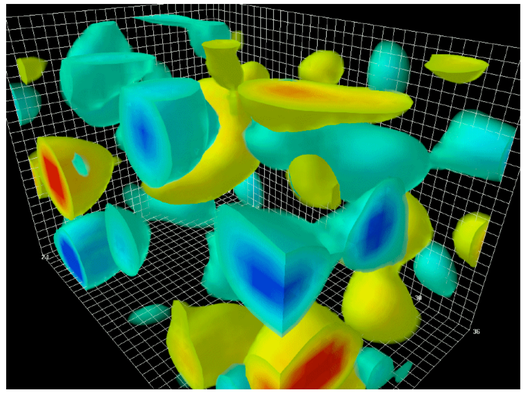
NuclearScience
Computing CenteratCCNU

New developments in Lattice QCD



Heng-Tong Ding (丁亨通)
Central China Normal University (华中师范大学)

中国物理学会高能物理分会第十一届全国会员代表大会暨学术年会

大连，辽宁师范大学, 2022.8.8-11

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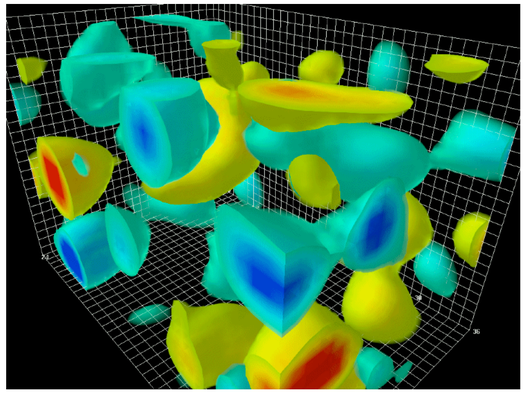

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Lattice QCD talks in this conference

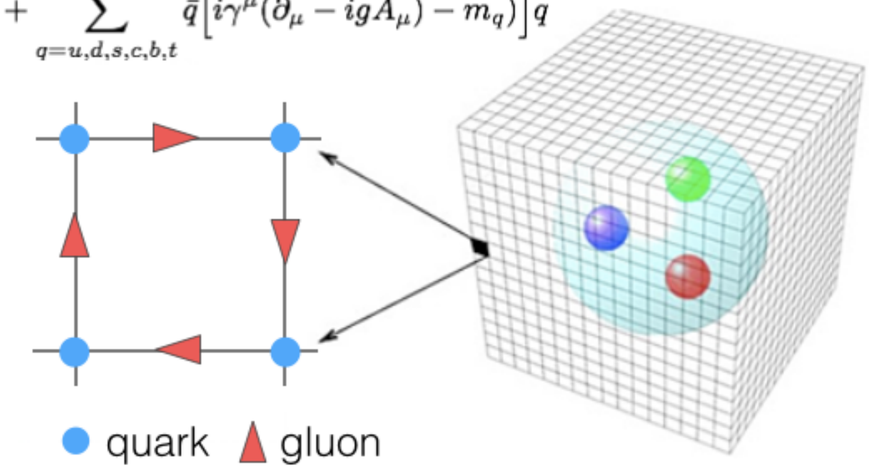
1. 孟　雨 [Aug. 9, 15:45] Lattice calculation of the $\eta_c\eta_c$ and $J/\psi J/\psi$ scattering length
2. 刘俊宏 [Aug. 10, 11:15] Fluctuations of conserved charges in strong magnetic fields
3. 傅　杨 [Aug 10 , 14:20], LQCD computation of two-photon exchange contribution to the muonic-hydrogen Lamb shift
4. 李胜泰 [Aug. 10, 15:35] Chiral condensates and screening masses of neutral pseudoscalar mesons
5. 黄玮平 [Aug. 10, 15:50] Criticality of QCD in correlated Dirac eigenvalues
6. 杨一玻 [Aug. 10, 16:40] Lattice QCD using Large momentum effective theory
7. 华　俊 [Aug. 10, 17:00] Pion and Kaon Distribution Amplitudes from Lattice QCD
8. 王选贺 [Aug. 10, 19:30] 质子电极化率的格点 QCD 计算
9. 马鹏翔 [Aug. 10, 19:36] 格点QCD在介子衰变辐射修正中的应用
10. 王子毓 [Aug. 10, 19:42] 双重子系统双 beta 衰变的格点计算
11. 脱心宇 [Aug. 11, 14:00] 格点计算稀有 K 介子衰变的新方案
12. 施　岐 [Aug. 11, 14:15] Lattice QCD prediction of kaon electromagnetic form factor at large Q^2 up to 10 GeV^2

Supercomputing the QCD matter based on first principles

Snowmass 2022: Theory & computational frontiers

QCD Lagrangian

$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \sum_{q=u,d,s,c,b,t} \bar{q}\left[i\gamma^{\mu}(\partial_{\mu} - igA_{\mu}) - m_q\right]q$$



Discretization in Euclidean space

quarks: lattice sites
gluons: lattice links

$$< \mathcal{O} >= \frac{1}{Z}\int \mathcal{D}U\ \mathcal{D}\psi\ \mathcal{D}\bar{\psi}\ \mathcal{O}\ e^{-S_{lat}}$$

$$S_{lat} = S_g + S_f$$

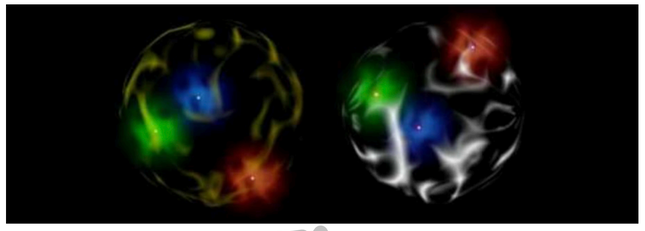
$$Z = \int \mathcal{D}U\ \mathcal{D}\psi\ \mathcal{D}\bar{\psi}\ e^{-S_{lat}} = \int \mathcal{D}U\ e^{-S_g}\ \det M_f$$

Physics from μeV to TeV

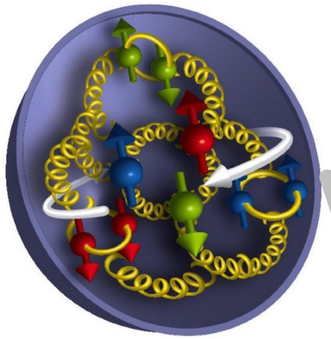
Hadron spectroscopy & interactions

EIC,
EicC,
Jlab,
…

BESIII,
LHC,
…

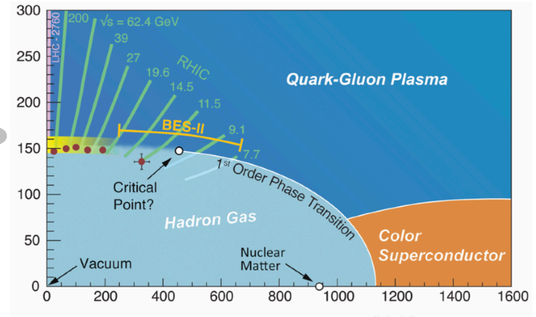


Hadron structure



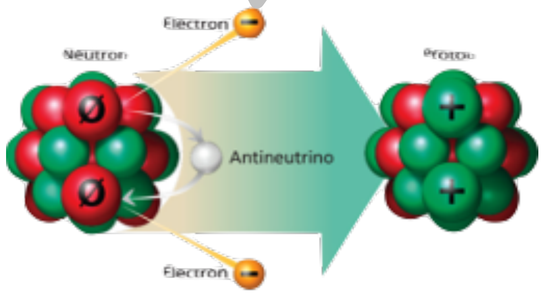
Softwares &
gauge production

Hot & dense QCD



RHIC, LHC
CEE, CBM,NICA
…

BESIII, Belle2,
CJPL, FNAL, LHC,
…

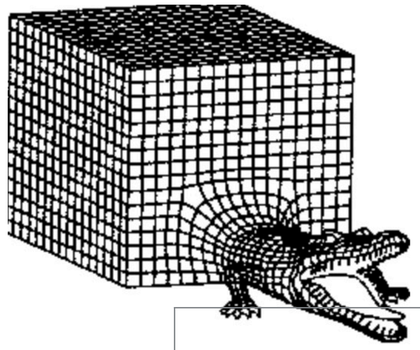


Standard Model parameters

CLQCD

China Lattice QCD
(CLQCD)
collaboration

北大，北航，北师大，
湖南师大，华南师大，
华中师大，江苏大学，
南开大学，上海交大，
四川大学，西安工大，
浙江大学，郑州大学，
中科院大学/高能所/
近物所/理论所…



Discretization schemes

Discretization schemes	Chiral symmetry	Cost	Collaborations
Wilson fermions	Explicitly broken	OK	CLQCD, ETMC, HALQCD, FlowQCD, PACS,...
Improved Staggered fermions	Partially reserved	Cheap	MILC, HotQCD, CLQCD, NPQCD, BMW,...
Domain Wall fermions	Almost reserved	Expensive	JLQCD, RBRC, UKQCD, TWQCD,...
Overlap fermions	Exactly reserved	Very expensive	chiQCD, Bielefeld-Chenai,...

To recover QCD, thermodynamic and continuum limits are required!

Ensemble generation in CLQCD

Zero temperature, Wilson-clover fermions, IHEP-IMP-ITP-SCNU

name	Volume	Lattice spacing	beta	Pion mass	Eta_s mass	L x M_pion	L	conf
C11P29S	24^3x72	0.105fm	6.20	290MeV	640MeV	3.8	2.6fm	900
C11P29M	32^3x64	0.105fm	6.20	290MeV	640MeV	5.0	3.5fm	700
C11P22M	32^3x64	0.105fm	6.20	220MeV	640MeV	3.9	3.5fm	450
C11P22L	48^3x96	0.105fm	6.20	220MeV	640MeV	5.6	5.4fm	400
C11P14L	48^3x96	0.105fm	6.20	135MeV	700MeV	3.4	5.4fm	60
C08P30S	32^3x96	0.08fm	6.41	300MeV	650MeV	3.9	2.6fm	500
C08P30M	48^3x96	0.08fm	6.41	300MeV	650MeV	5.0	3.8fm	400
C08P21S	32^3x64	0.08fm	6.41	210MeV	650MeV	4.1	2.6fm	460
C08P21M	48^3x96	0.08fm	6.41	210MeV	650MeV	4.1	3.8fm	450
C06P30S	48^3x144	0.054fm	6.72	300MeV	650MeV	4.0	2.6fm	300

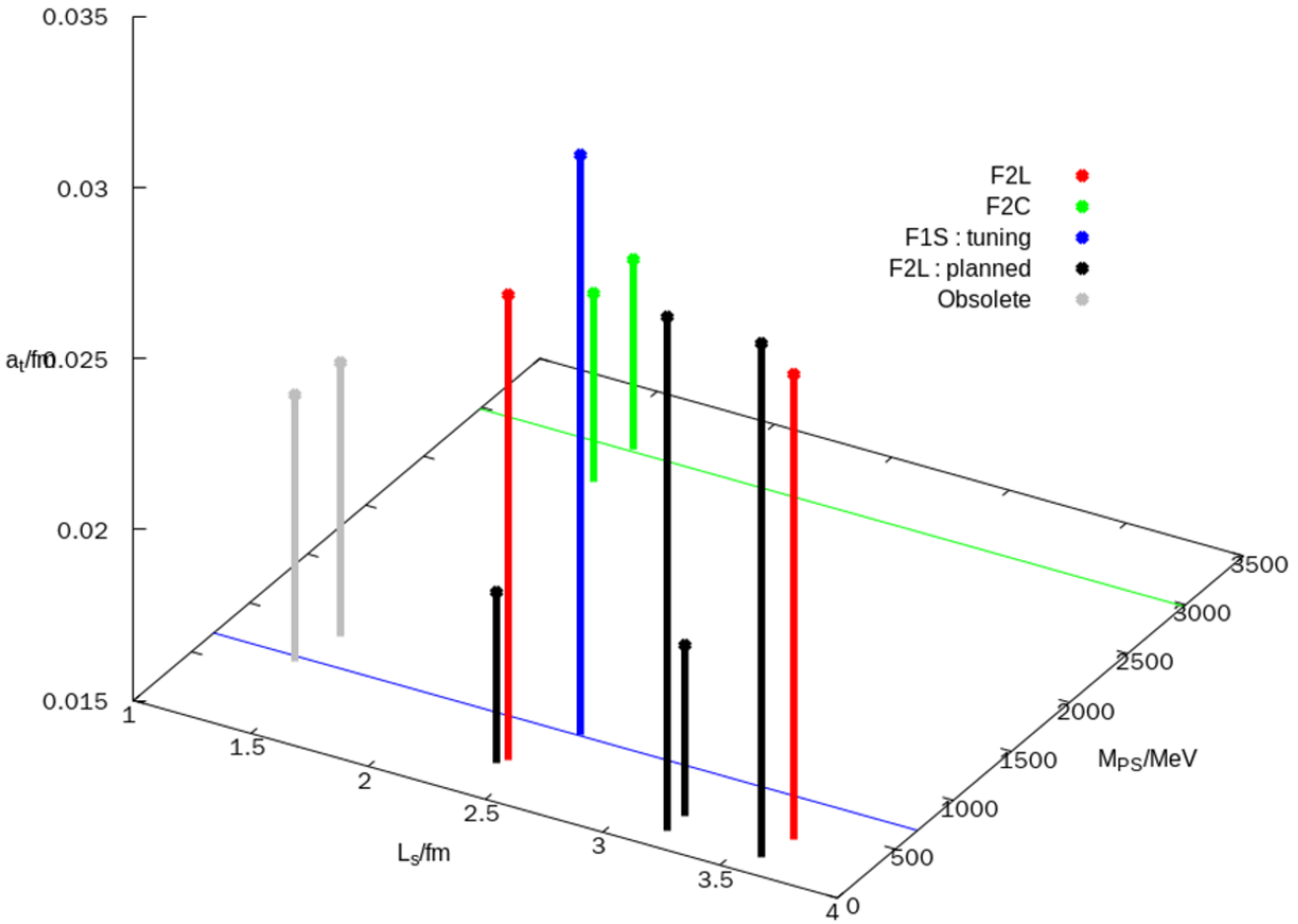
张其安 et al., Chin.Phys.C 46 (2022)011002, 刘柳明 et al., arXiv: 2207.00183，杨一玻 et al., arXiv:2207.14132

Ensemble generation in CLQCD

Zero temperature,
anisotropic Wilson-clover fermions, IHEP

CLQCD

Charmed hadrons, glueballs
and exotic particles



陈莹 et al., arXiv:2207.04694, 2206.02724,
arXiv:2206.06185, 2205.12541 [hep-lat],
Chin. Phys. C46 (2022) 043102 ,
Phys. Lett. B 827 (2022) 136960,
Chin. Phys. C42 (2018) 093103
.. …

Ensemble generation in CLQCD

Nonzero & zero temperature, HISQ fermions, CCNU

Nonzero magnetic field ensembles

N_b	eB [GeV^2]	N_b	eB [GeV^2]	$N_\sigma^3 \times N_\tau$	T [MeV]	# conf.
0	0	16	0.836	$32^3\times6$	280.9	$\mathcal{O}(4000)$
1	0.052	20	1.045	$32^3\times8$	210.8	$\mathcal{O}(5000)$
2	0.104	24	1.255	$32^3\times10$	168.5	$\mathcal{O}(5000)$
3	0.157	32	1.673	$32^3\times12$	140.4	$\mathcal{O}(5000)$
4	0.209	40	2.09	$32^3\times14$	120.4	$\mathcal{O}(5000)$
6	0.314	48	2.510	$32^3\times16$	105.3	$\mathcal{O}(6000)$
8	0.418	-	-	$32^3\times18$	93.6	$\mathcal{O}(6000)$
10	0.523	-	-	$32^3\times24$	70.2	$\mathcal{O}(1000)$
12	0.627	-	-	$32^3\times96$	17.6	$\mathcal{O}(3000)$

丁亨通 et al., Phys.Rev.D 105 (2022) 034514

Phys.Rev.Lett. 126 (2021) 082001,

Phys.Rev.D 104 (2021) 014505,

Eur.Phys.J.A 57 (2021) 202,

Phys.Rev.D 102 (2020) 5, 054505,

Phys.Rev. Lett. 123 (2019) 062002,

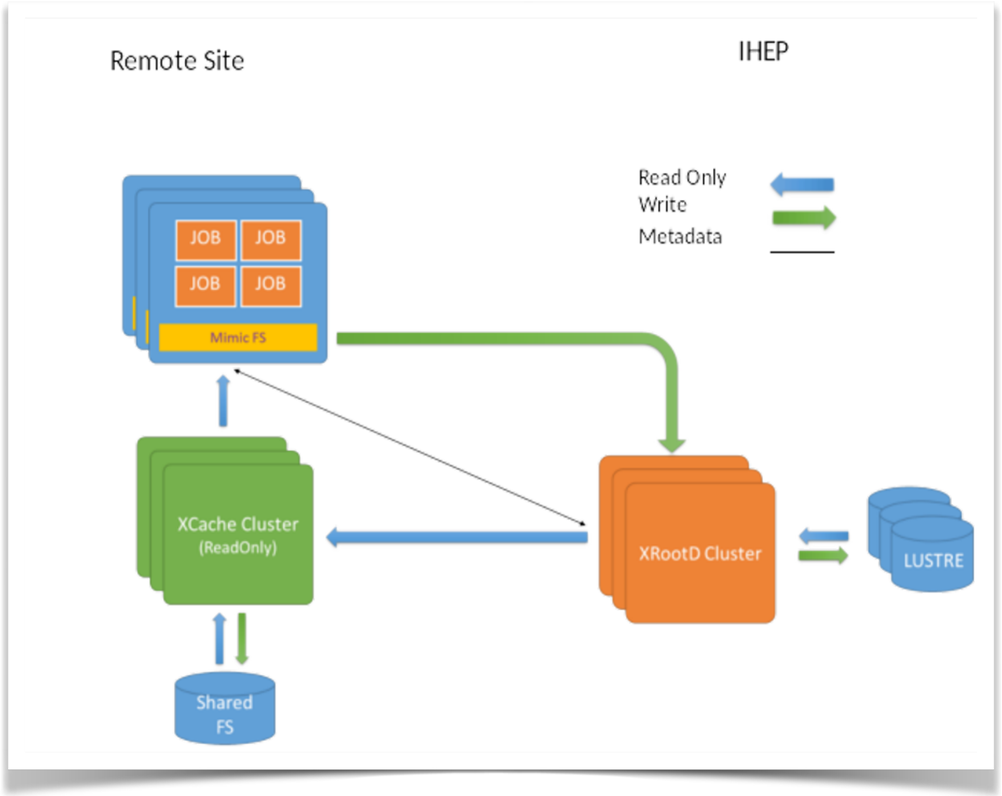
… …

Small quark mass ensembles

β	am_s	am_l	m_π[MeV]	$N_\sigma^3 \times N_\tau$	#conf
6.664	0.0514	0.002570	160	$32^3 \times 8$	4054
		0.001904	140	$32^3 \times 8$	6707
		0.001285	110	$40^3 \times 8$	5625
		0.0006425	80	$32^3 \times 8$	3842
		0.0006425	80	$40^3 \times 8$	11863
		0.0006425	80	$56^3 \times 8$	7341
		0.0006425	80	$72^3 \times 8$	5954
		0.00032125	55	$56^3 \times 8$	8473
7.078	0.034	0.00170	160	$48^3 \times 12$	8507
		0.001259	140	$48^3 \times 12$	6575
		0.000850	110	$60^3 \times 12$	5314
		0.000425	80	$48^3 \times 12$	9021
		0.000425	80	$60^3 \times 12$	6746
		0.000425	80	$72^3 \times 12$	2365
7.356	0.026	0.0013	160	$64^3 \times 16$	3227
		0.000963	140	$64^3 \times 16$	3639
		0.000650	110	$64^3 \times 16$	3498
		0.000325	80	$64^3 \times 16$	4092
		0.000325	80	$80^3 \times 16$	5316

