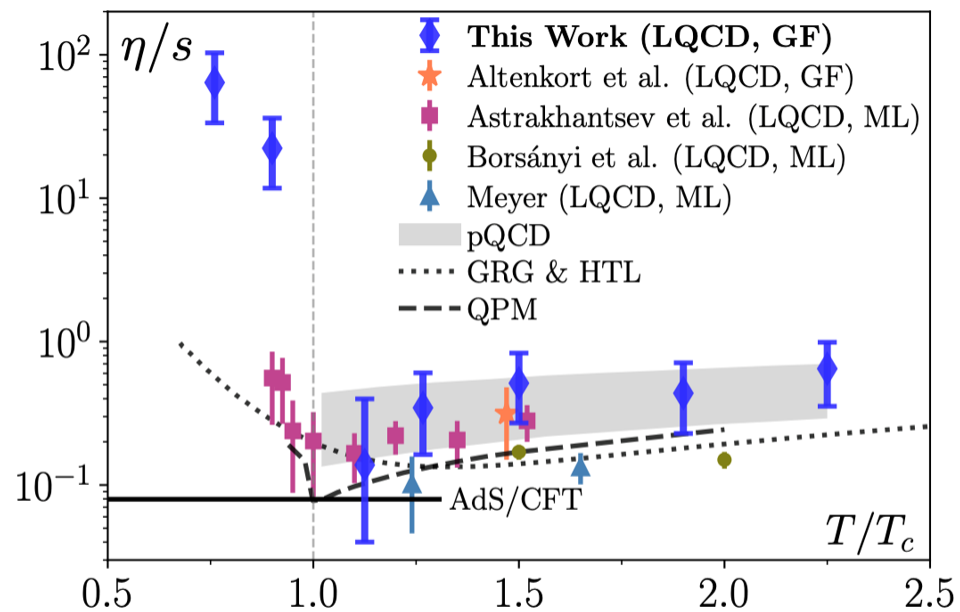
零温度强磁场下，中性pion质量(左图)单调下降，带电pion质量(右图)随磁场有非单调变化



丁亨通, 张丹, Phys.Rev.D 113 (2026) 9, 094503

例二：利用梯度流的方法得到了淬火近似下剪切和体粘滞系数随温度的变化

(Courtesy to Heng-Tong)