… …

Lattice QCD data sharing within CLQCD and beyond



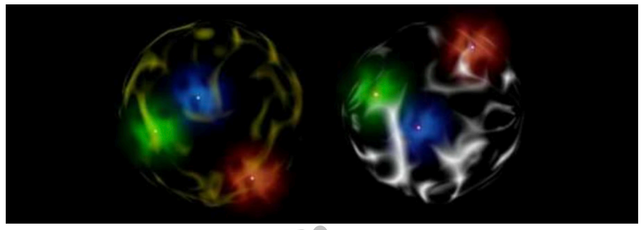
LATTICE 2022

Aug. 8-13
2022
Bonn

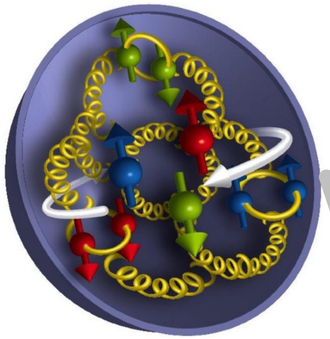
孙鹏, 宫明, 刘柳明, 杨一玻,丁亨通, [CLQCD], Lattice 2022 talk

https://indico.hiskp.uni-bonn.de/event/40/contributions/853/

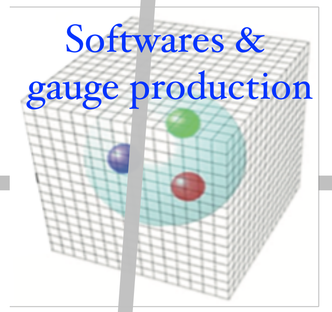
Hadron spectroscopy & interactions



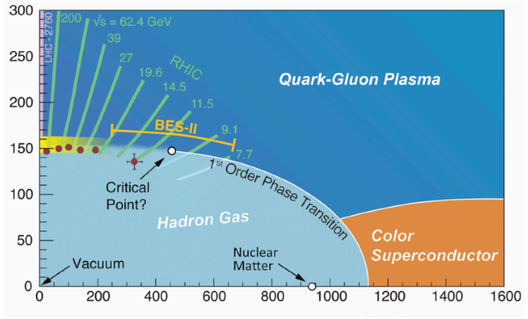
Hadron structure

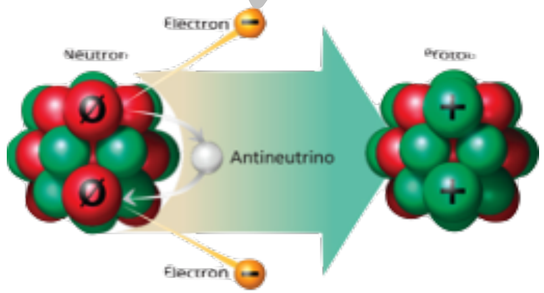


Softwares & gauge production



Hot & dense QCD





Standard Model parameters

- 孟　雨 [Aug. 9, 15:45]
  Lattice calculation of the $\eta_c\eta_c$ and $J/\psi J/\psi$ scattering length
- …

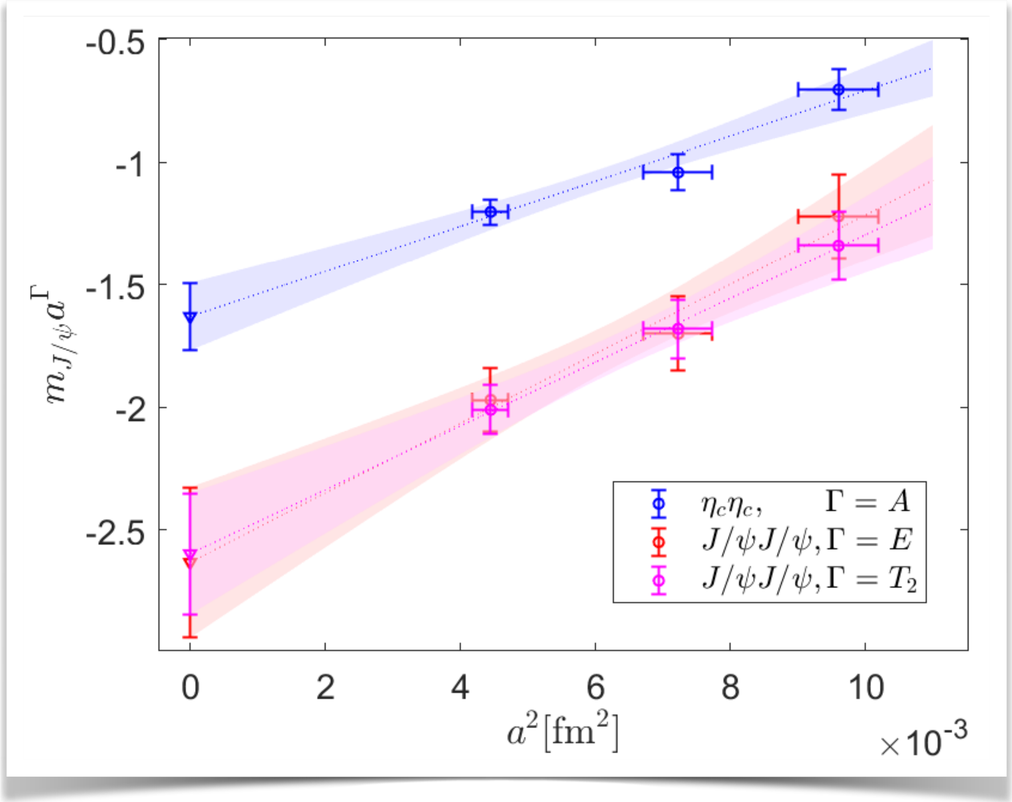
Lattice calculation of the $\eta_c\eta_c$ and $J/\psi J/\psi$ scattering length

孟雨
Tue Aug. 9
15:45-16:00

LHCb, CMS & ATLAS: Narrow structures in $J/\psi J/\psi$ invariant mass spectrum

Interpretations vary from model studies

Lüscher method: $\delta E = -\frac{4\pi a^\Gamma}{mL^3}\left[1 + c_1\frac{a^\Gamma}{L} + c_2\left(\frac{a^\Gamma}{L}\right)^2 + \mathcal{O}(L^{-3})\right]$



- S-wave scattering length

$$a^{0^+}_{\eta_c\eta_c} = -0.104(09)\ \mathrm{fm}$$
$$a^{2^+}_{J/\psi J/\psi} = -0.165(16)\ \mathrm{fm}$$

- Weak repulsive interaction

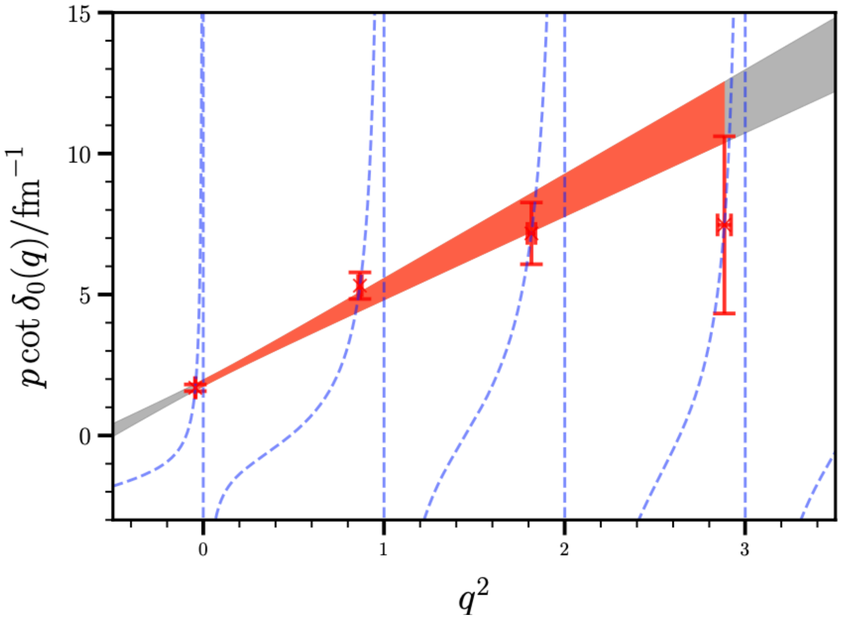
孟雨 et al., work in preparation

$T_{cc}^{+}(3875)$ relevant S-wave DD^* scattering from $N_f = 2$ LQCD

S. Chen et al., IHEP, arXiv:2206.06185

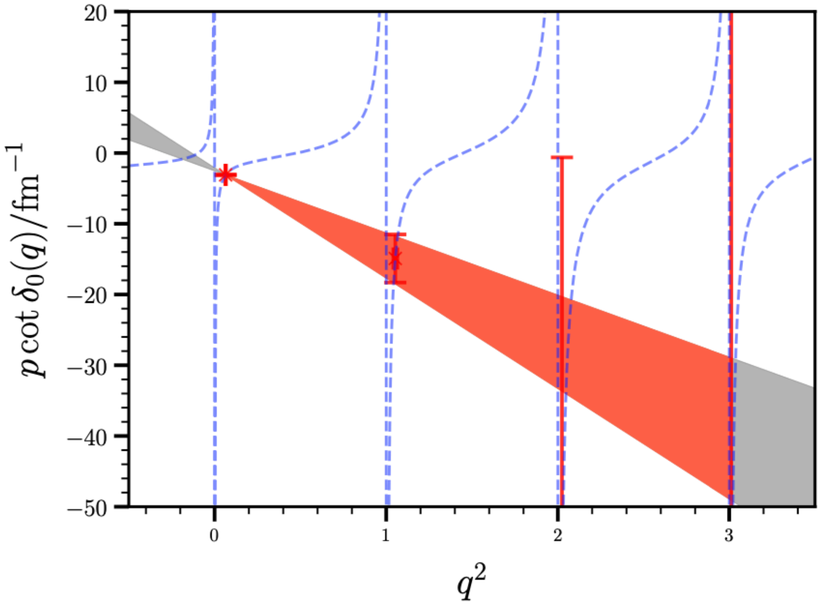
$$I = 0: \quad |DD^*\rangle = \frac{1}{\sqrt{2}}\left(|D^0 D^{*+}\rangle - |D^+ D^{*0}\rangle\right)$$

$$I = 1: \quad |DD^*\rangle = \frac{1}{\sqrt{2}}\left(|D^0 D^{*+}\rangle + |D^+ D^{*0}\rangle\right)$$



$a_0^{(I=0)} = 0.538(33)$ fm, $\quad r_0^{(I=0)} = 0.99(11)$ fm.

Attractive interaction with scattering in a wide momentum range



$a_0^{(I=1)} = -0.433(43)$ fm, $\quad r_0^{(I=1)} = -3.6(1.0)$ fm.

Repulsive interaction near the DD^* threshold

Conceptually in agreement: $T_{cc}^{+}(3875)$ only found in $D^0 D^{*+}$ system

Hidden-charm Hexaquarks ($uscd\bar{s}\bar{c}$)

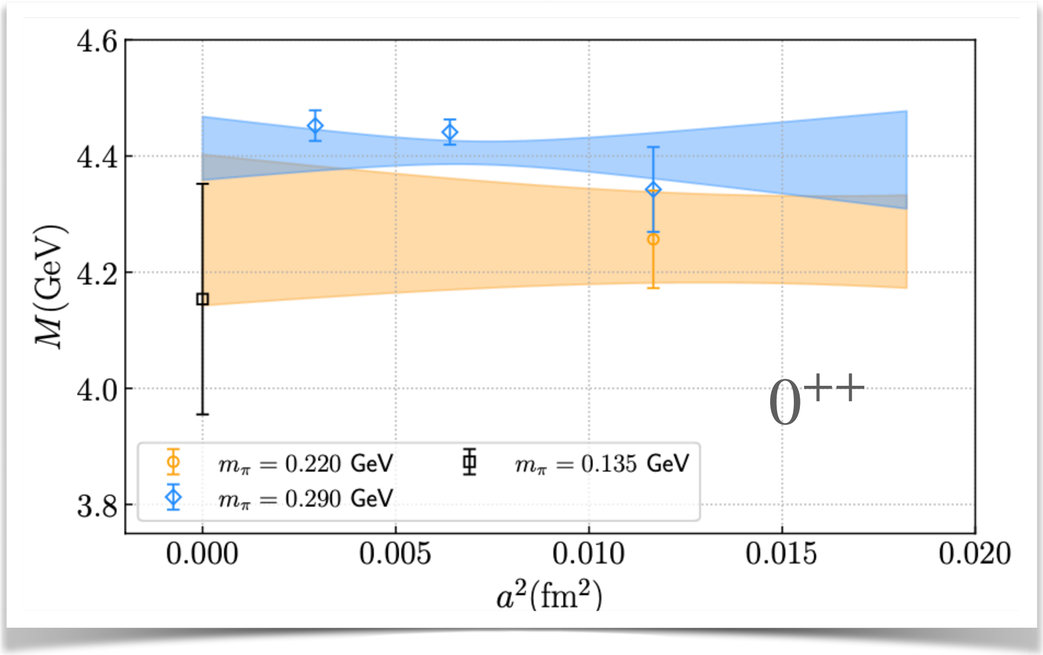
$$J^{PC} = 0^{++},\ 0^{-+},\ 1^{++}\ \&\ 1^{--}$$

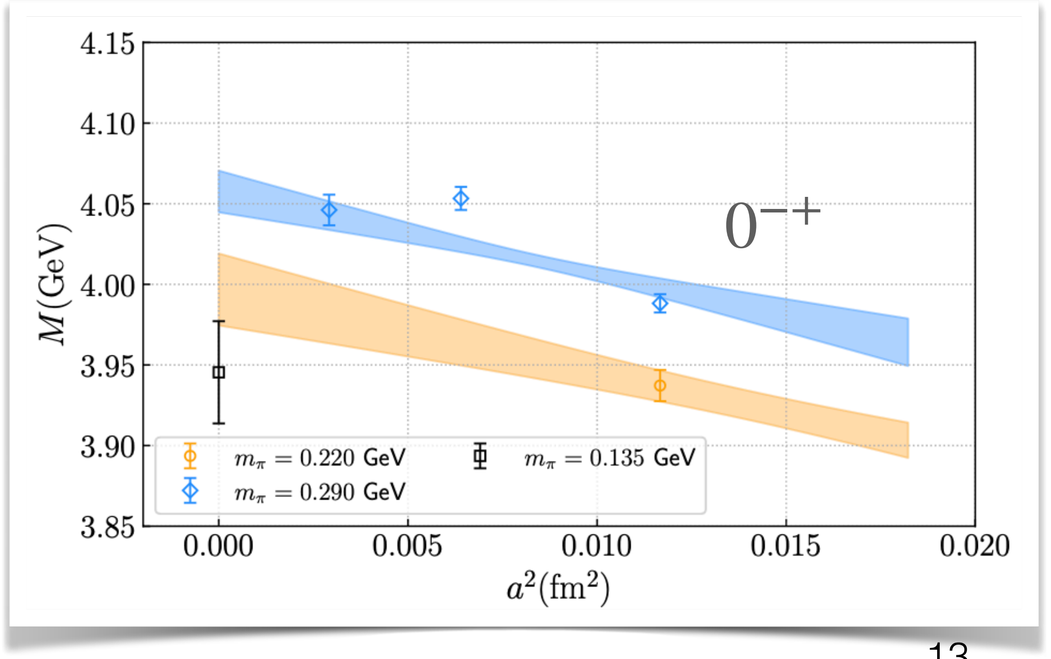
$$0^{++} : \mathcal{O}_1 = \epsilon^{abc}\epsilon^{def}[u_a^T C\gamma_5 s_b][\bar{d}_d C\gamma_5 \bar{s}_e^T] \times [\bar{c}_f c_c]$$
$$0^{-+} : \mathcal{O}_2 = \epsilon^{abc}\epsilon^{def}[u_a^T C\gamma_5 s_b][\bar{c}_d C\gamma_5 \bar{s}_e^T] \times [\bar{c}_f \gamma_5 c_c]$$
$$1^{++} : \mathcal{O}_3 = \epsilon^{abc}\epsilon^{def}[u_a^T C\gamma_5 s_b][\bar{d}_d C\gamma_5 \bar{s}_e^T] \times [\bar{c}_f \gamma_i\gamma_5 q_c]$$
$$1^{--} : \mathcal{O}_4 = \epsilon^{abc}\epsilon^{def}[u_a^T C\gamma_5 s_b][\bar{d}_d C\gamma_5 \bar{s}_e^T] \times [\bar{c}_f \gamma_i c_c]$$

$I(J^{PC})$	$1(0^{-+})$	$1(1^{--})$	$1(0^{++})$	$1(1^{++})$
mass(GeV)	3.945(32)	4.144(35)	4.15(20)	4.22(23)

All below $\Xi_c\bar{\Xi}_c$ threshold
the lightest one around $\eta_c K^+K^-$ threshold

H. Liu et al., SJTU-IMP-ITP-BUAA, arXiv: 2207.00183





Charmed and ϕ meson decay constants in N_f=2+1 LQCD

Domain wall fermions with physical pion mass

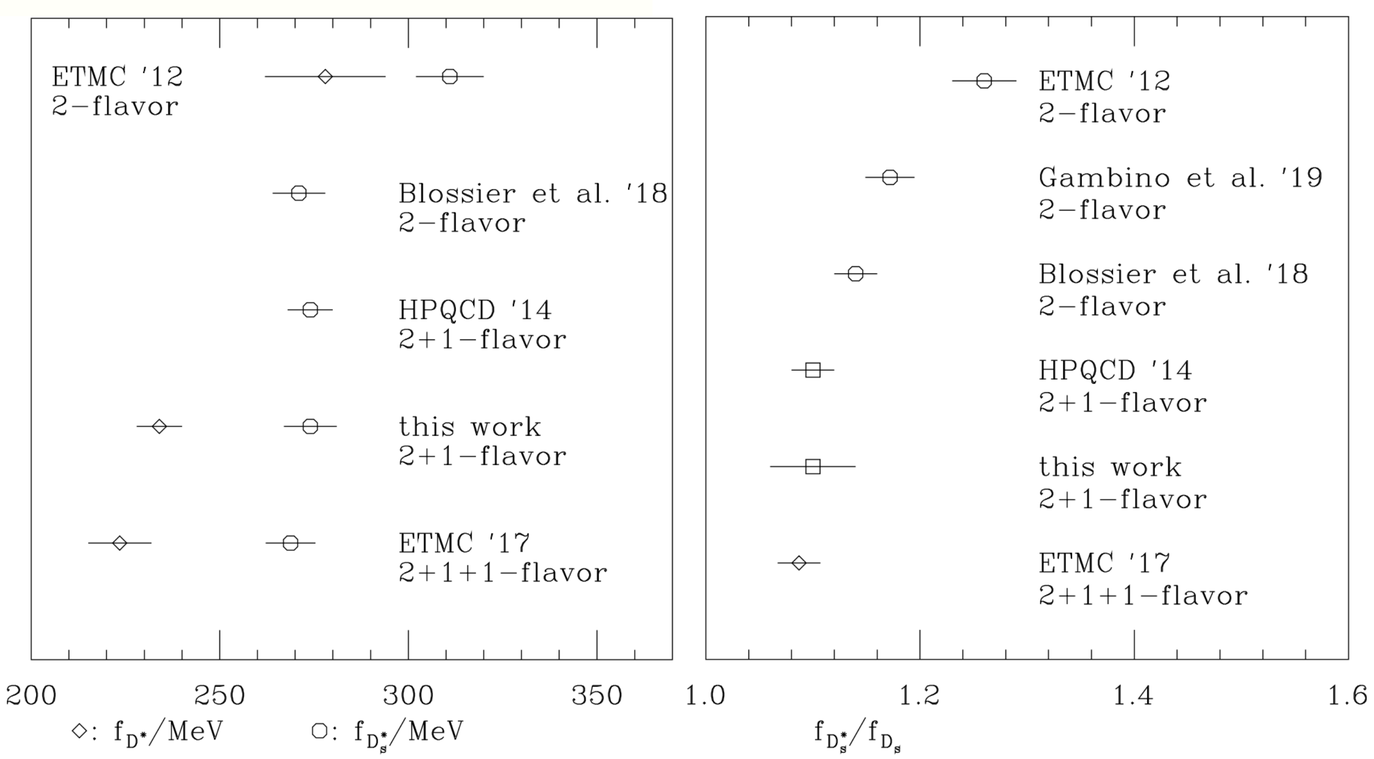


Table 9. Decay constants of $D_{(s)}^{(*)}$ and ϕ in units of MeV. f_V^T/f_V is given in the $\overline{\text{MS}}$ scheme at the scale of 2 GeV.

	D_s	D_s^*	D	D^*	ϕ
$f_{P/V}$/MeV	249(7)	274(7)	213(5)	234(6)	241(9)
f_V^T/f_V	–	0.92(4)	–	0.91(4)	–

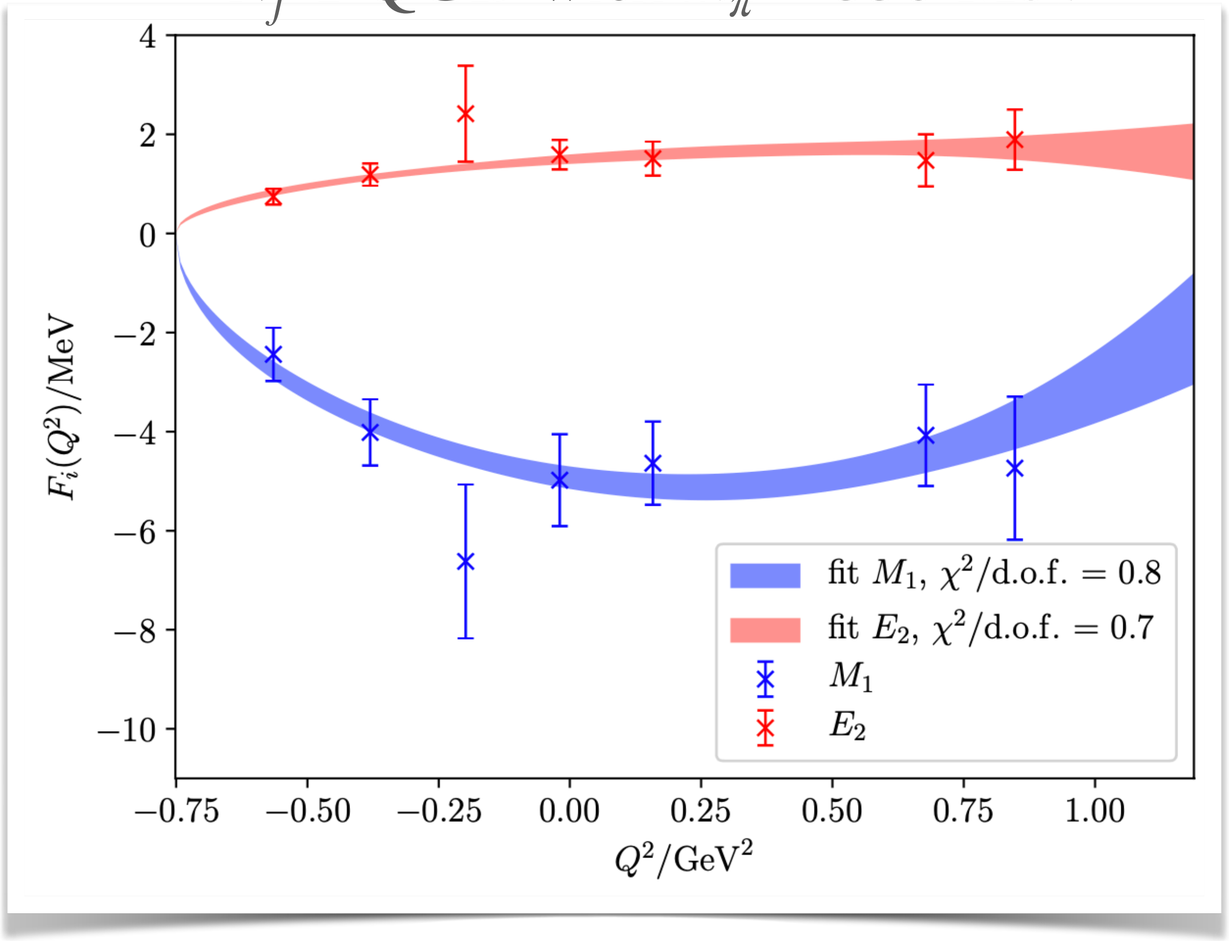
A first computation of couplings of D^* and D_s^* to the tensor current f_V^T

陈莹, 邱伟峰, 宫明, 刘朝峰 &马运恒, IHEP, [χQCD], Chin. Phys. C 45(2021)023109

1^{-+} Hybrid in J/ψ radiative decays

Nature of $\eta_1(1855)$?