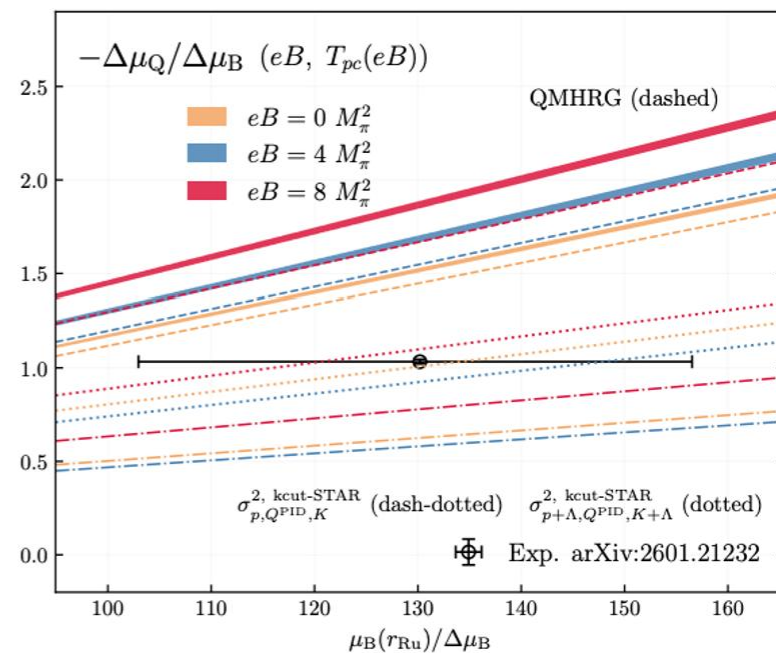
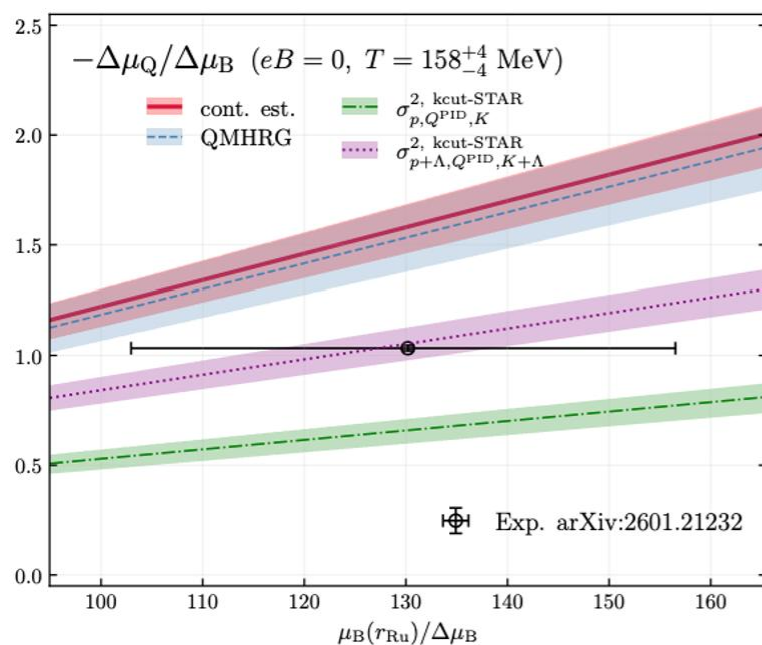


丁亨通, 舒海涛, 张成, PRD 113 (2026) 7, 074503

例三：

See talk by 倪佳

提出在格点QCD里计算同量异位素碰撞中化学势能差别的方案，与实验结果对比



丁亨通, 顾锦彪, A. Kumar, 倪佳, [arXiv:2606.30164](https://arxiv.org/abs/2606.30164)

六、AI/ML在格点场论研究中的应用

(一) 课题 (2025.9-2026.9)

1. Detecting **Multiple Phase Transitions** in Lattice Systems with **Intrinsic Dimensions**, [arXiv:2608.29090](#)
2. Chemical Potential and Analytic Continuation for Non-Hermitian Lattice Fermions, [arXiv:2608.08862](#)
3. **LQCDMaster**: Agentic Scientific Computing for Lattice Quantum Chromodynamics Research, [arXiv:2607.15001](#)
4. Weight-Space Physics: **Interpretable Hypernetworks** for Lattice Quantum Field Theories, [arXiv:2607.07127](#)
5. **Stochastic Path Sampler** For Lattice Field Theory, [arXiv:2606.13790](#) (港中深)
6. **Conditional Model-Adequacy Tests** for Spectral Uncertainty Claims in Lattice QCD, [arXiv:2606.11617](#)
7. **Automated Extraction of Collins-Soper Kernel** from Lattice QCD using An Autonomous AI Physicist System, [arXiv:2603.22471](#)
1. Reducing the Computational Cost Scaling of **Tensor Network Algorithms via Field-Programmable Gate Array Parallelism**, [arXiv:2602.05900](#)
2. Thermodynamic Consistency as a Reliability Test for Complex Langevin Simulations, [arXiv:2601.20527](#)
3. **Generalizable Equivariant Diffusion Models** for Non-Abelian Lattice Gauge Theory, [arXiv:2601.19552](#)
4. **Variational Autoregressive Networks** Applied to ϕ^4 Field Theory Systems, [arXiv:2512.19575](#) (港中深)
5. Approaches to the **Inverse Fourier Transformation with Limited and Discrete Data**, [arXiv:2511.03593](#)
6. **AI for Pattern Hunter**: Application in Wilson Loop of 2D Lattice Yang-Mills Theory, [arXiv:2510.24494](#)
7. Combining complex Langevin dynamics with score-based and energy-based **diffusion models**, [arXiv:2510.01328](#) (港中深)
8. **Machine Learning Unveils Finite-volume Energy Shifts in Three-body System**, [arXiv:2608.28700](#)