N_f=2 QCD with $m_\pi \approx 350$ MeV



$$\Gamma(J/\psi \to \gamma\eta_1) = \frac{4\alpha}{27}\frac{|\vec{p}_\gamma|}{m^2_{J/\psi}}\left(|M_1(0)|^2 + |E_2(0)|^2\right)$$

$\Gamma(J/\psi \to \gamma\eta_1)$ = **2.29(77)eV**

Consider $\eta_1(1855)$ is an 1^{-+} hybrid

Br$(J/\psi \to \gamma\eta_1(1855))$=$6.2(2.2) \times 10^{-5}$

Br$(\eta_1(1855) \to \eta\eta') \sim 4.3\,\%$

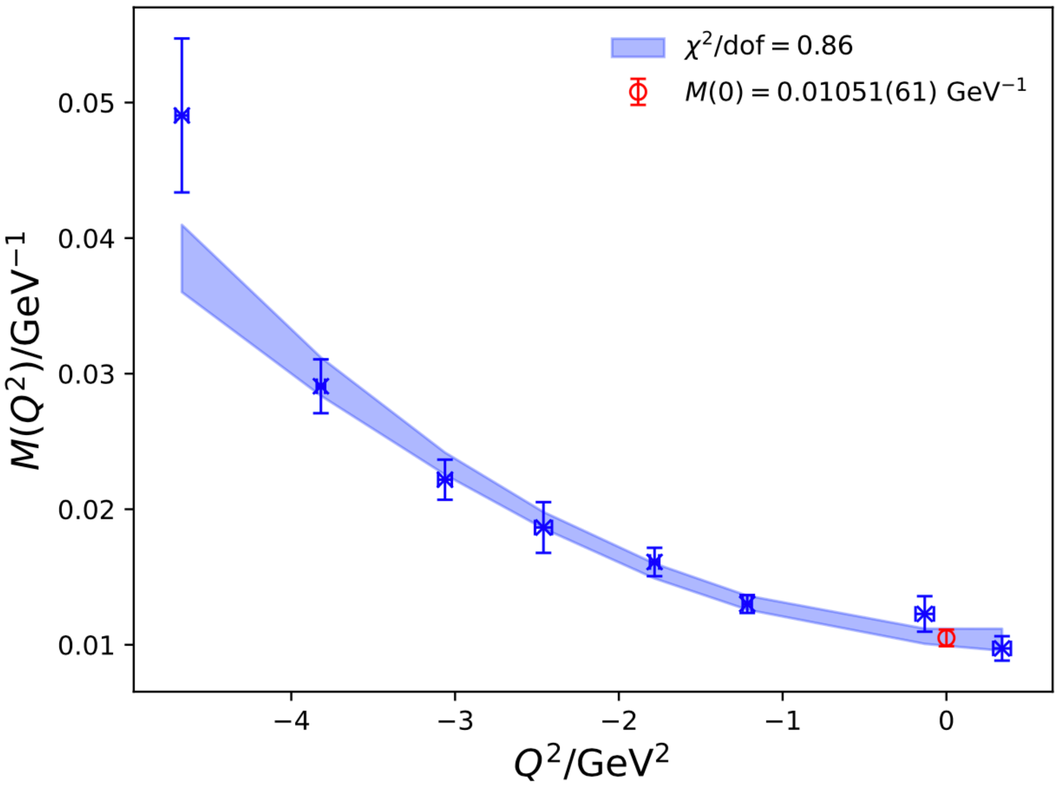
F. Chen et al., IHEP, arXiv:2207.04694

A first LQCD computation on radiative decay width of $J/\psi \to \gamma\eta$

Effect of axial U1 anomaly

X. Jiang et al., IHEP, arXiv:2206.02724

$$\Gamma(J/\psi \to \gamma\eta) = \frac{4\alpha}{27}|\vec{q}_\gamma|^3 M^2(0)$$



- $N_f = 2$ QCD with $m_\pi \approx 350$ MeV

$$\Gamma(J/\psi \to \gamma\eta) = 0.385(45) \ \text{keV}$$
$$\text{Br}(J/\psi \to \gamma\eta) = 4.16(49) \times 10^{-3}$$

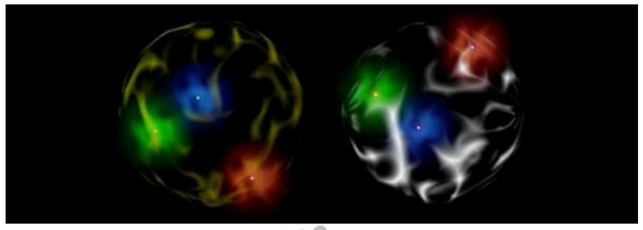
- Extrapolating to $N_f = 3$ considering $\eta - \eta'$ mixing

$$\text{Br}(J/\psi \to \gamma\eta) = 1.15(14) \times 10^{-3}$$
$$\text{Br}(J/\psi \to \gamma\eta') = 4.49(53) \times 10^{-3}$$

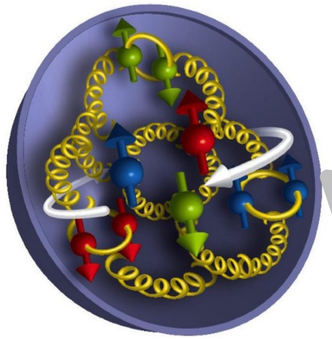
In good agreement with PDG 2020 values

$\text{Br}(J/\psi \to \gamma\eta) = 1.11(3) \times 10^{-3}$, $\text{Br}(J/\psi \to \gamma\eta') = 5.25(7) \times 10^{-3}$

Hadron spectroscopy & interactions

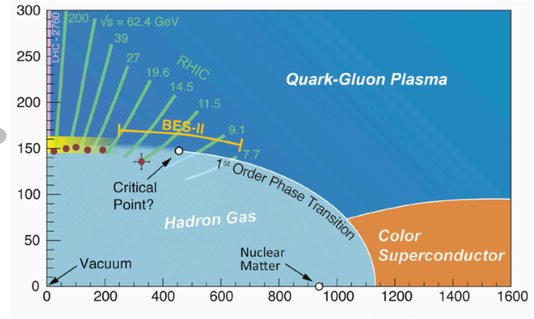


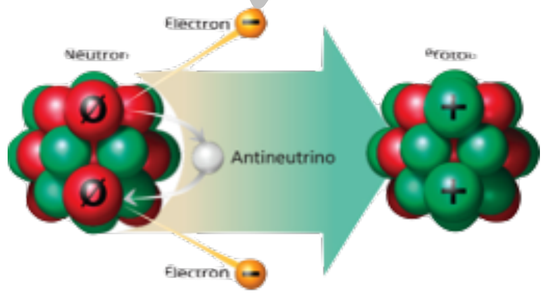
Hadron structure



Softwares & gauge production

Hot & dense QCD



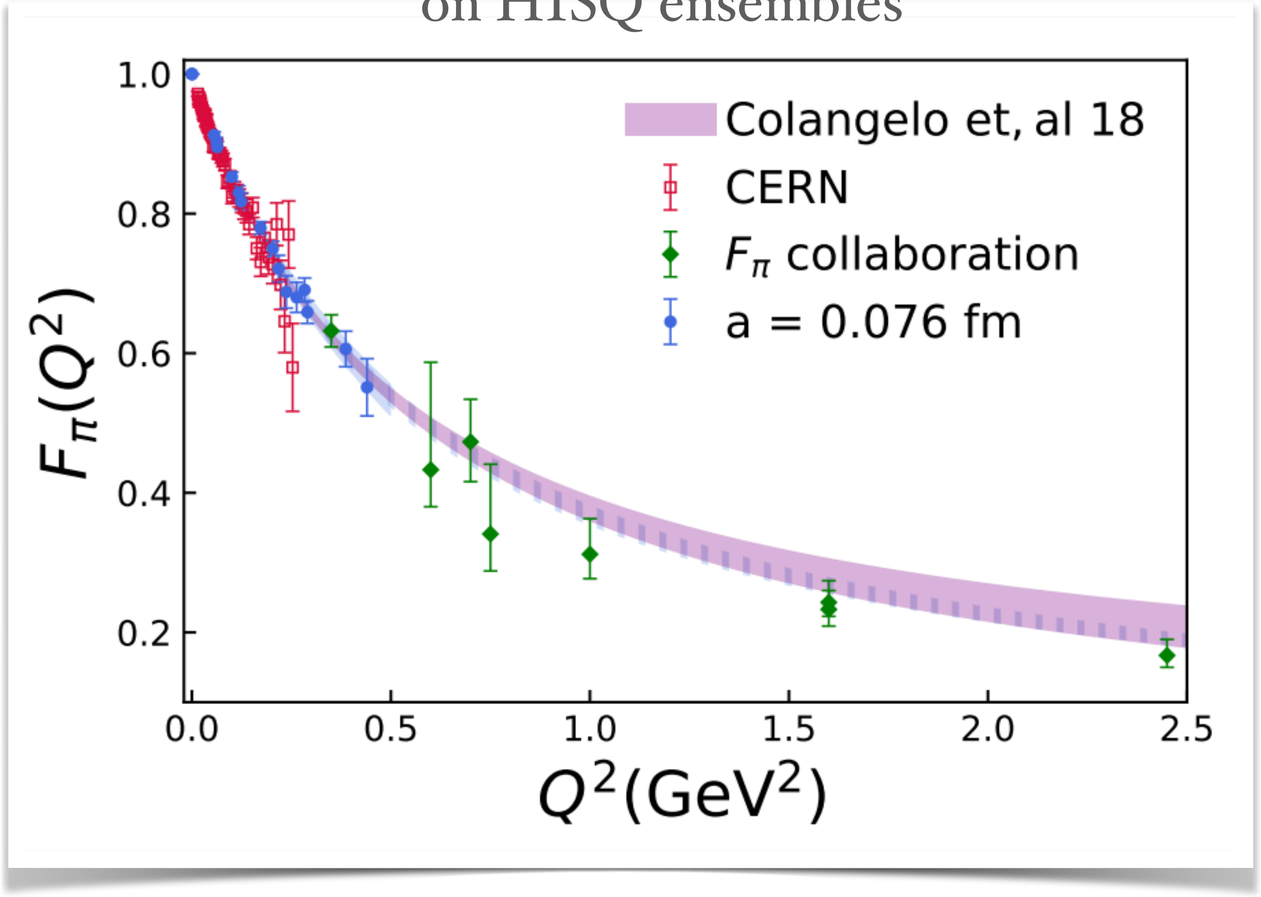


Standard Model parameters

- 杨一玻 [Aug. 10, 16:40]
  Lattice QCD using Large momentum effective theory
- 华　俊 [Aug. 10, 17:00]
  Pion and Kaon Distribution Amplitudes from Lattice QCD
- 施　岐 [Aug. 11, 14:15]
  Lattice QCD prediction of kaon electromagnetic form factor at large Q^2 up to 10 GeV^2
- …

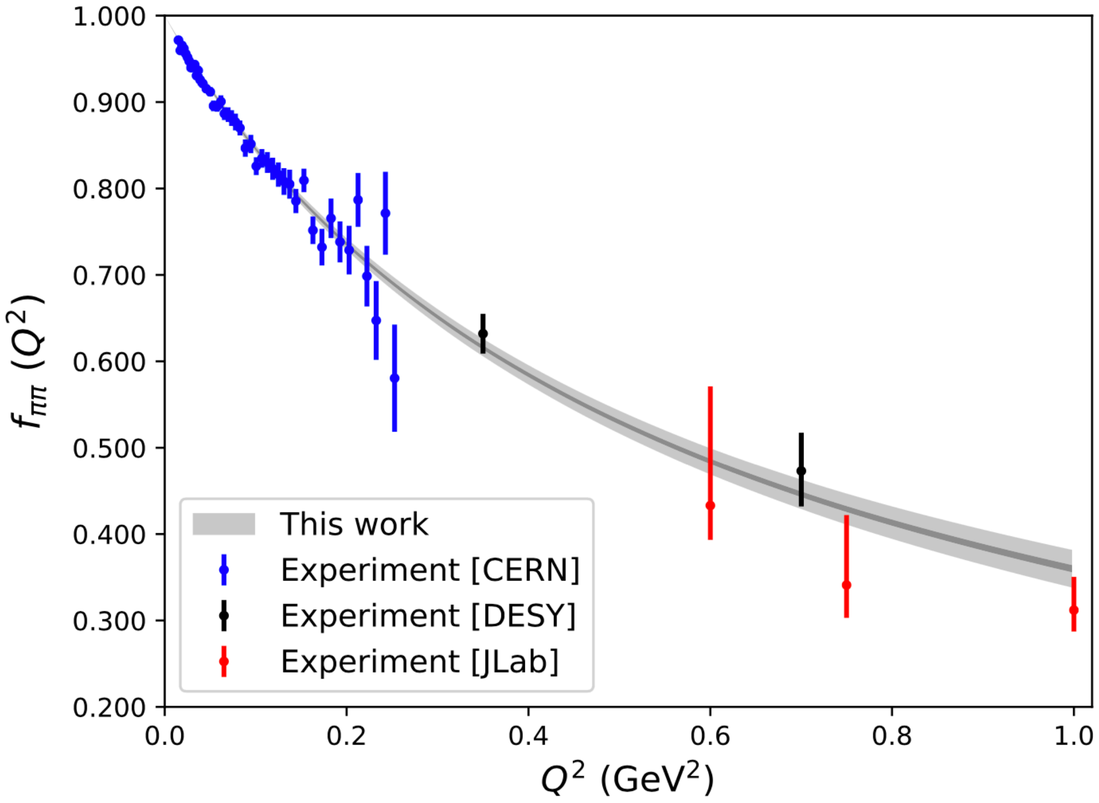
Pion electromagnetic form factor

Wilson-Clover fermion
on HISQ ensembles



高翔 et al., Tsinghua-BNL-ANL,
Phys. Rev. D 104 (2021) 114515

Overlap fermions
on Domain Wall ensembles

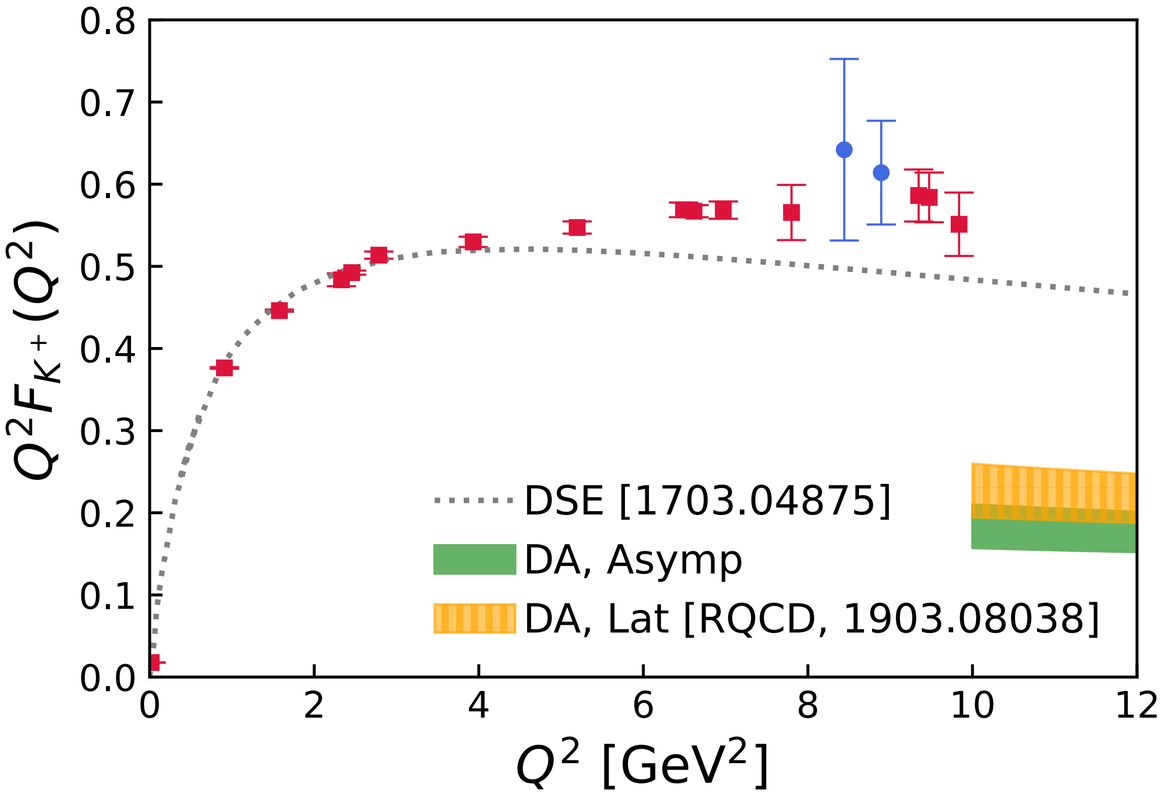


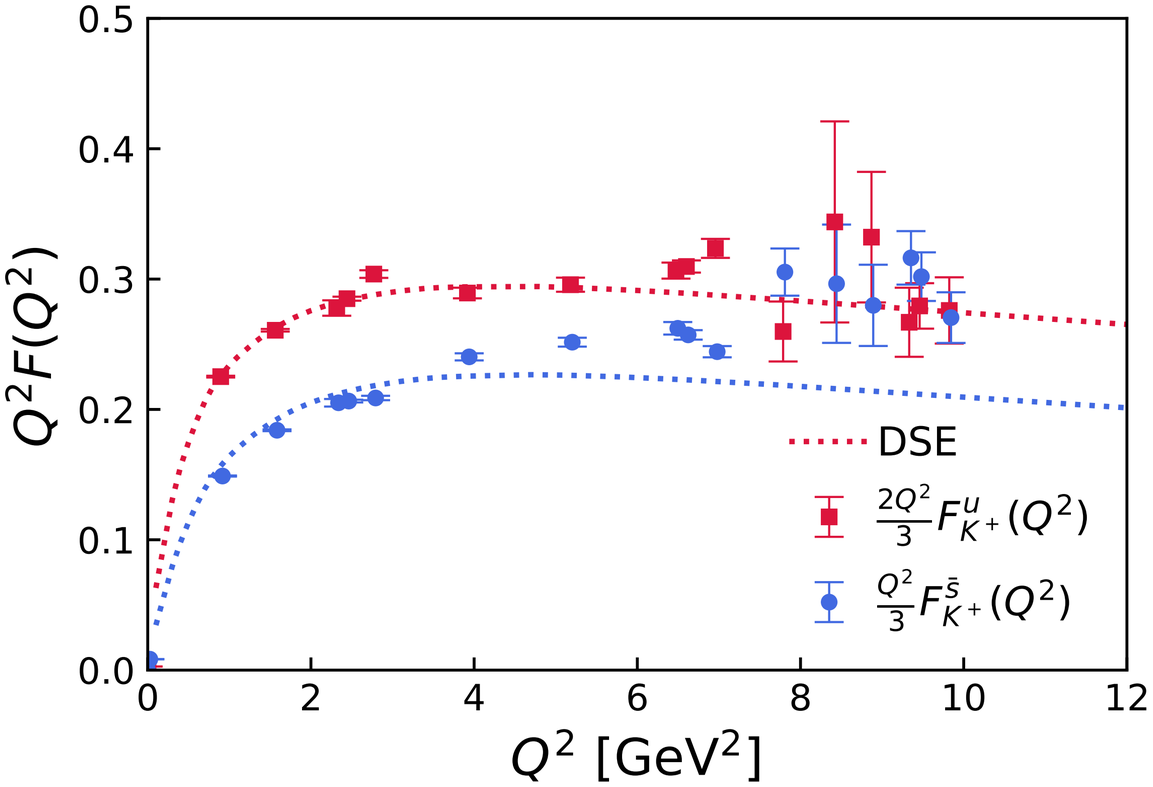
王根 et al.,Kentucky-SCNU-ITP, [χQCD],
Phys. Rev. D 104 (2021) 074502

LQCD prediction of Kaon electromagnetic form factor at $Q^2 \lesssim 10$ GeV^2

HISQ ensembles with a=0.076 fm

施岐
Thu Aug. 11
14:15-14:30



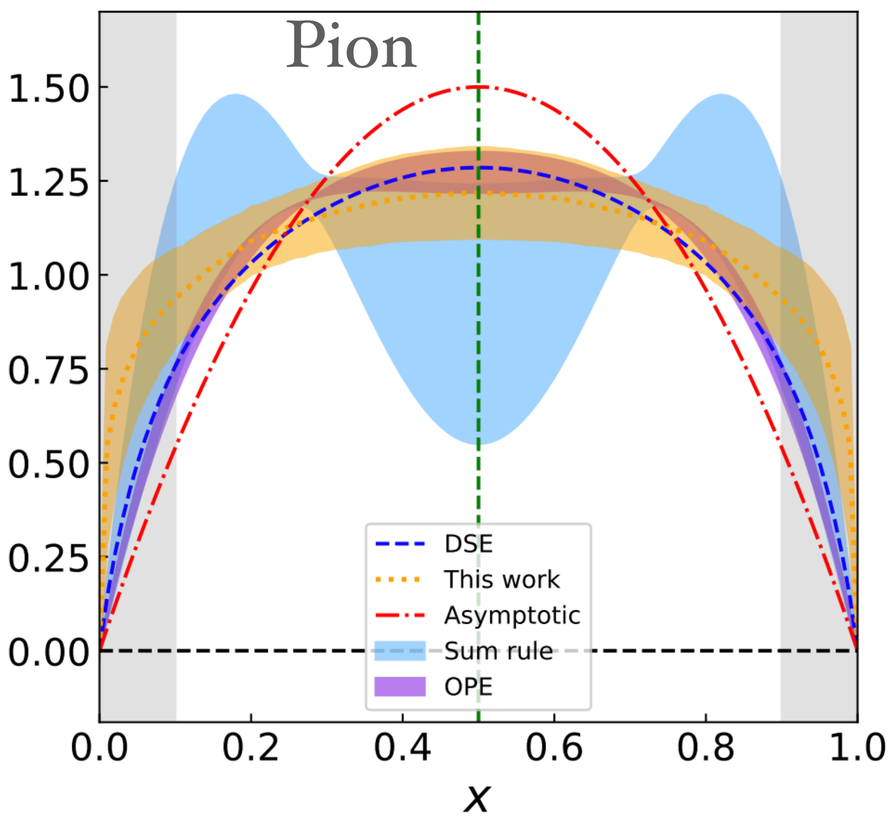


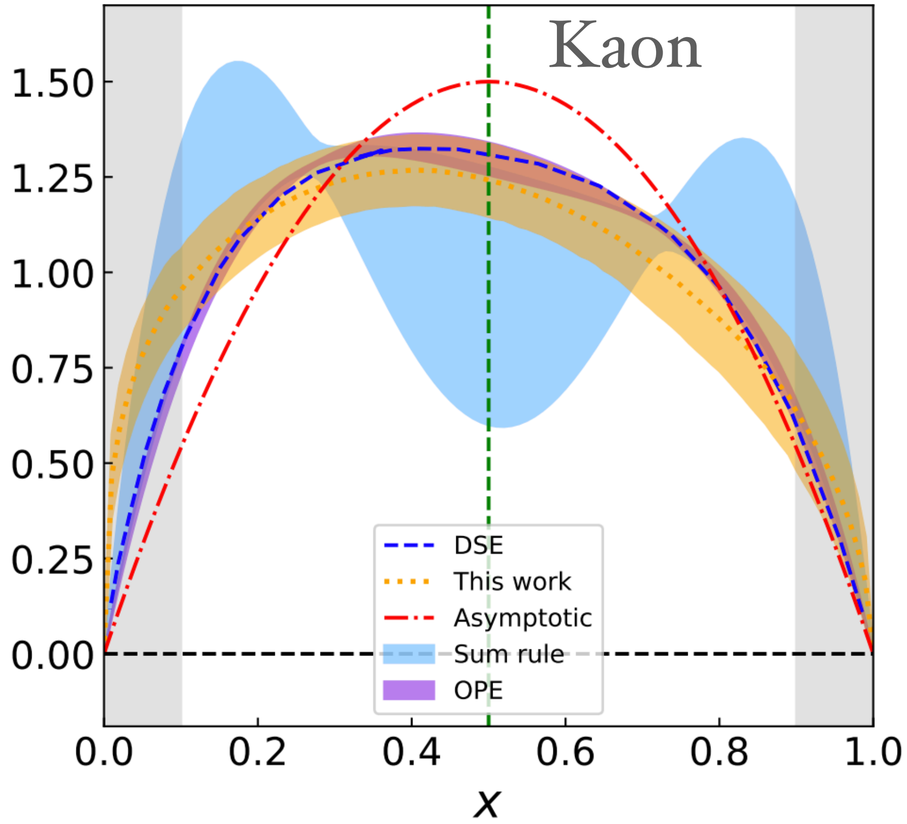
施岐 et al., CCNU-BNL-ANL, in preparation

Distribution Amplitudes of Pion & Kaon

Hybrid renormalization scheme + continuum extrapolation

华俊
Wed. Aug. 10
17:00-17:15



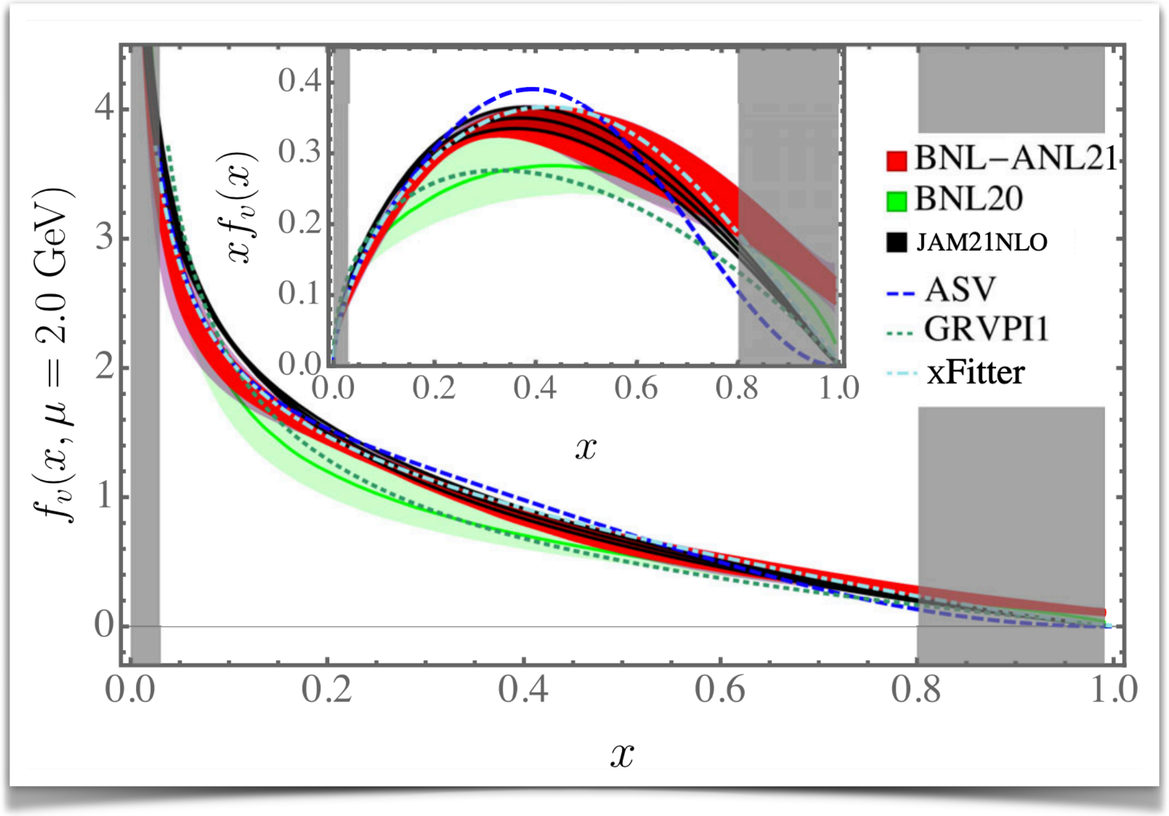


华俊 et al., SJTU-NJNU-ZU-IMP-BUAA, [LPC collaboration],
Distribution of K^* and ϕ, Phys. Rev. Lett. 127 (2021) 062002

华俊 et al., SCNU-SJTU-Maryland-Regensburg-ZU-ITP-BNU-BUAA [LPC collaboration], arXiv:2201.09173

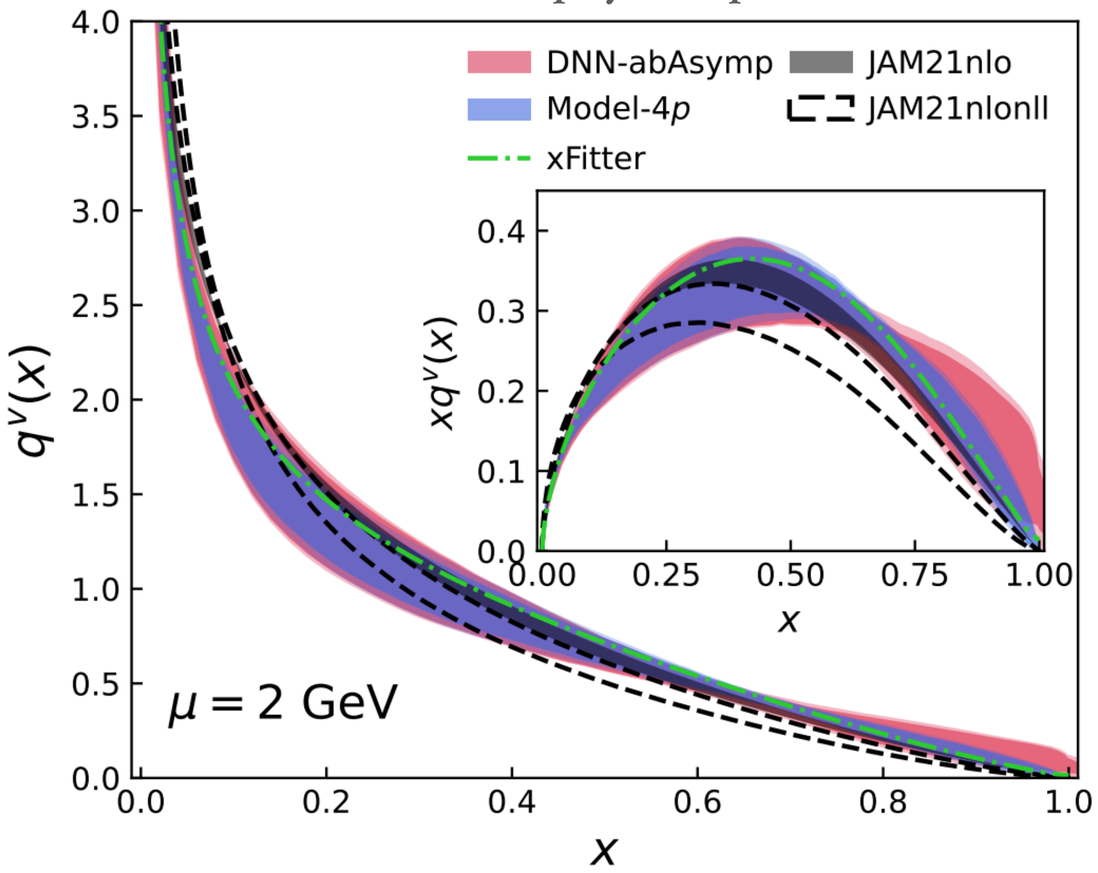
Bjorken-x dependence of pion valence Parton Distribution Functions at NNLO

Nf=2+1 QCD using HISQ,
a=0.04 and 0.06 fm & $m_\pi^{valence} = 300$ MeV



高翔 et al.,CCNU-BNL-SBU-ANL,
Phys. Rev. Lett. 128 (2022) 142003

Continuum extrapolated results
at the physical point

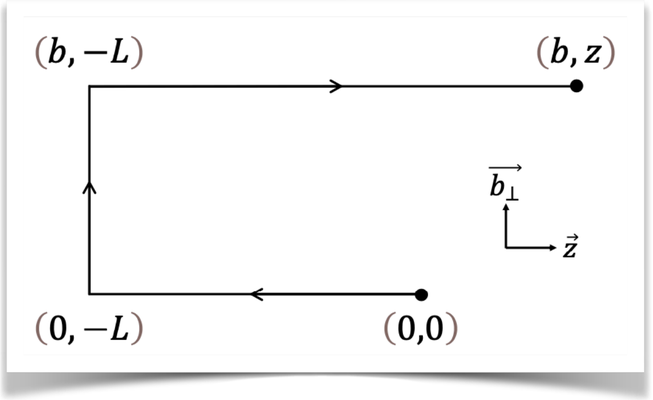


高翔 et al., ANL-BNL-SBU-Frankfurt,
arXiv:2208.02297

Renormalization of transverse-momentum-dependent parton distribution (TMDPDF) in LaMET on the lattice

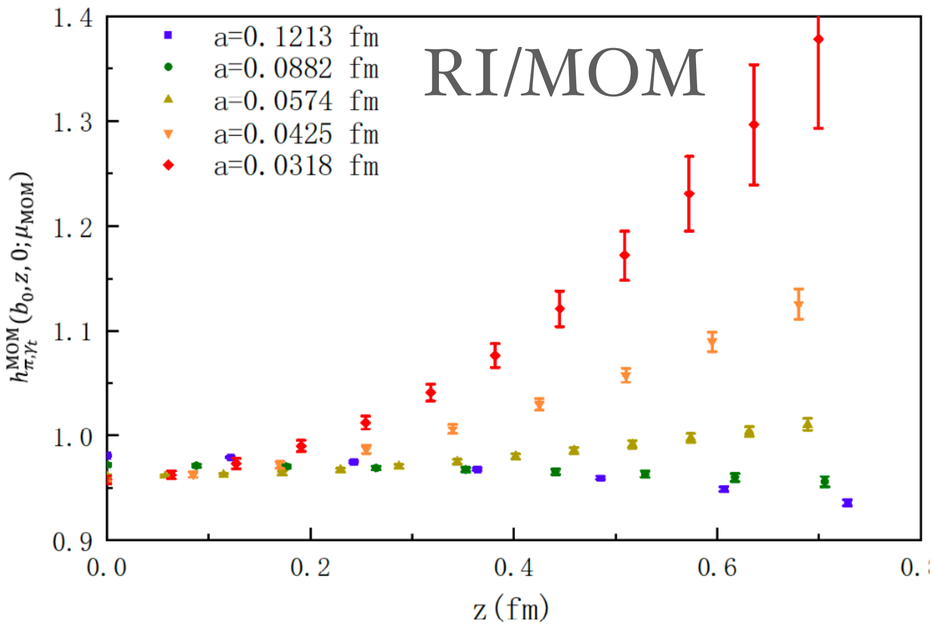
杨一玻
Wed. Aug. 10
16:40-17:00

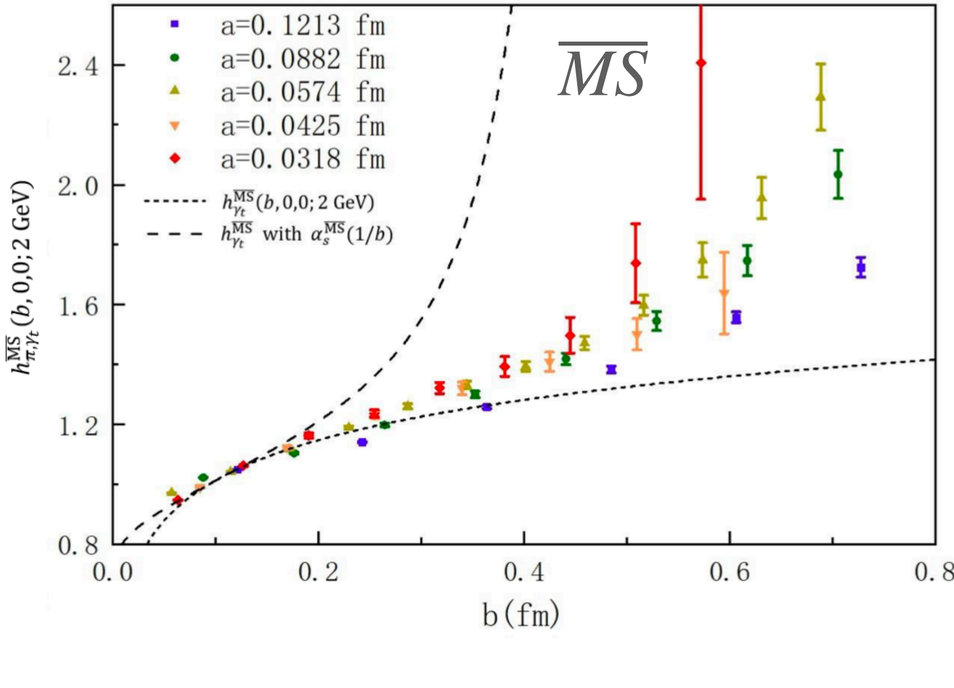
Wilson line needed in the quasi-TMDPDF operator



Pion matrix element of the TMDPDF operator

$M_\pi^{HISQ,sea} \sim 310$ MeV, $M_\pi^{valence} \sim 280 - 320$ MeV



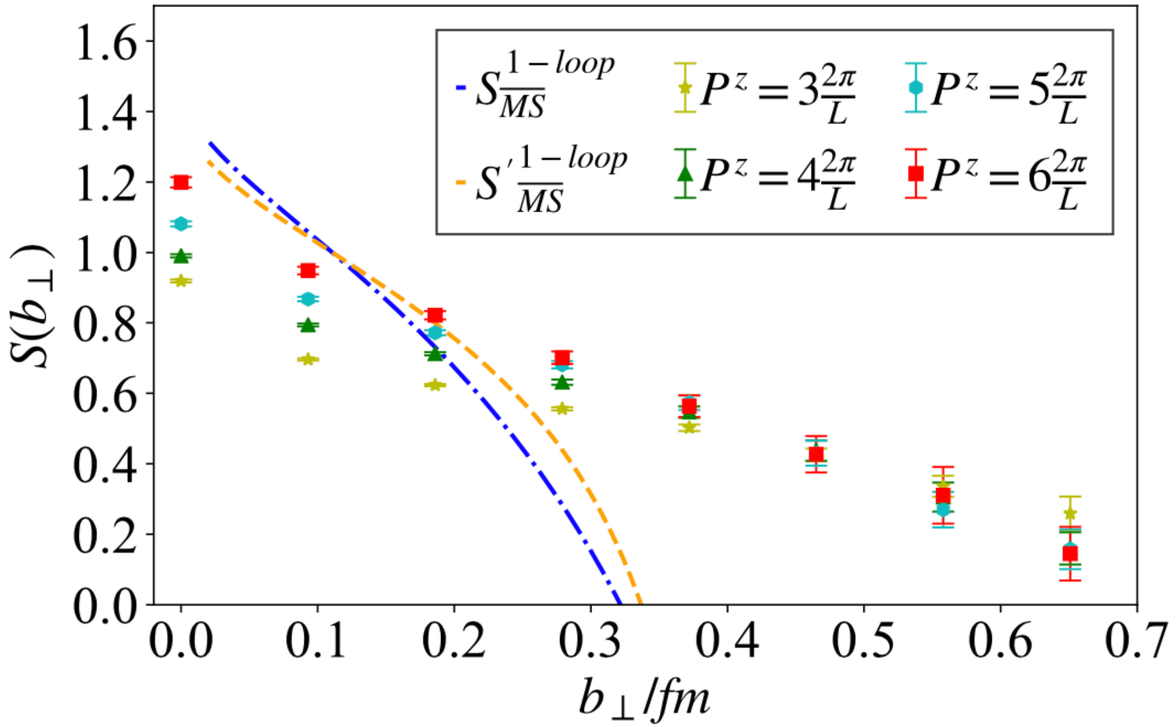


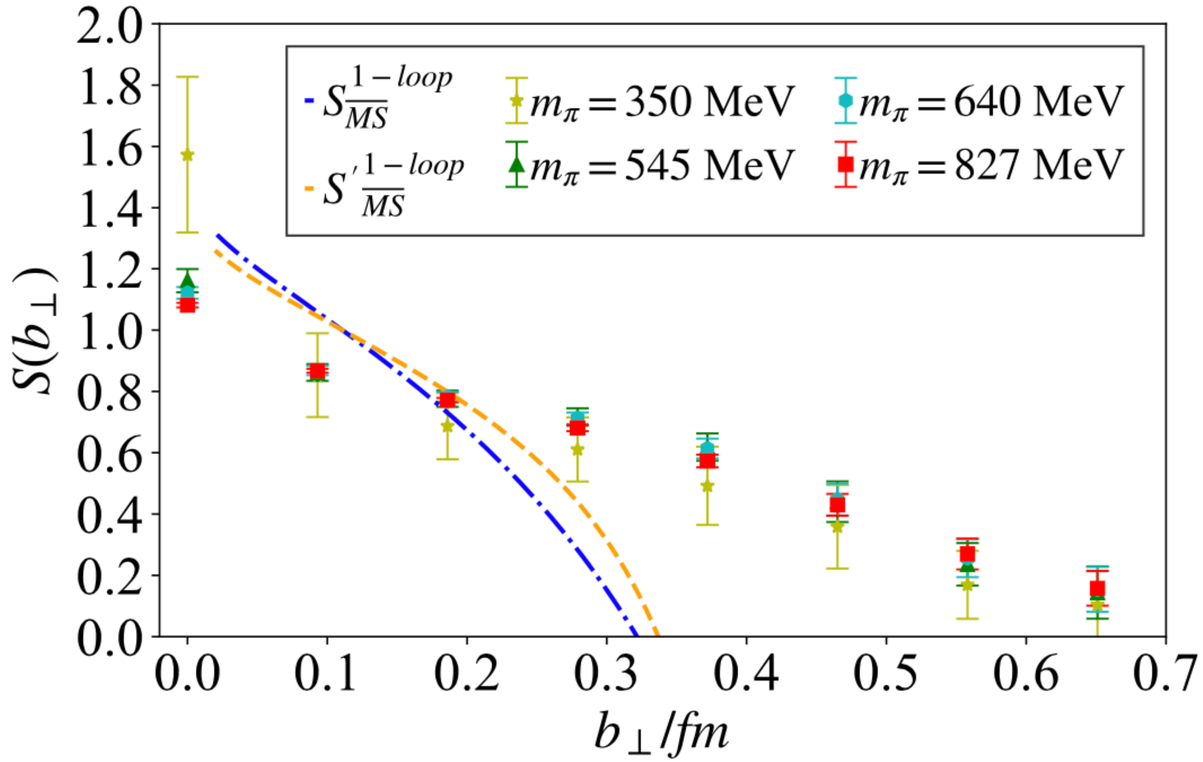
张宽 et al, ITP-Maryland-BNU, [LPC], arXiv:2205.13402, to appear in PRL