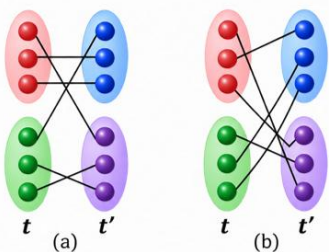
格点QCD研究的工程化难度

1 物理设计

到底该怎么算？

选择观测量和插入流算符

Wick Contraction

确定传播子、源汇结构等
处理 γ 矩阵、味、自旋、颜色等指标一个符号或收缩错误，
就可能改变最终物理量

2 程序实现

公式怎样变成代码？

关联函数构造

传播子求解

规范链、边界条件处理

PyQUDA/QUDA/Chroma

程序实现

```
from pyquda import ...
gauge = load_gauge(...)
src = point_source(x0)
prop = invert(D, src)
corr = contract(prop, r)
save(corr)
```

从纸面的公式到可运行程序
需要大量时间

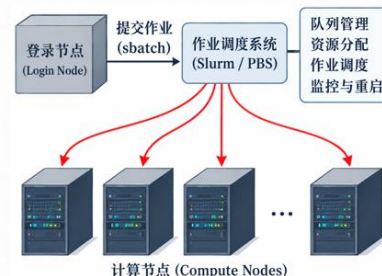
3 HPC 执行

代码能不能真正跑起来？

GPU/MPI并行计算

批量作业与参数遍历

日志、I/O与失败重

一个观测量=成百上千个
计算任务

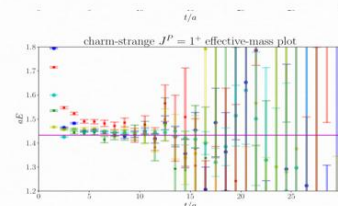
4 校验分析

结果到底对不对？

Effective mass检查

拟合、误差分析

交叉检验与结果的可复现性

程序跑完不代表物理
结果正确

从物理想法到可靠的计算结果，格点QCD存在非常高的工程化难度

(Courtesy to Wang Wei)

LQCDMaster设计理念：把工程交给 AI，把物理问题留给物理学家



Gao, et.al, arXiv:2607.15001 [hep-lat]