Transverse-Momentum-Dependent (TMD) Soft function

$$F_\Gamma(b_\perp, P^z) = \langle \pi(-P^z)|\bar{u}\Gamma u(b_\perp)\bar{d}\Gamma d(0)|\pi(P^z)\rangle$$

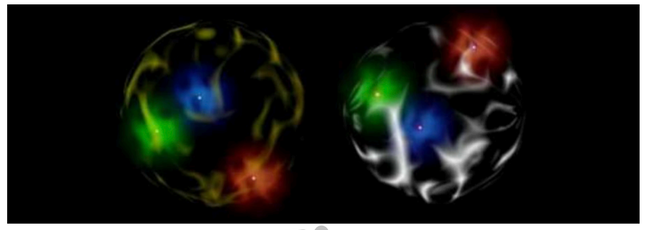
$$F_\Gamma(b_\perp, P^z) \underset{\text{LO kernel}}{\overset{P^z\to\infty}{=}} S(b_\perp,\mu)H^0_\Gamma|\phi(z=0,b_\perp,l=\infty,P^z)|^2$$



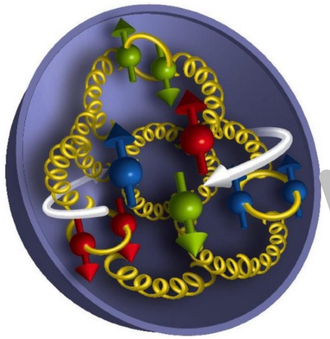


Yuan Li et al., PKU-ETMC, PRL 128 (2022)062002

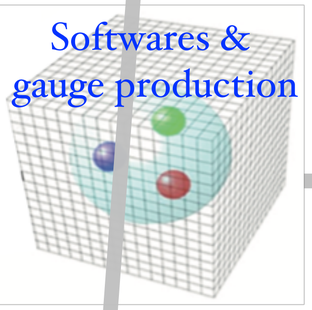
Hadron spectroscopy & interactions



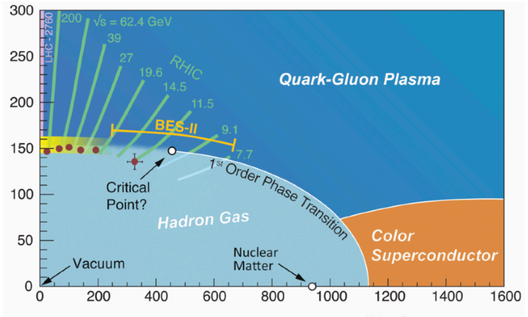
Hadron structure

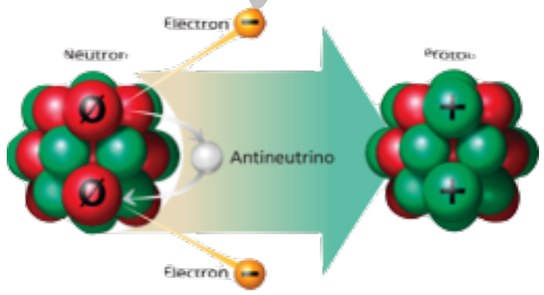


Softwares & gauge production



Hot & dense QCD

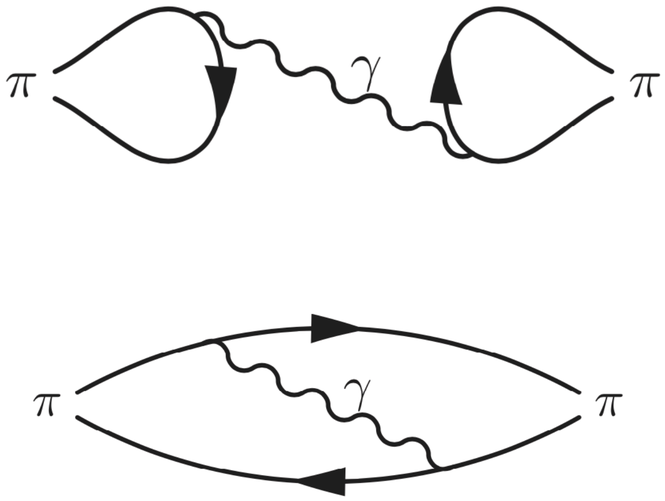


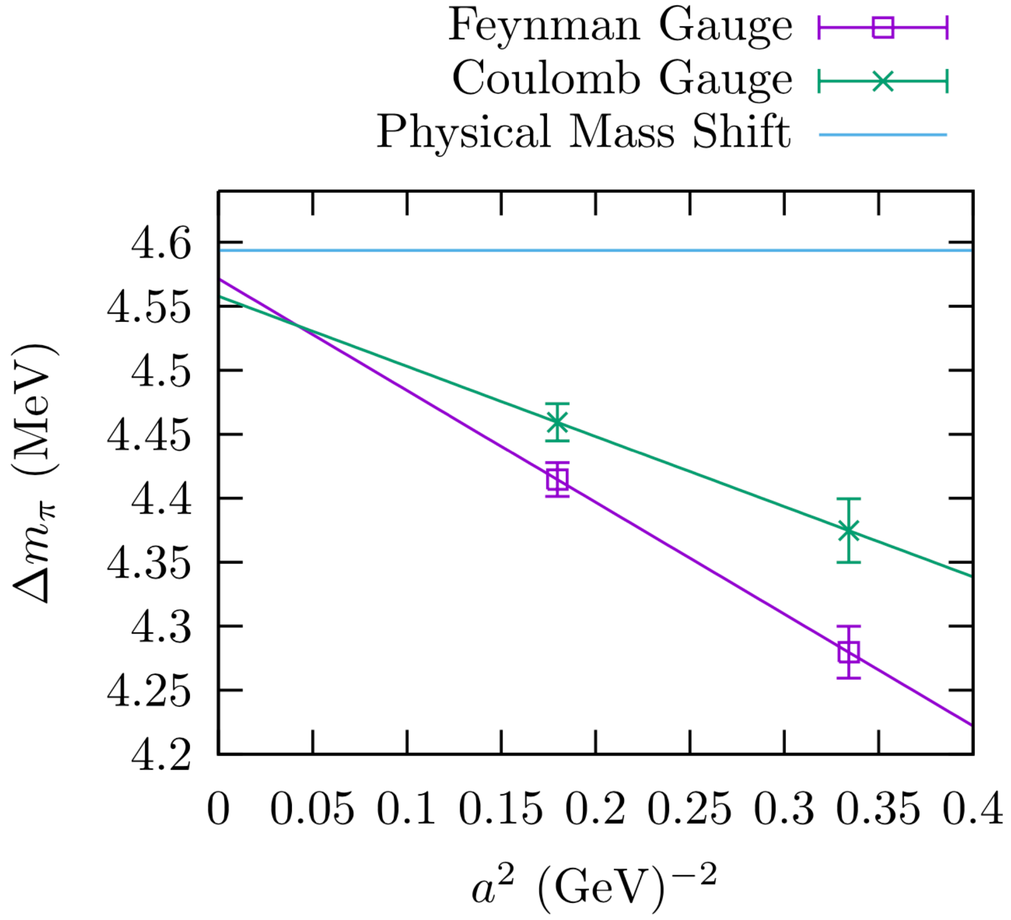


Standard Model parameters

- 傅　杨 [Aug 10 , 14:20], [晨光杯] Lattice QCD computation of two-photon exchange contribution to the muonic-hydrogen Lamb shift
- 王选贺 [Aug. 10, 19:30] 质子电极化率的格点 QCD 计算
- 马鹏翔 [Aug. 10, 19:36] 格点QCD在介子衰变辐射修正中的应用
- 王子毓 [Aug. 10, 19:42] 双重子系统双 beta 衰变的格点计算
- 脱心宇 [Aug. 11, 14:00] 格点计算稀有 K 介子衰变的新方案
- …

Neutral and charged pion mass splitting





LQCD:

$\Delta m_\pi = 4.534(42)_{\text{stat}}(43)_{\text{sys}}$ MeV

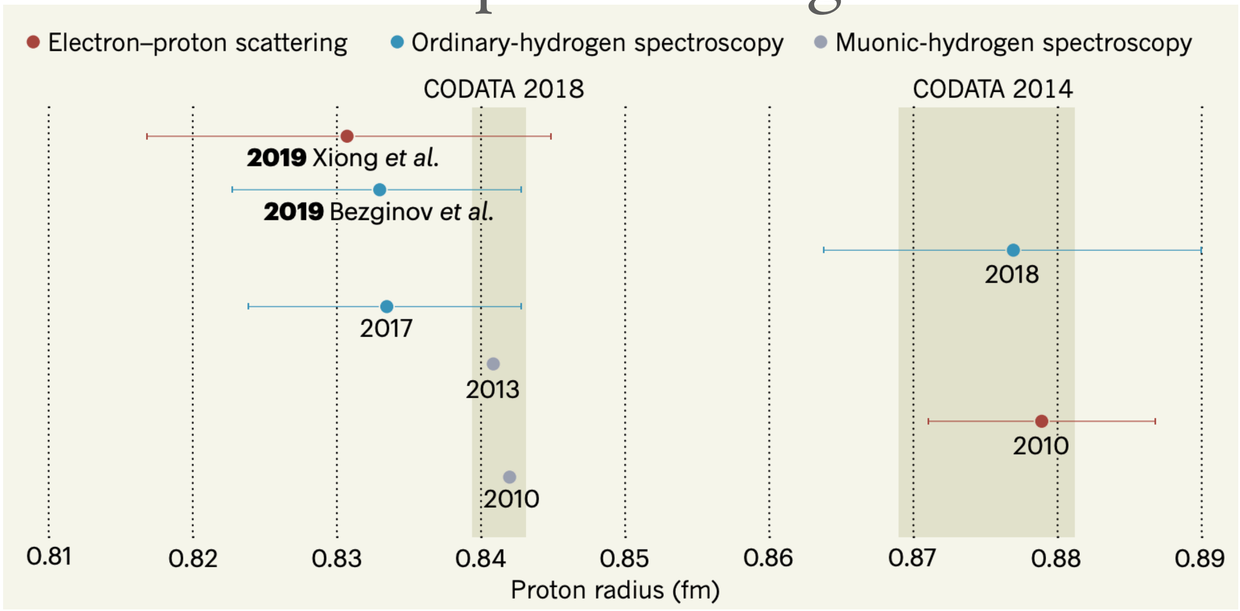
PDG: 4.5936(5) MeV

冯旭, Luchang Jin, Michael Riberdy, PKU-Connecticut, PRL 128(2022) 052003

Two-photon exchange (TPE) contribution to the muonic-hydrogen Lamb shift

晨光杯报告
傅杨
Wed Aug. 10
14:20-14:40

Puzzle on proton charge radius



Karr & Marchand, Nature 575 (2019) 61

$$\Delta E_{\rm LS}^{\rm theory} = 206033.6(1.5) - 5227.5(1.0)\langle r_p^2\rangle + \Delta E_{\rm TPE}$$

$$\Delta E = \frac{2m\alpha^2}{\pi M}|\phi_n(0)|^2\Big\{\sum_{i=1,2}\Big[\int_{-t_s}^{t_s} d^4x\omega_i(\mathbf{x},t)H_i(\mathbf{x},t) + \int d^3\mathbf{x}L_i(\mathbf{x},t_s)H_i(\mathbf{x},t_s)\Big] - 2M\int_\varepsilon \frac{dQ^2}{Q^4}\int d\theta\alpha_2(Q)(K_2 - 4\pi T_2^{pt})\Big\}.$$

$\Delta E_{\rm TPE} = 37.4(4.9)\ \mu$eV :consistent with previous theoretical computations (20,50)μeV

Further improvements can be done with finer lattices

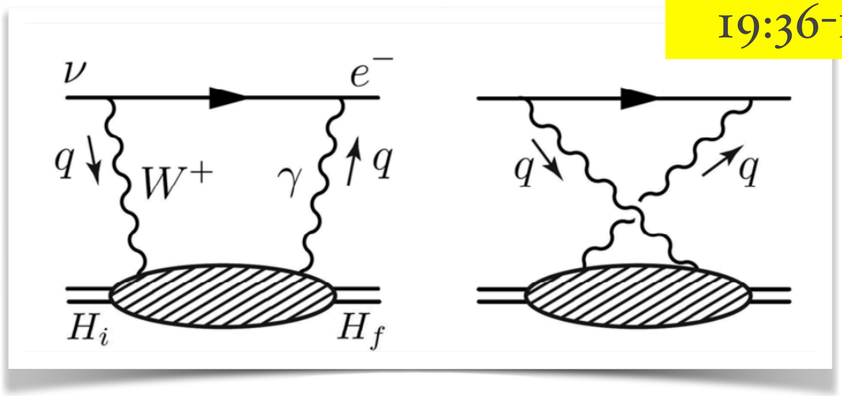
傅杨 et al., PKU-Connecticut, Phys.Rev.Lett. 128, 172002 (2022)

Axial γW-box correction for the pion & kaon semileptonic decay

马鹏翔
Wed Aug. 10
19:36-19:42

$\pi^- \to \pi^0 \ell^- \nu$: $\Gamma_{\pi\ell 3} = \dfrac{G_F^2 |V_{ud}|^2 m_\pi^5 |f_+^\pi(0)|^2}{64\pi^3}(1+\delta) I_\pi$

Sirlin's formule: $\delta = \dfrac{\alpha_e}{2\pi}\left[\bar{g} + 3\ln\dfrac{m_Z}{m_p} + \ln\dfrac{m_Z}{m_W} + \tilde{a}_g\right] + \delta_{\rm HO}^{\rm QED} + 2\Box_{\gamma W}^{VA}$



$H_i \to H_f e \bar{\nu}_e$

$$\Box_{\gamma W}^{VA}|_H = \frac{1}{F_+^H}\frac{\alpha_e}{\pi}\int_0^\infty dQ^2 \frac{m_W^2}{m_W^2+Q^2} \times \int_{-\sqrt{Q^2}}^{\sqrt{Q^2}} \frac{dQ_0}{\pi}\frac{(Q^2-Q_0^2)^{3/2}}{(Q^2)^2} T_3(Q_0, Q^2)$$

Hadronic function by LQCD

Pion: $\delta = 0.0332(1)_{\gamma W}(3)_{\rm HO}$

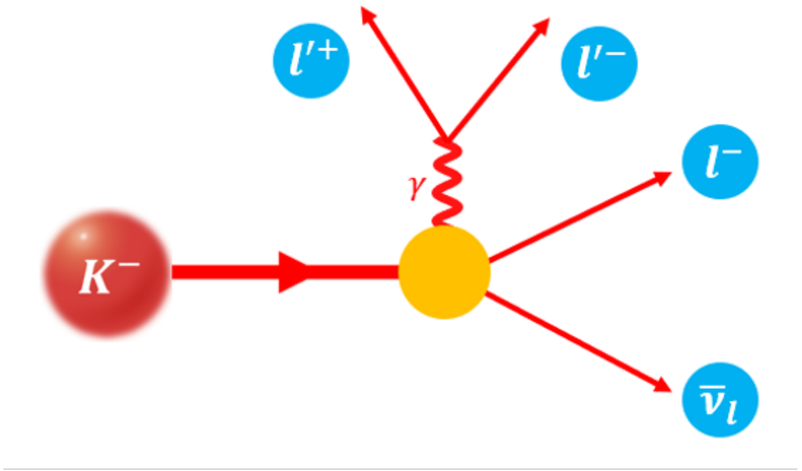
冯旭 et al., PKU-Mainz-Connecticut-Bonn, Phys.Rev.Lett., 124 (2020) 192002

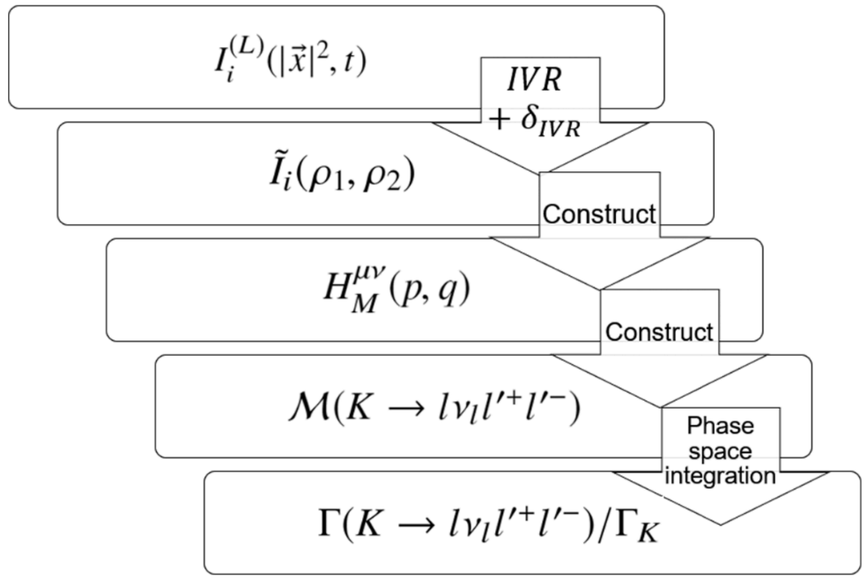
$K \to \pi \ell \nu$: $\Gamma_{K\ell 3} = \dfrac{G_F^2 m_K^5}{192\pi^3} S_{\rm EW}(1+\delta_K^\ell + \delta_{SU2}) C^2 |V_{us}|^2 f_+^2(0) I_K^\ell$

Kaon: $\Box_{\gamma W}^{VA}|_{K^0,{\rm SU(3)}}$ + Low energy constants $\Longrightarrow$ $\Box_{\gamma W}^{VA}|_{K^0}$

马鹏翔 et al., Phys.Rev. D 103(2021)114503

New methodology in computing the Kaon decay on Lattice





脱心宇
Thu Aug. 11
14:00-14:15

Scalar function + Infinite Volume Reduction method

Channels	m_{ee} cuts	Lattice ($m_\pi = 352$ MeV)	ChPT [5]	Experiments
$\mathrm{Br}[K \to e\nu_e e^+ e^-]$	140 MeV	$1.77(16) \times 10^{-8}$	3.39×10^{-8}	$2.91(23) \times 10^{-8}$ [3]
$\mathrm{Br}[K \to \mu\nu_\mu e^+ e^-]$	140 MeV	$10.59(33) \times 10^{-8}$	8.51×10^{-8}	$7.93(33) \times 10^{-8}$ [3]
$\mathrm{Br}[K \to e\nu_e \mu^+ \mu^-]$	...	$0.72(5) \times 10^{-8}$	1.12×10^{-8}	$1.72(45) \times 10^{-8}$ [4]
$\mathrm{Br}[K \to \mu\nu_\mu \mu^+ \mu^-]$	...	$1.45(6) \times 10^{-8}$	1.35×10^{-8}	...