https://github.com/sjtu-sai-agents/LQCD_Master

LQCDMaster: 将自然语言研究需求转化为可验证的格点 QCD workflow

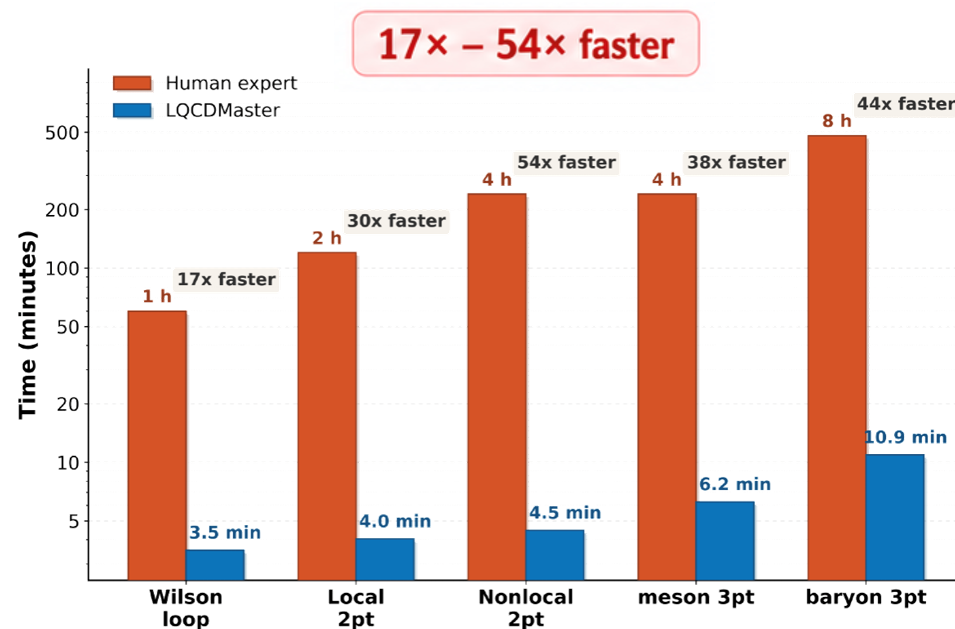
LQCDMaster的系统验证：算得准 + 跑得快

(Courtesy to Wang Wei)

1. 与专家结果逐项数值验证

任务类别	任务目标	任务数	精确匹配	准确率
Local 2pt	质量、衰变常数	20	20	100%
Nonlocal 2pt	LCDA	10	8	80.0%
Wilson loop	重夸克势	12	12	100%
Meson 3pt	形状因子	13	13	100%
Baryon 3pt	形状因子	15	10	66.7%
Total		70	63	90.0%

2. 与专家手写代码的开发时间对比



Gao, et.al, arXiv:2607.15001 [hep-lat]

LQCDMaster在两点函数、三点函数、规范圈等物理量有超过90%的成功率，且开发效率有超过一个量级的提升

LQCDMaster的科研场景举例：轻核与超核的谱

如果你关注轻核或超核的性质，希望从QCD第一性原理出发，快速探索氕核、氘核以及含 Λ 超子的少体体系。真正的瓶颈往往不在物理想法本身，而是多强子算符构造与Wick contraction实现的复杂度。

收缩项数随着夸克数增加呈多项式型增长！

	p	pn	pnn	Λ	p Λ	p $n\Lambda$
夸克数	3	6	9	3	6	9
收缩项数	2	36	2880	1	12	576

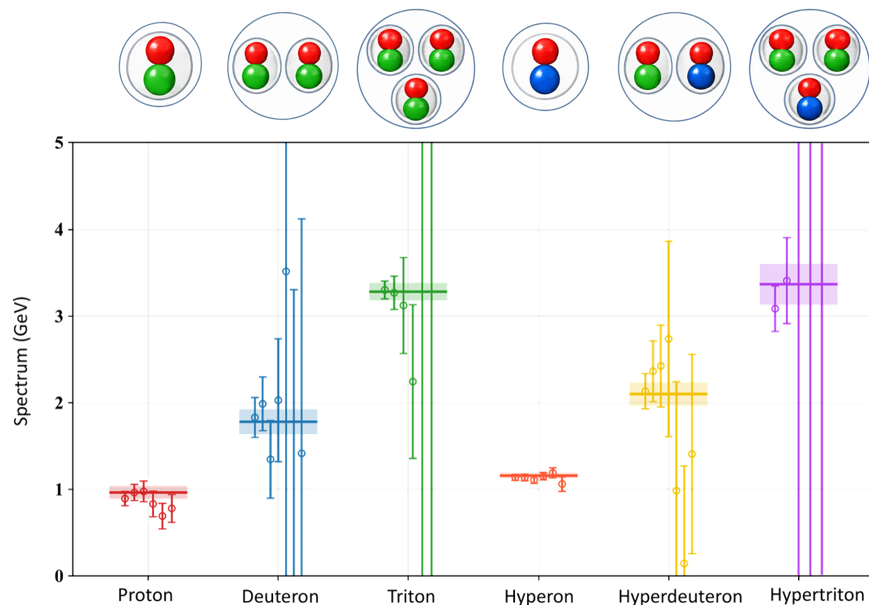
```
Triton 2pt

Use multi_hadron_2pt to compute the combined three-baryon two-point function for a local 9-quark operator. The combined interpolating operator at source and sink is:

O = (u^T Cg5 d) d * (u^T Cg5 d) u * (u^T Cg5 d) d

Use single-term baryon operators only (no octet flavor combinations). Apply P_plus projector on each baryon block individually (per-baryon block projection, not composite-level). The contraction should be one multi-hadron 2pt object, NOT a product of separate baryon 2pt correlators.
```

(Courtesy to Wang Wei)



对于新任务，LQCDMaster只需要一段提示词，即可在10分钟的量级生成计算程序

七、格点QCD算法与软件

(Courtesy to Heng-Tong)

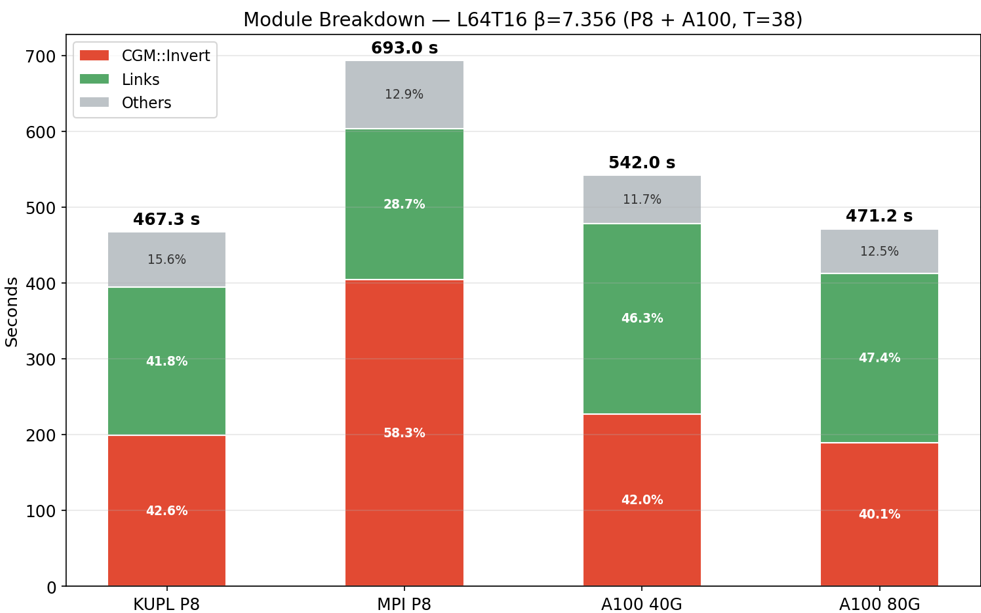
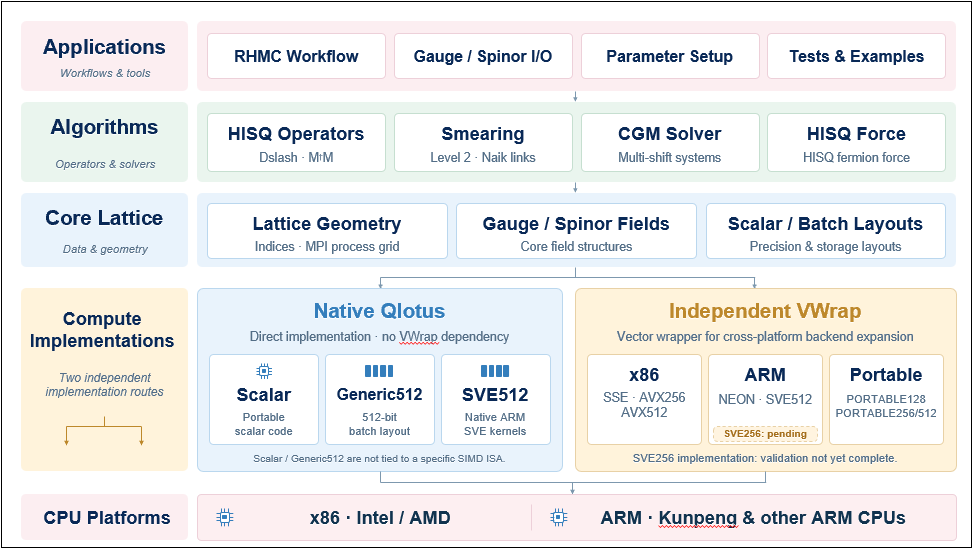