脱心宇, X. Feng, L. Jin, T. Wang, PKU-Conneticut, PRD105 (2022) 054518

Lattice study of Dibaryon nuclear $\beta\beta$ decay

王子毓
Wed Aug. 10
19:42-19:48

Domain Wall fermions + Iwasaki gauge action

$pp \to d$ fusion: NME/g_A=1.0(4)

$2\nu2\beta$: NME/g_A^2 = 1.02(6)

Consistent with NPLQCD Savage et al., PRL 17

$0\nu2\beta$: NME/$(g_A^2/2m_\nu V)$ = 13(4)

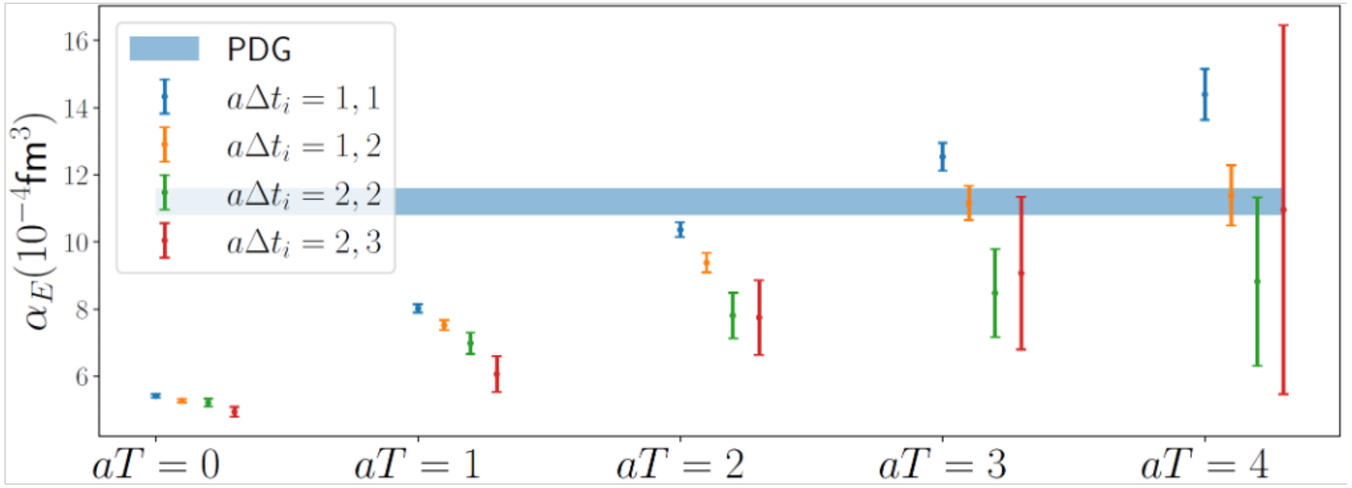
王子毓,PKU, PoS(Lattice 2021)629, work in progress

Electric polarizability of Proton extracted from Compton scattering

王选贺
Wed Aug. 10
19:30-19:36

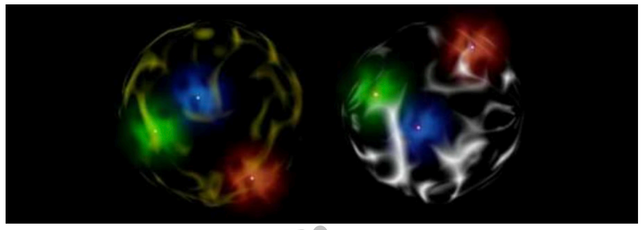
4-point correlation func. of proton:

$$\langle N(t+\Delta t_1) J^\mu(t) J^\nu(0) \bar{N}(-\Delta t_2)\rangle$$

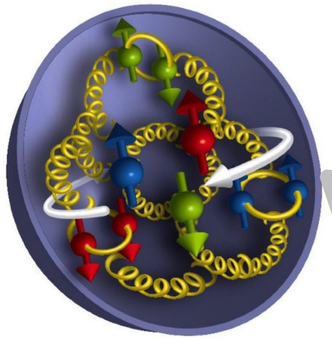


王选贺 et al., PKU-Connecticut, work in progress

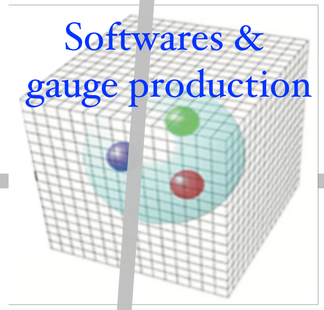
Hadron spectroscopy & interactions



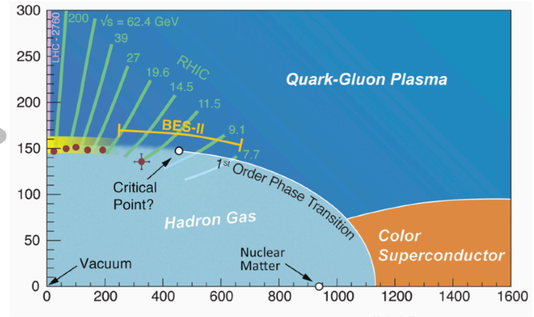
Hadron structure

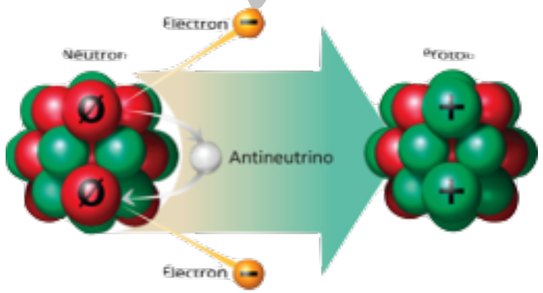


Softwares & gauge production



Hot & dense QCD



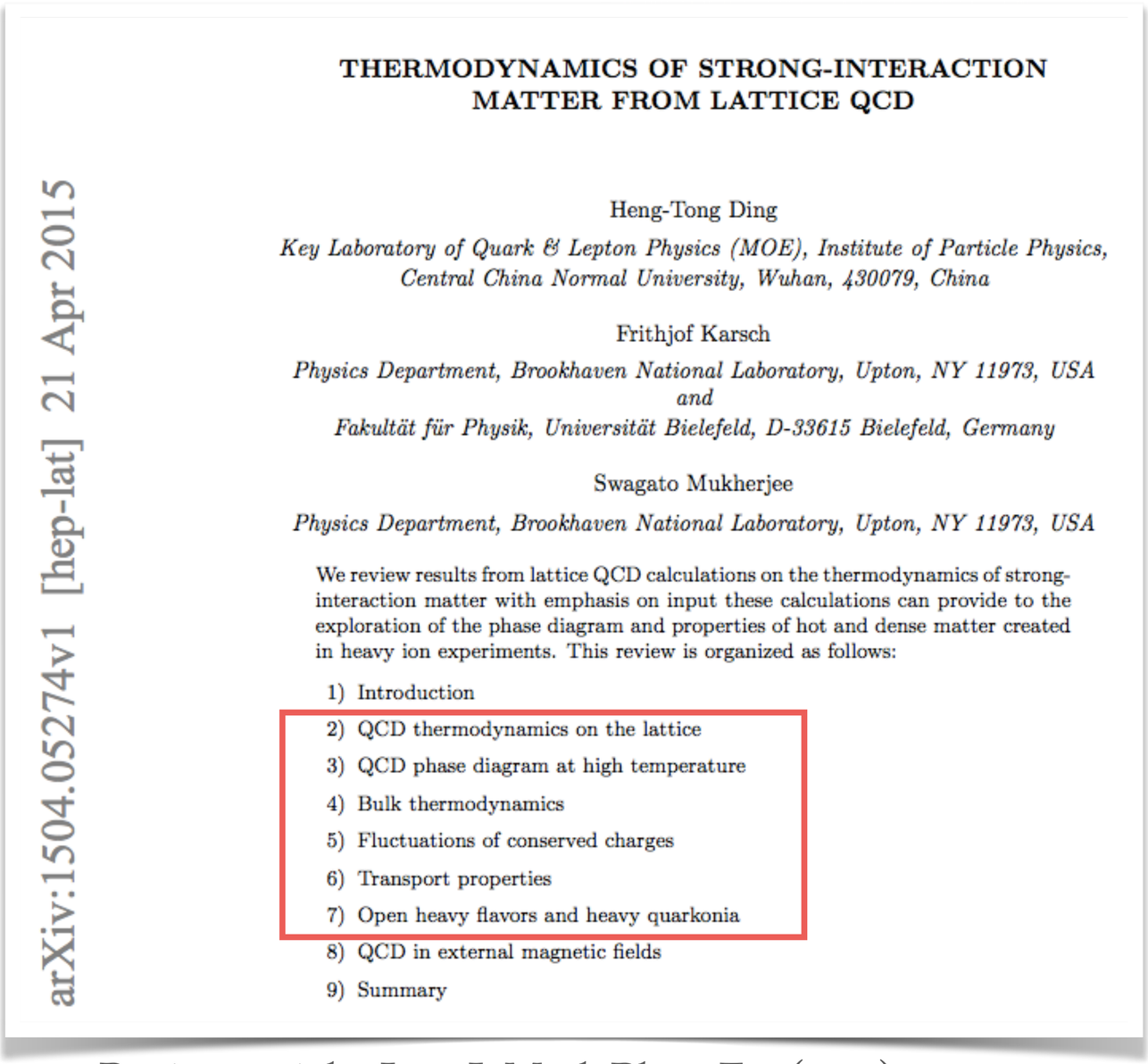


Standard Model parameters

- 李胜泰 [Aug. 10, 15:35]
  Chiral condensates and screening masses of neutral pseudoscalar mesons
- 黄玮平 [Aug. 10, 15:50]
  Criticality of QCD in correlated Dirac eigenvalues
- 刘俊宏 [Aug. 10, 11:15]
  Fluctuations of conserved charges in strong magnetic fields
- …

HotQCD collaboration

- Brookhaven National Laboratory, USA
- Bielefeld University, Germany
- Central China Normal University, China
- Michigan State University, USA
- Tsukuba University, Japan
- Indian Institute of Science, India
- Institute of Mathematical Sciences, India



THERMODYNAMICS OF STRONG-INTERACTION MATTER FROM LATTICE QCD

Heng-Tong Ding

Key Laboratory of Quark & Lepton Physics (MOE), Institute of Particle Physics, Central China Normal University, Wuhan, 430079, China

Frithjof Karsch

Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA and Fakultät für Physik, Universität Bielefeld, D-33615 Bielefeld, Germany

Swagato Mukherjee

Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA

We review results from lattice QCD calculations on the thermodynamics of strong-interaction matter with emphasis on input these calculations can provide to the exploration of the phase diagram and properties of hot and dense matter created in heavy ion experiments. This review is organized as follows:

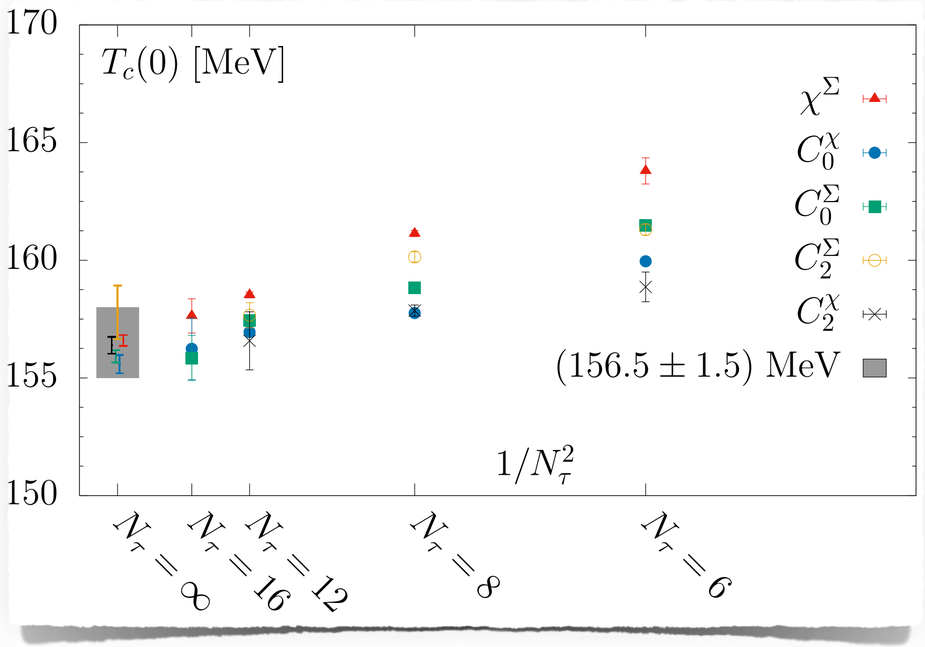
Review article: Int. J. Mod. Phys. E24(2015)1530007, cited by 298 records

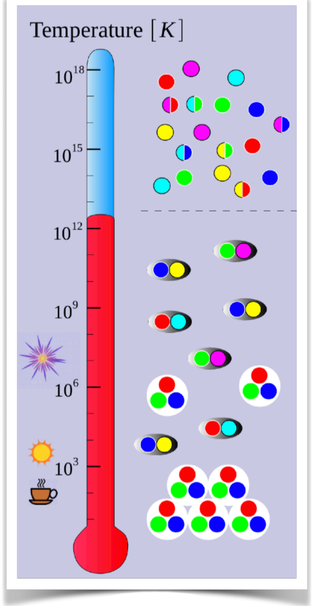
Chiral crossover/phase transition temperature at physical point and $m_q \to 0$

Made in

华中师大
核科学计算中心

Rigorous definition from O(4) universality class





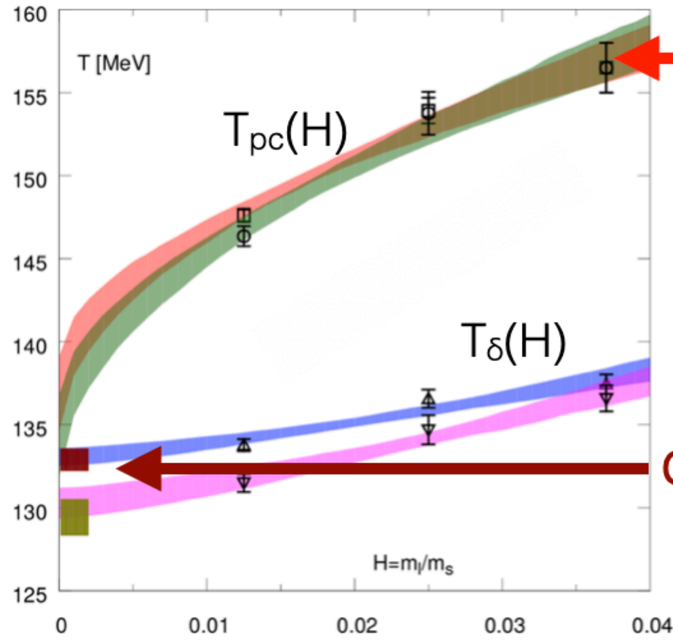
A. Bazavov, 丁亨通, P. Hegde et al. [HotQCD], Phys. Lett. B795 (2019) 15, 被引360次

Chiral crossover transition

T=156.5(1.5) MeV ~ 1.8×10^{12} K

Consistent results from Wuppertal-Budapest, PRL125 (2020) 052001

Based on O(4) scaling analyses



Chiral crossover
$T_{pc}^{phy} = 156.5(1.5)$ MeV

$$T_{pc}(H) = T_c^0 \left(1 + \frac{z_p}{z_0} H^{\frac{1}{\beta\delta}}\right)$$

Chiral phase transition T

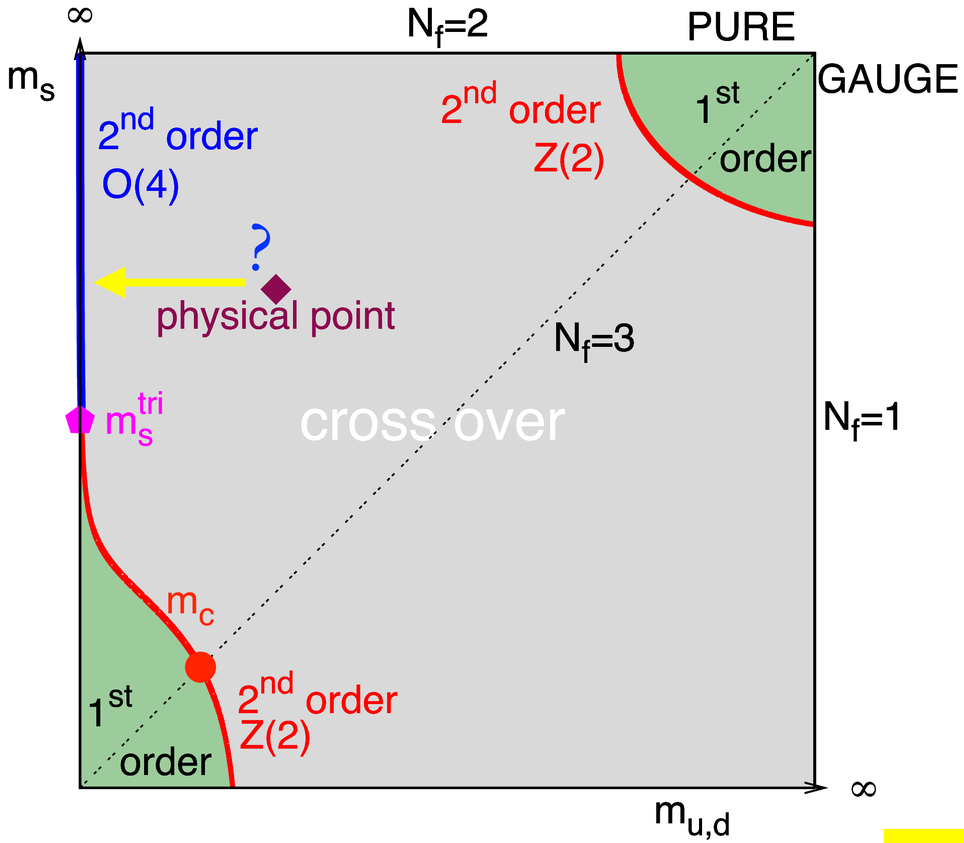
$$T_c^0 = 132^{+3}_{-6} \text{ MeV}$$

丁亨通, P. Hegde, O. Kaczmarek et al.[HotQCD], Phys. Rev. Lett. 123 (2019) 062002, 被引147次

Chiral phase transition T is a possible upper bound of T_{CEP}

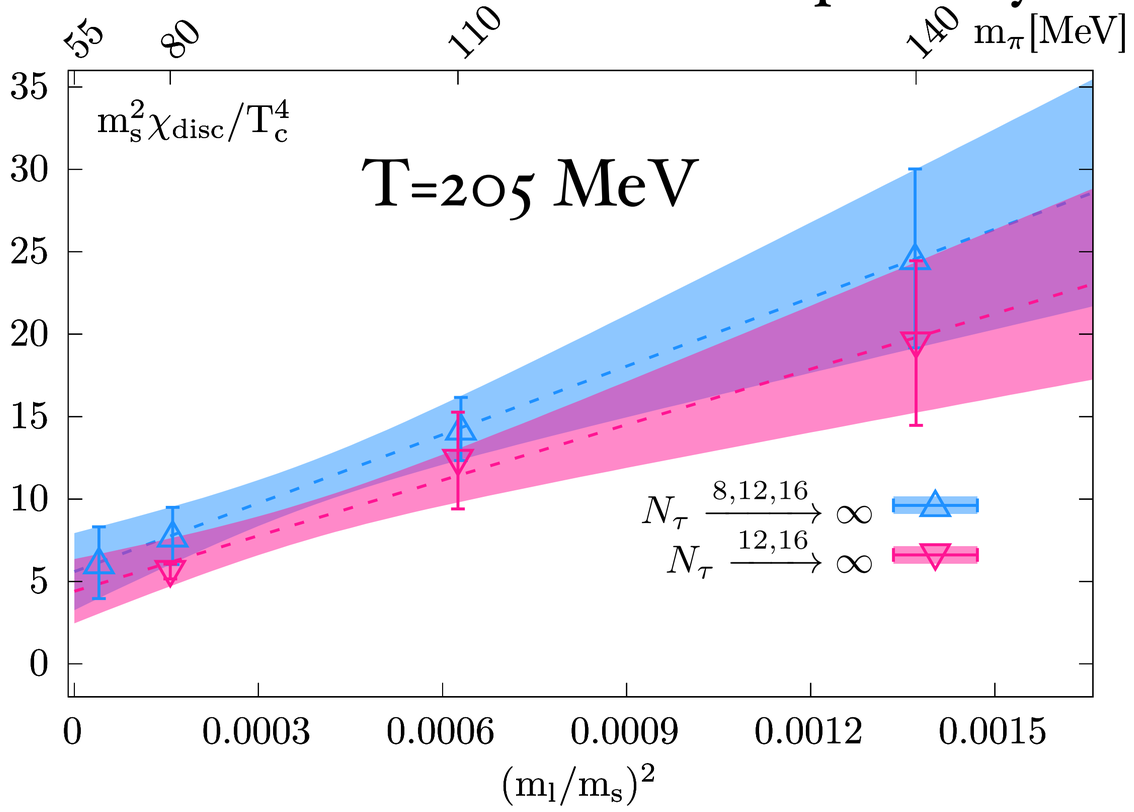
Fate of the Axial U1 anomaly at nonzero T