Qlotus 软件包

See talk by 张克龙

Qlotus — QCD Lattice Optimization Toolkit for United Systems

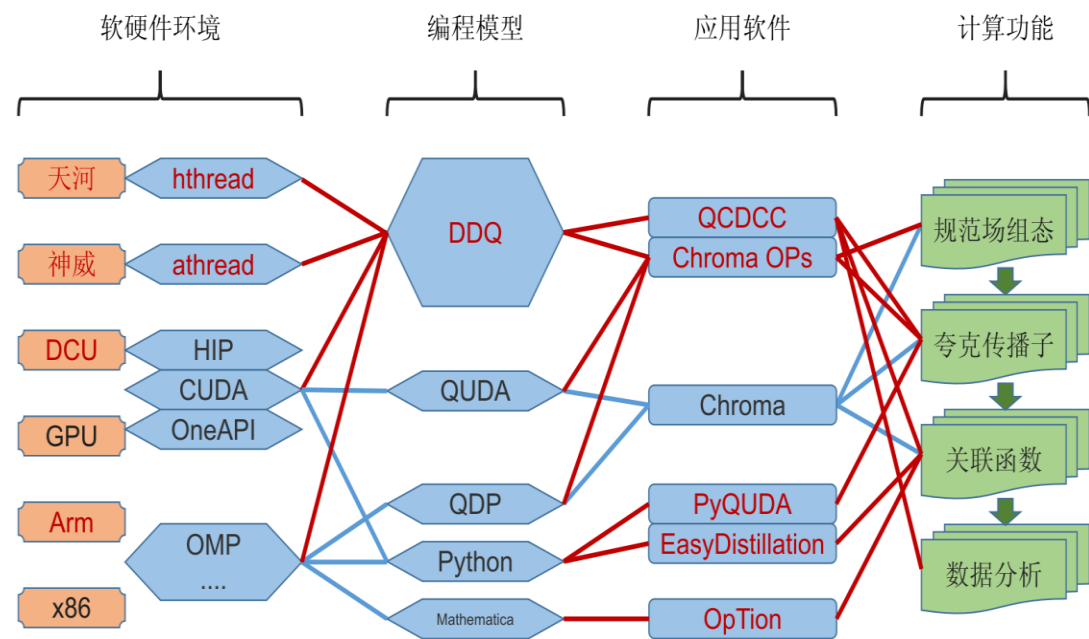
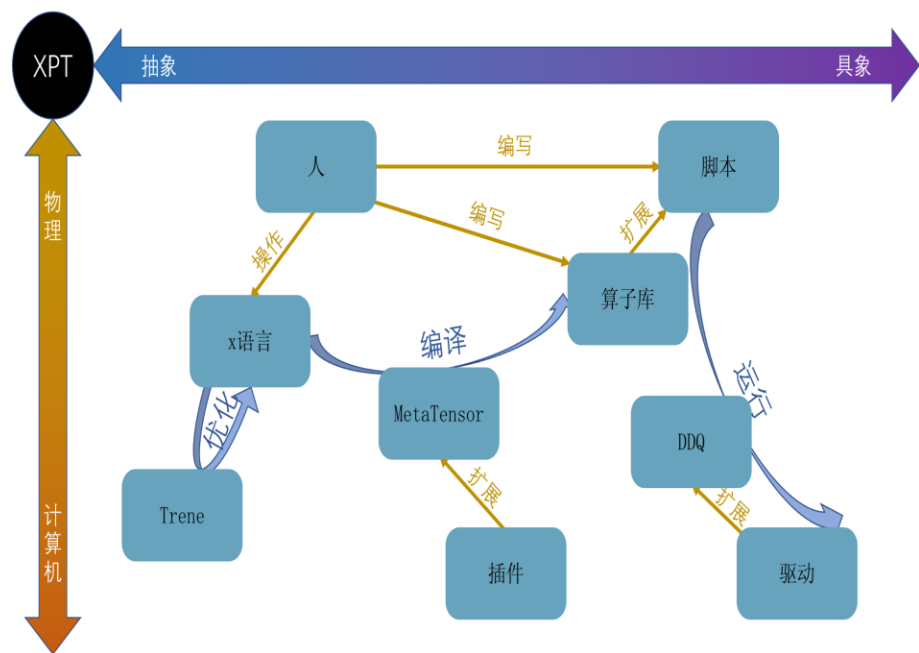
Qlotus Architecture