Made in NSD



丁亨通, 李胜泰, 复谷昭夫,
S. Mukherjee, 汪晓丹, 张瑜,
CCNU-IMP-BNL,
Phys.Rev.Lett. 126 (2021) 082001

disconnected chiral susceptibility



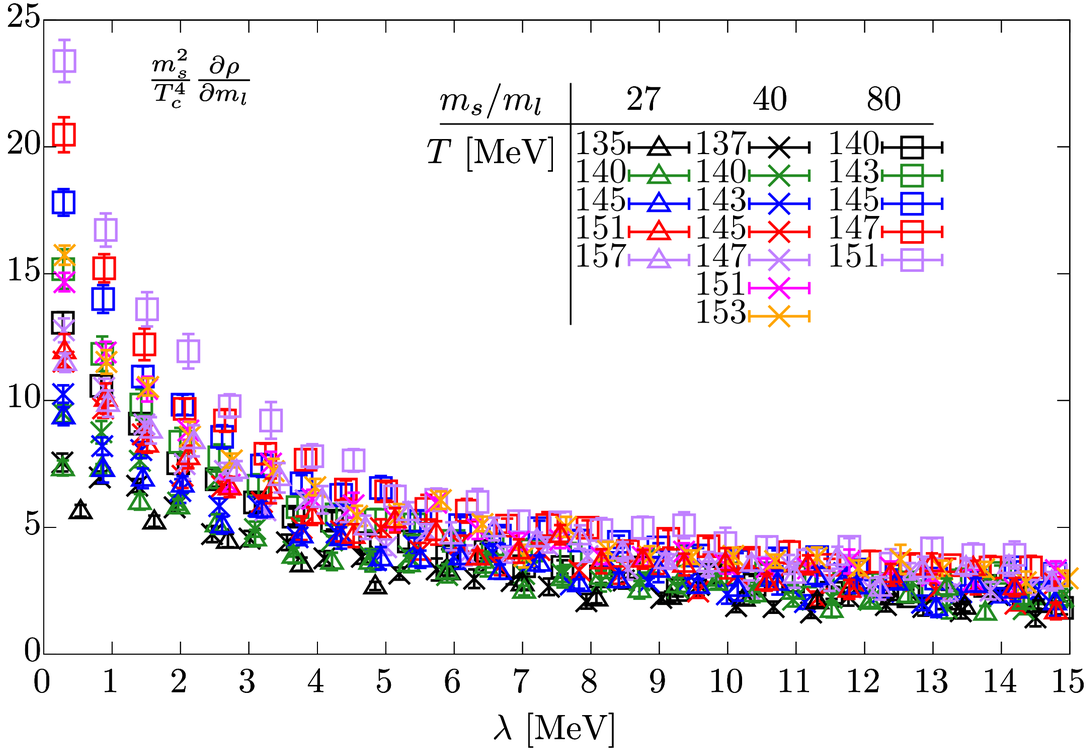
Axial anomaly remains manifested at a 2-3σ level

Chiral phase transition:
2nd order in O(4) universality class

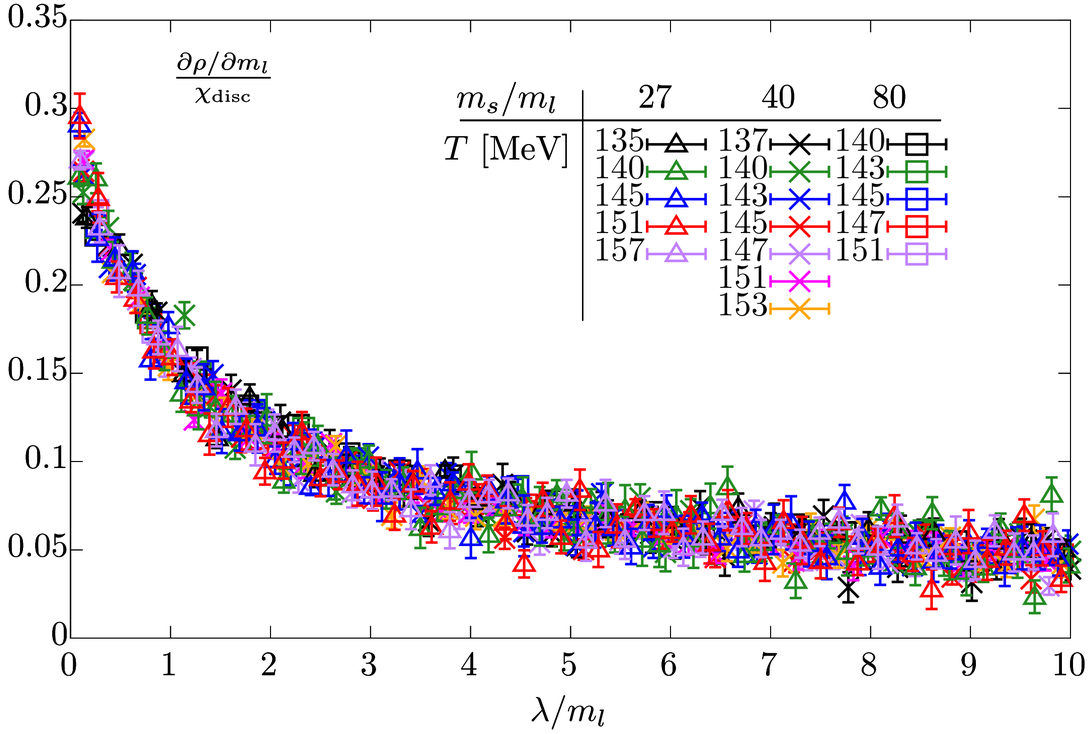
Microscopic manifestation of chiral phase transition

黄玮平
Wed Aug.10
15:50-16:05

Quark mass derivative of
Dirac Eigenvalue spectrum $\partial\rho/\partial m$



Rescaled $\partial\rho/\partial m$
by disconnected chiral susceptibility



黄玮平 et al., CCNU-BNL-RIKEN, work in progress

Lattice QCD in strong magnetic fields

No sign problem

- *B* pointing to the z direction & Gauge link multiplied by a U(1) factor

$$u_x(n_x,n_y,n_z,n_\tau) = \begin{cases} \exp[-iqa^2BN_xn_y] & (n_x = N_x - 1) \\ 1 & (\text{otherwise}) \end{cases}$$

$$u_y(n_x,n_y,n_z,n_\tau) = \exp[iqa^2Bn_x],$$

$$u_z(n_x,n_y,n_z,n_\tau) = u_t(n_x,n_y,n_z,n_\tau) = 1.$$

- Quantization of the magnetic field

$$qB = \frac{2\pi N_b}{N_xN_y}a^{-2}$$

q_u=2/3e, q_d=-1/3e, q_s=-1/3e

$$eB = \frac{6\pi N_b}{N_xN_y}a^{-2}$$

CCNU LQCD group has developed GPU/C++ codes for LQCD simulations at eB=/=0

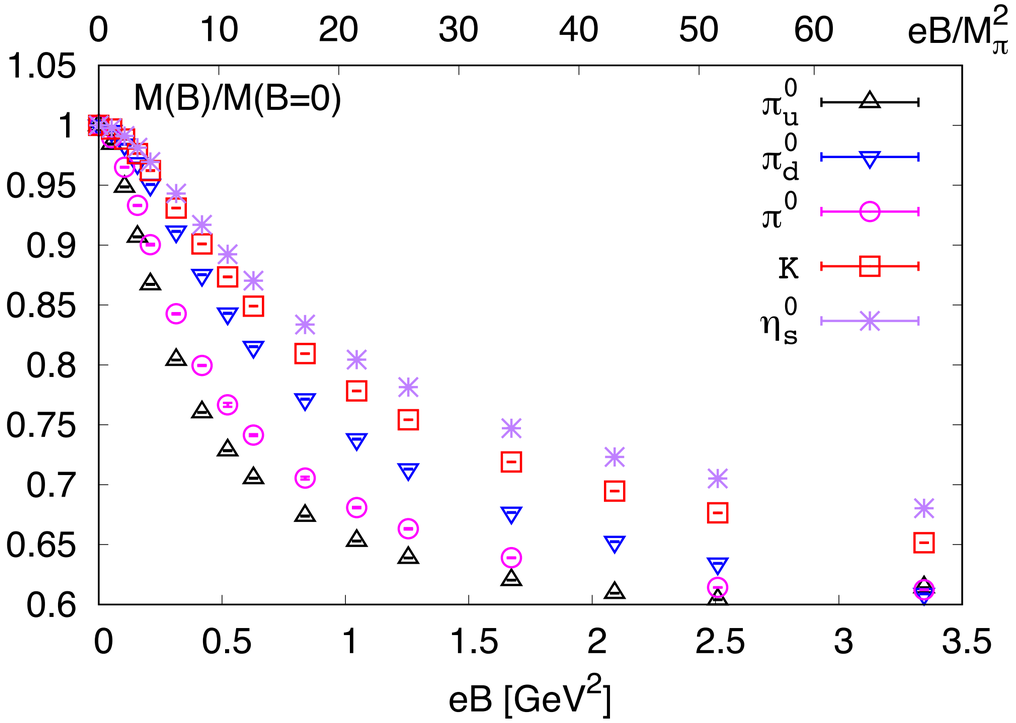
contributors: Akio Tomiya, 李胜泰, 汪晓丹, 李韶荣, 张瑜

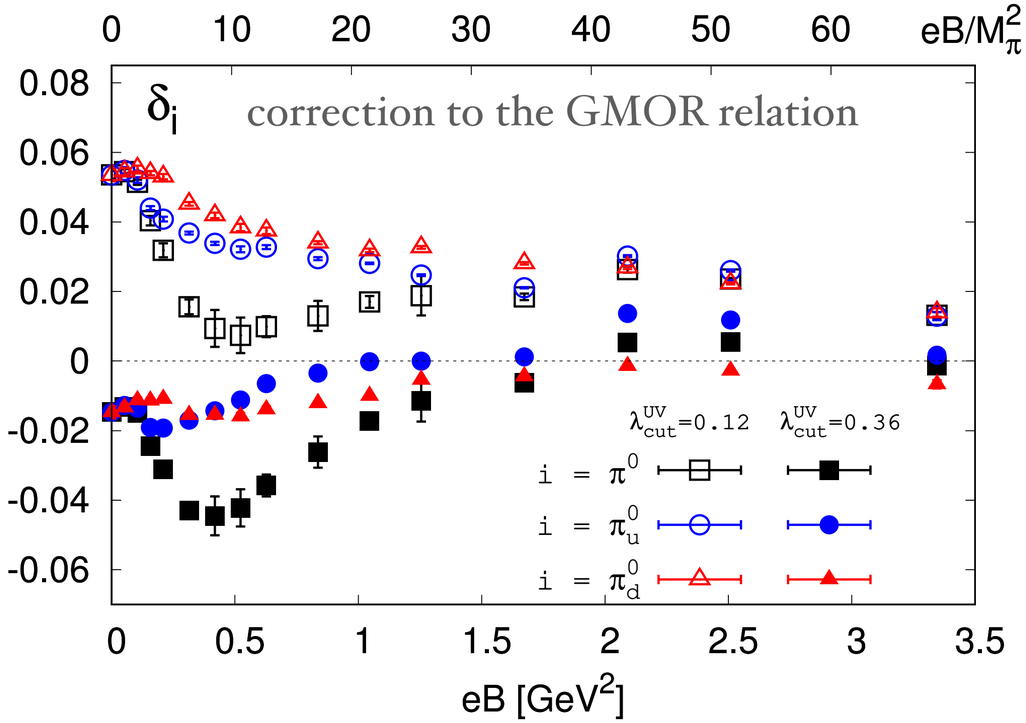
Made in

EPJ Web Conf. 175 (2018) 07041, *PoS* LATTICE2018 (2019) 163 ,
PoS LATTICE2019 (2020) 250, *Phys.Rev.D* 102 (2020) 5,*Eur.Phys.J.A* 57 (2021) 6, 202,
Phys.Rev.D 104 (2021) 1, Acta Phys.Polon.Supp. 14 (2021) 403, Phys.Rev.D 105 (2022) 3, 034514
… …

Gell-Mann-Oakes-Renner relation at $eB \neq 0$ and T=0

$$(m_u + m_d)\ \left(\langle\bar{\psi}\psi\rangle_u + \langle\bar{\psi}\psi\rangle_d\right) = 2f_\pi^2 M_\pi^2 \left(1 - \delta_\pi\right)$$





N_f=2+1 QCD, $M_\pi(eB = 0) \approx 220$ MeV, on $32^3 \times 96$ lattices with $a^{-1} \approx 1.7$ GeV^{-1} and HISQ action at T=0

HTD, S.-T. Li, A. Tomiya, X.-D. Wang, Y. Zhang, PRD 126 (2021) 082001

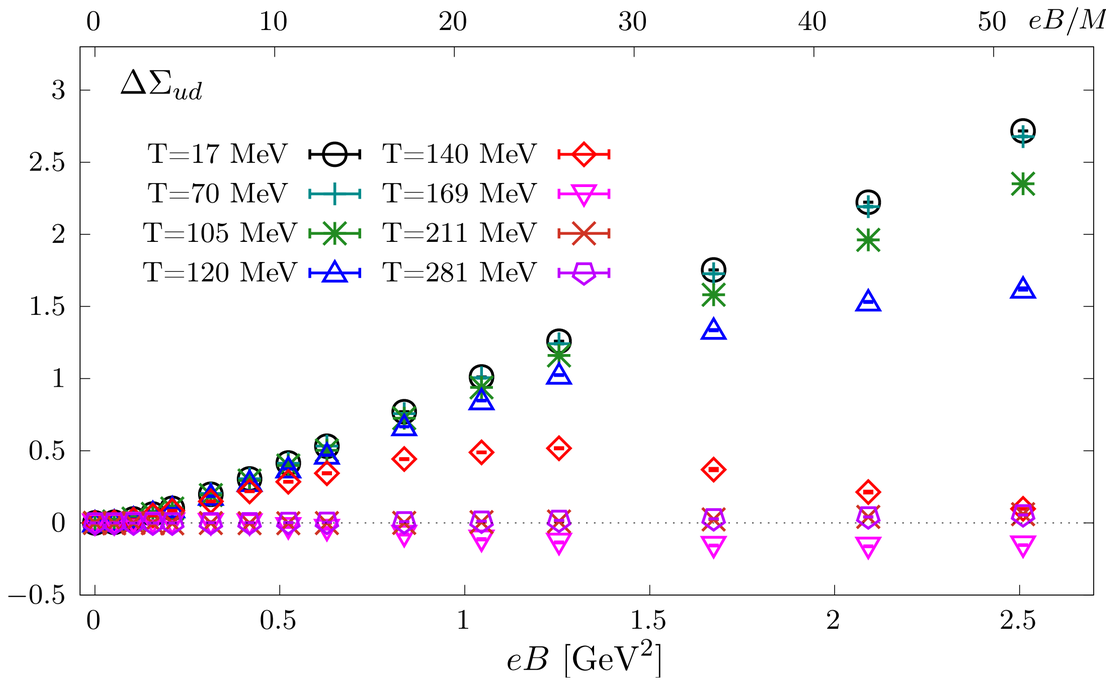
(inverse) magnetic catalysis ⟺ hadron screening masses

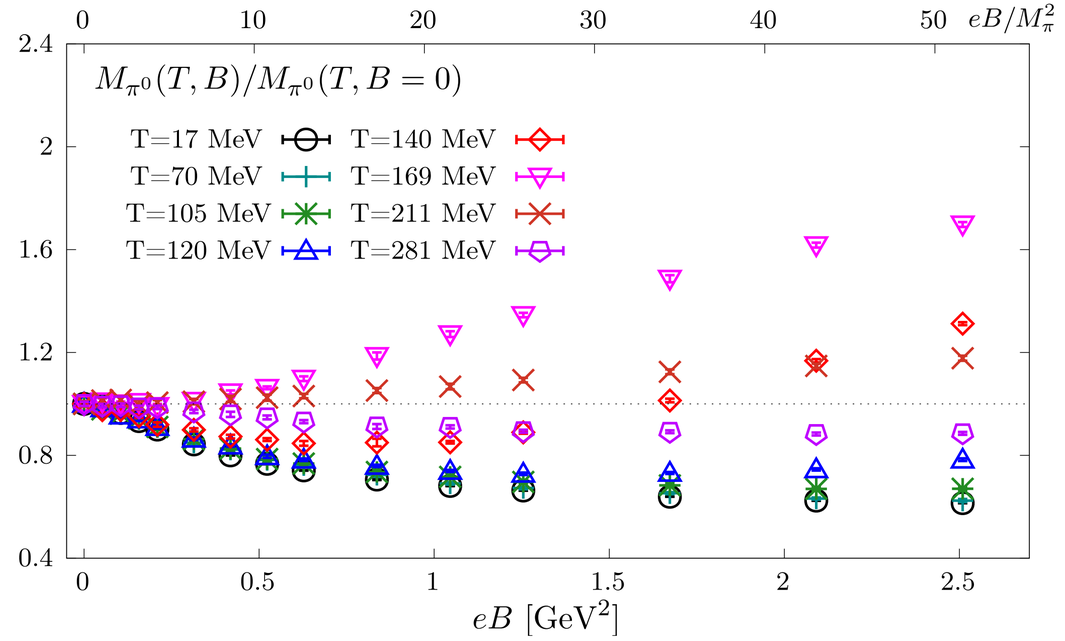
李胜泰
Wed Aug. 10
15:35-15:50

Ward Identity: $\langle\bar{\psi}\psi\rangle_u + \langle\bar{\psi}\psi\rangle_d = (m_u + m_d)\,\chi_{\pi^0}$

$$\chi_{\pi^0} = \int \mathrm{d}z\, G_{\pi^0}(z), \qquad \lim_{z\to\infty} G_{\pi^0}(z) = A_{\pi^0} e^{-M_{\pi^0} z}$$

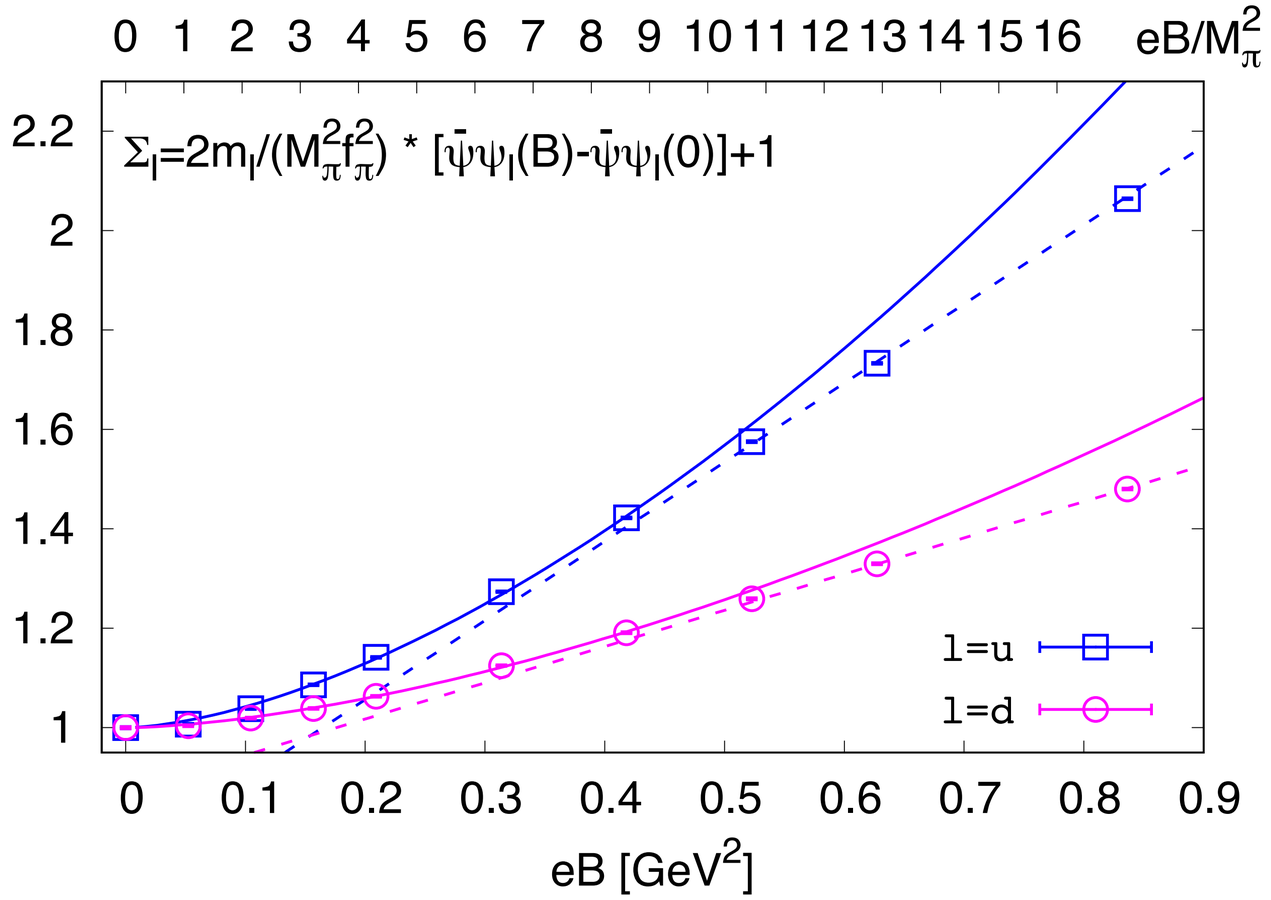
M_{π^0}: Screening mass of π^0





丁亨通,李胜泰, 刘俊宏, 汪晓丹, Phys. Rev. D105(2022)034514

Isospin symmetry breaking at $eB \neq 0$ manifested in chiral condensates



HTD, S.-T. Li, A. Tomiya, X.-D. Wang and Y. Zhang, PRD 126 (2021) 082001

See also in reviews e.g. M. D'Elia, Lect.NotesPhys.871(2013)181

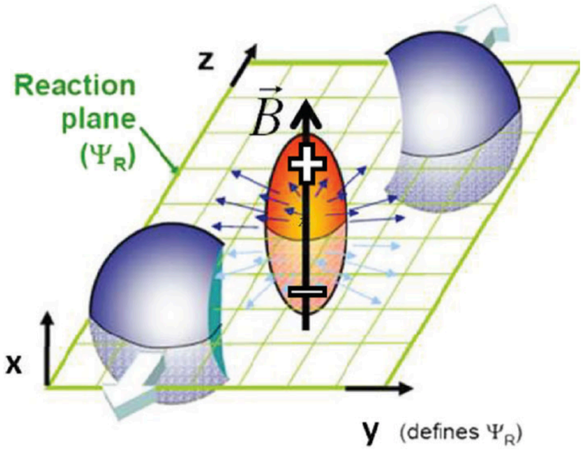
Not accessible in Heavy Ion Collision experiments