基于国产鲲鹏芯片开发的格点QCD模拟软件，已实现HISQ组态生成，
鲲鹏920F单处理器性能与A100相当，已实现跨平台多后端支持(x86, Arm)

To be released: 丁亨通, 李胜泰, 罗冉, 张克龙, <https://github.com/CCNU-LQCD/qlotus.git>

面向国产超算的新一代格点QCD软件框架——新平台 (XPT)



八、量子算法、量子模拟及张量网络

1. Particle Physics Driven by Quantum Technology - Quantum Simulations and Quantum Sensing, [arXiv:2609.20500](#)
2. Collider Detector Observables from Lattice Spin Systems, [arXiv:2609.17664](#)
3. Investigating Interacting Fermionic Models with Locality-Preserving Qubit Encodings, [arXiv:2609.16142](#)
4. Efficient Quantum Simulations of Yang-Mills theory with Maximal-tree Gauge, [arXiv:2608.27267](#)
5. Physics-informed quantum algorithms for glueball-like excitations in a $\mathbb{Z}_2$ lattice gauge theory, [arXiv:2608.25696](#)
6. Entanglement spectrum ordering and flavor polarization in the two-flavor Schwinger model at vacuum angle $\theta = \pi$, [arXiv:2608.14296](#)
7. Particle Production, Equilibration, and Quantum Recurrences from Classical Fields, [arXiv:2608.11316](#)
8. Hardware-efficient quantum simulation of intense-field QED, [arXiv:2607.09844](#)
9. Digital Quantum Simulation of Nonequilibrium Dynamics in the Schwinger Model under a Strong External Electric Field, [arXiv:2607.02894](#)
10. Quantum Simulation of Generalized Parton Distributions in the Schwinger Model, [arXiv:2606.22602](#)
11. Hadronic tensor in lattice gauge theories by quantum computing, [arXiv:2606.17003](#)
12. Exponentially improved quantum simulation of scalar QFT, [arXiv:2604.26226](#)
13. Quantum computing for effective nuclear lattice model, [arXiv:2604.13430](#)
14. Protecting Quantum Simulations of Lattice Gauge Theories through Engineered Emergent Hierarchical Symmetries, [arXiv:2604.11085](#)
15. Quantum simulation of baryon scattering in $SU(2)$ lattice gauge theory, [arXiv:2604.06716](#)
16.

总结与展望

1. 过去一年里，中国格点场论研究取得了丰硕成果。
2. AI 时代改变了科研范式，降低了格点研究的门槛，格点研究队伍迅速壮大。
3. 中国的格点研究如何应对AI时代，是值得思考的问题——
AI 的应用改变不了格点研究对算力的需求；
我们有了处于国际先进水平的格点基础数据（组态和传播子）；
在已有的理论框架下，AI应用显著提高研究效率；
如何突破现有理论和方法框架，在理论和方法上做出原创性的贡献（如LaMET）
4.

谢谢！