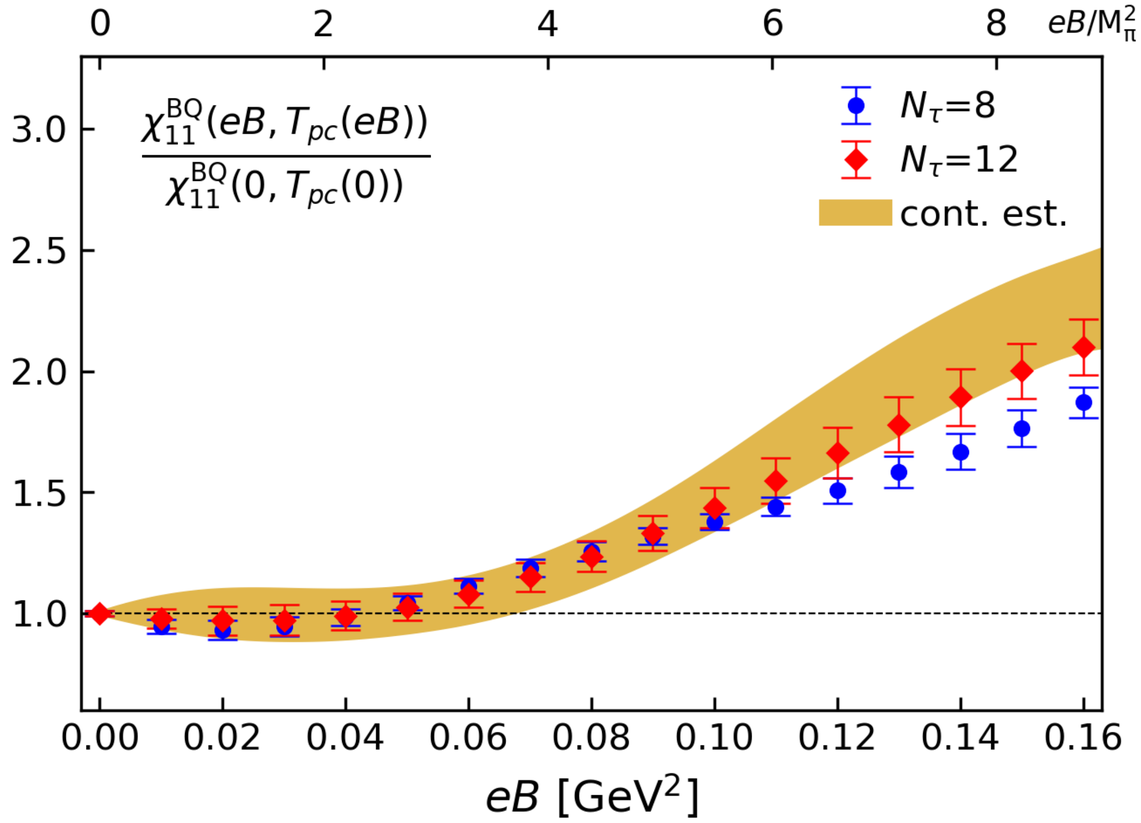
eB related physics in HIC:
See next talk by Xu-Guang Huang

Ratio X(eB)/X(eB=0) for 2nd order off-diagonal fluctuations

刘俊宏
Wed, Aug. 10
11:15-11:30

N_f=2+1 QCD, $M_\pi(eB=0) \approx 135$ MeV, $T_{pc}(eB=0) \approx 157$ MeV,
$32^3 \times 8$ and $48^3 \times 12$ lattices with HISQ action





Central Collisions
Smaller eB

Peripheral Collisions
Larger eB

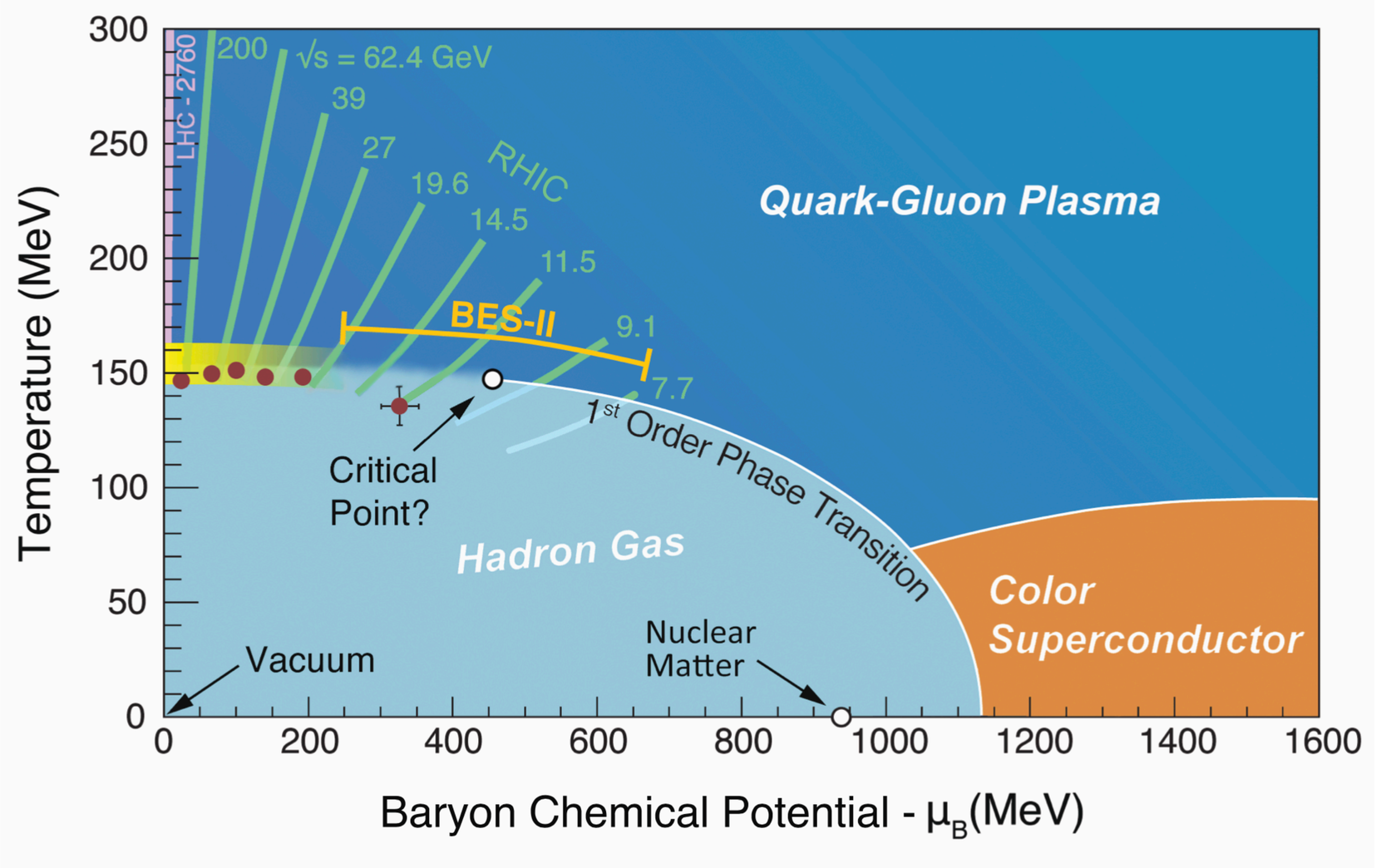
X(eB)/X(eB=0) :
Rcp like observable

At $eB \simeq 8M_\pi^2$: ~2 !

刘俊宏 et al., CCNU, QM 2021 talk
& work in progress

QCD phase structure at nonzero baryon density

QCD critical endpoint



- RHIC/BESII
- NA61/SHINE
- HADES
- CEE
- CBM
- NICA

See recent reviews:

罗晓峰，许怒，Nucl.Sci.Tech. 28(2017)112

丁亨通, Nucl.Phys.A1005(2021)21940

付伟杰，arXiv:2205.00468

Taylor expansion of pressure in μ_B

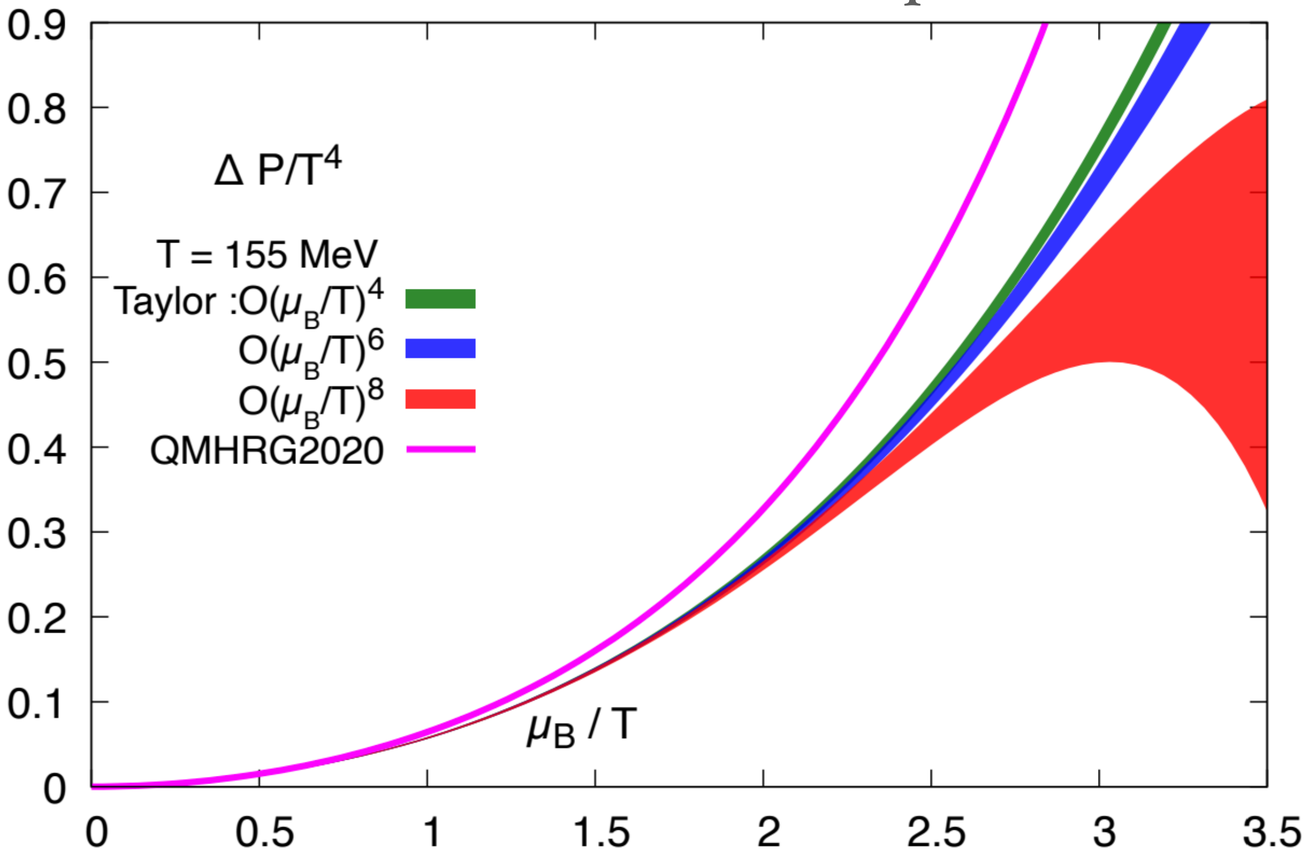
Taylor expansion in μ_B

$$\frac{P}{T^4} = \frac{1}{VT^3} \ln Z(V,T,\mu) = \sum_{n=0}^{\infty} \frac{\chi_n^B}{n!} \left(\frac{\mu_B}{T}\right)^n$$

$$\chi_n^B(T) = \frac{\partial^n P(T,\mu_B)/T^4}{\partial \hat{\mu}_B^n}\Big|_{\hat{\mu}_B=0}$$

$$\Delta P = P(T,\mu_B) - P(T,\mu_B = 0)$$

State-of-the-art results on pressure



D. Bollweg et al., [HotQCD], Phys. Rev. D 105(2022)074511

Resummed Taylor expansion: all orders in μ_B

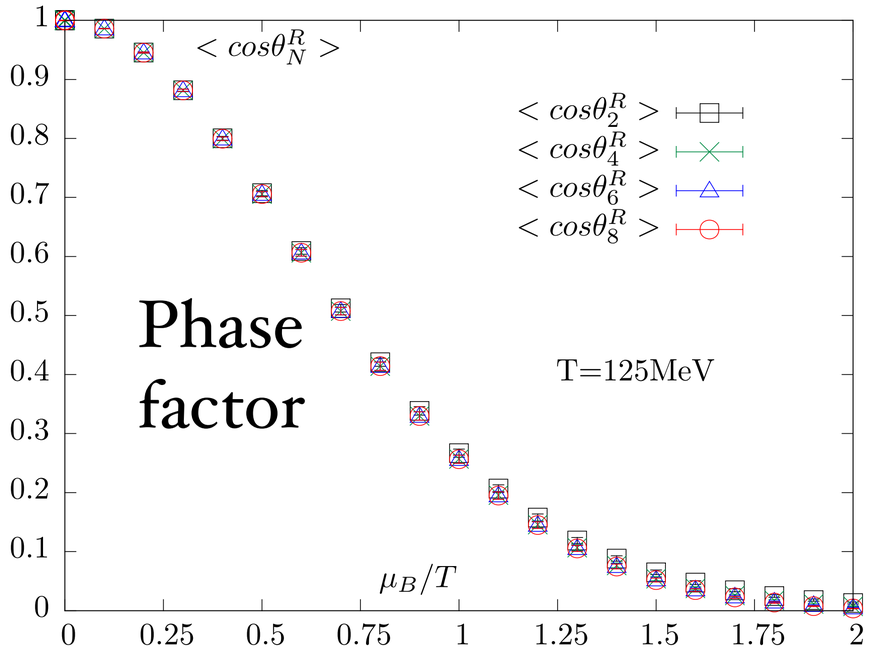
$$\bar{D}_n = \frac{1}{n!}\frac{\partial^n \ln\det[M(T,\mu_B)]}{\partial(\mu_B/T)^n}\bigg|_{\mu_B=0}$$

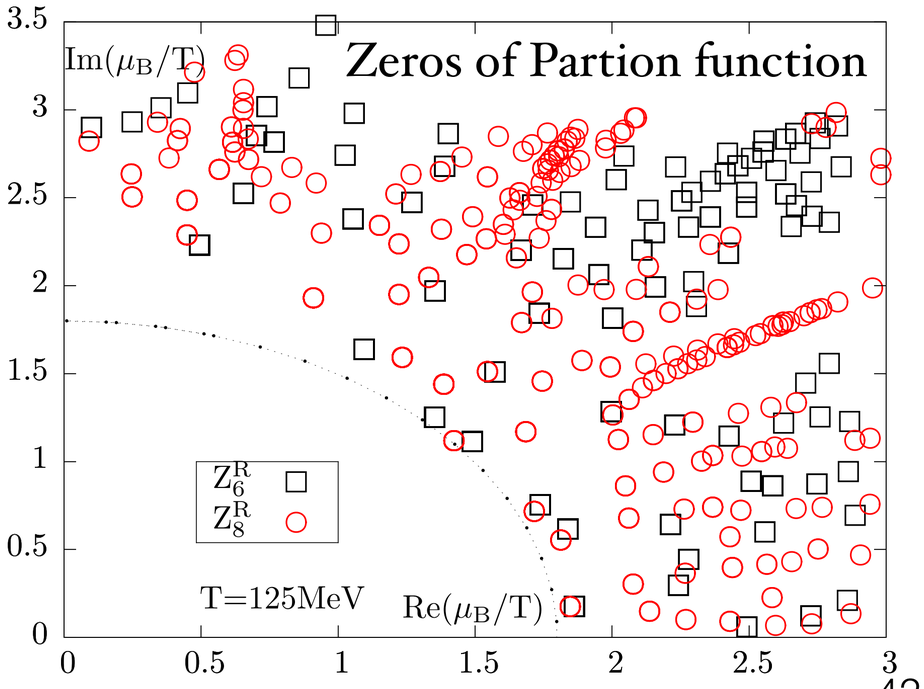
$$\frac{\Delta P_N^R}{T^4} = \frac{1}{VT^3}\ln\left(\frac{Z_N^R(T,\mu_B)}{Z(T,0)}\right) = \frac{1}{VT^3}\ln\left\langle \exp\left[\sum_{n=1}^{N}\bar{D}_n\left(\frac{\mu_B}{T}^n\right)\right]\right\rangle$$

$$\langle\cos\Theta_N^R\rangle = \left\langle \cos\left(\sum_{n=1}^{N/2}\mathrm{Im}[\bar{D}_{2n-1}]\left(\frac{\mu_B}{T}\right)^{2n-1}\right)\right\rangle$$

S. Mondal, S. Mukherjee & P. Hegde, PRL 128 (2022) 022001

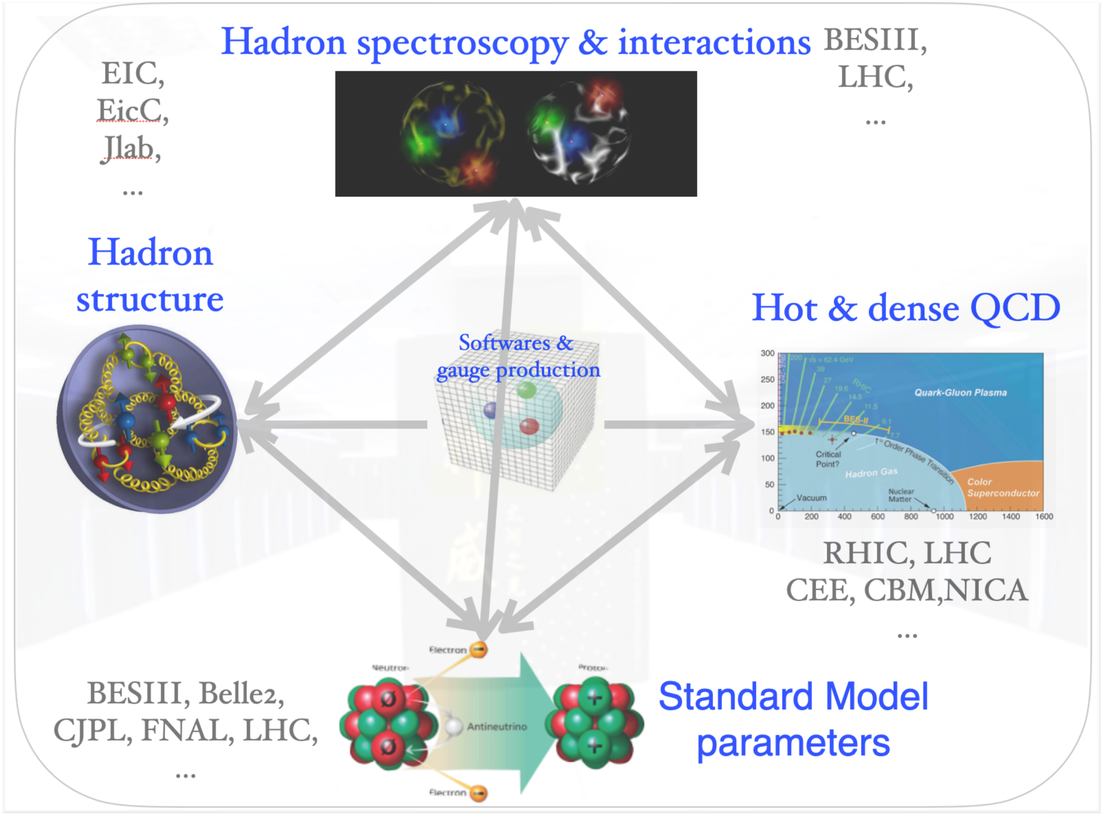
李文汐 et al., CCNU-BNL, work in preparation





Summary & Outlook

刘川, 2006,
中国物理学会高能物理分会
第七届学术年会
大会报告



CLQCD

2021-2022: 7 PRL +...

Lattice 2022 plenary talks:

刘柳明(近物所)

晨光杯:

2014 桂龙成(高能所)
2021 李胜泰(华中师大)
2022 傅杨(北大, 候选人)

$\Longrightarrow$ Lattice QCD applications on Exa-scale supercomputers in China

第二届中国格点QCD研讨会

时间：2022年10月7-10日

地点：李政道研究所

交流格点QCD研究最新进展

谋划E级超算上的格点应用

欢迎各位莅临交流指导！

https://indico-tdli.sjtu.edu.cn/event/1198/overview