Toward the precise determination of the disconnected quark diagram

傅子文

(Ziwen Fu)

10/11/2019

四川大学原子核科学技术研究所(720所)

热烈欢迎来自全国的格点QCD专家莅临四川大学指导工作

四川大学有格点QCD的历史渊源

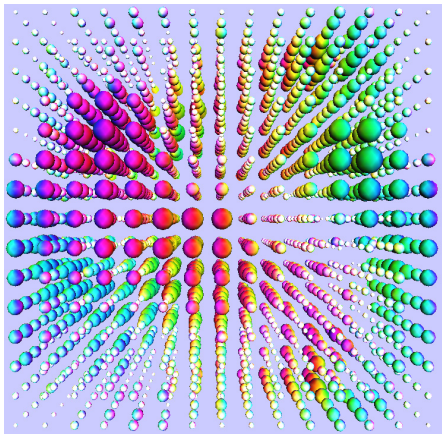
- 郑希特教授是我国第一代格点人之一
- 王顺金教授

  光锥QCD等效场论与介子结构

  用格点QCD研究真空的拓扑结构
- 吕晓夫教授涉及格点QCD

Motivation

(Why disconnected quark diagram?)



两个“情怀”

1: MILC Study of Scalar Meson(标量介子)

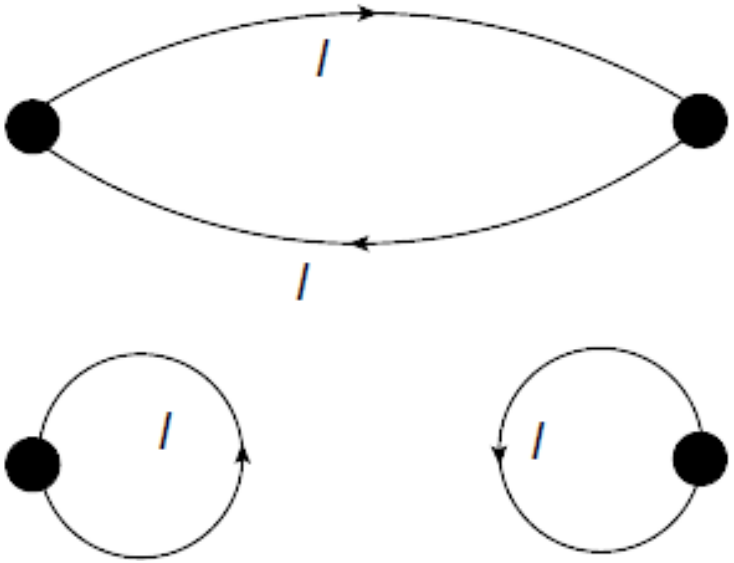
- **Carleton E. DeTar**, John B. Kogut , **Measuring the Hadronic Spectrum of the Quark Plasma,** Phys.Rev. D36 (1987) 2828
- **Carleton E. DeTar**, Teiji Kunihiro, **Linear σ Model With Parity Doubling, Phys.Rev. D39 (1989) 2805**

More than **six years** of Ph.D study on scalar mesons

Teiji Kunihiro et al, Scalar meson in lattice QCD, Phys. Rev. D 70, 034504 (2004)

C. Bernard，C. DeTar, Ziwen Fu，S. Prelovsek，Scalar meson spectroscopy with lattice staggered fermions , Phys. Rev. D 76, 094504 (2007)

First meet disconnected quark diagrams



Two diagrams appearing in the sigma correlation

- Teiji Kunihiro et al, Phys. Rev. D 70, 034504 (2004)
- **Q. Liu**, PoS **LAT2009**, 101 (2009)
- C. Bernard, C. DeTar, Ziwen Fu, S. Prelovsek, Phys. Rev. D 76, 094504 (2007)
- **Ph.D dissertation gives the details (FFT, etc)**

Motivation

2: 2006~2009 美国标准技术研究院 (标准技量局) 中子研究中心任客座研究员 (Guest Researcher)

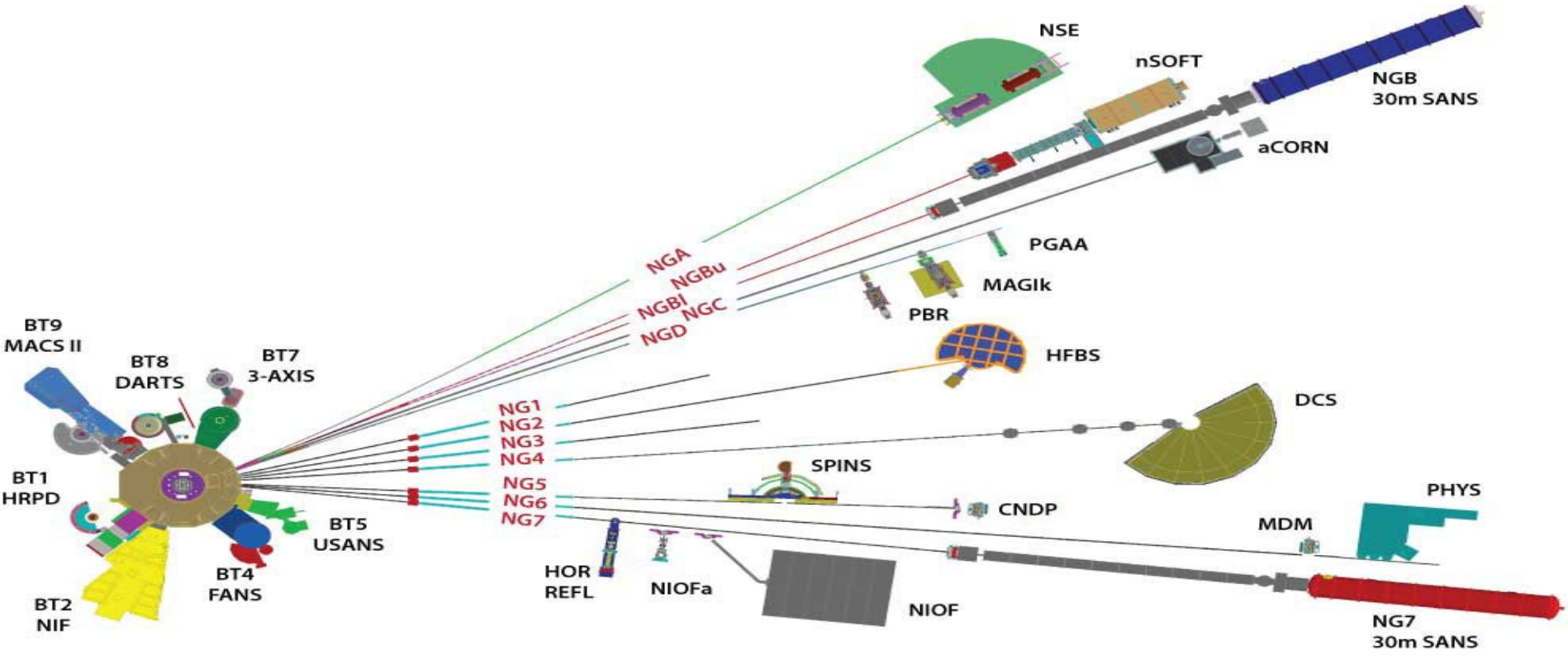
(Neutron scattering)中子散射:

NIST Center for Neutron Research (NCNR)

Experiment, Fit, modeling, Code development.

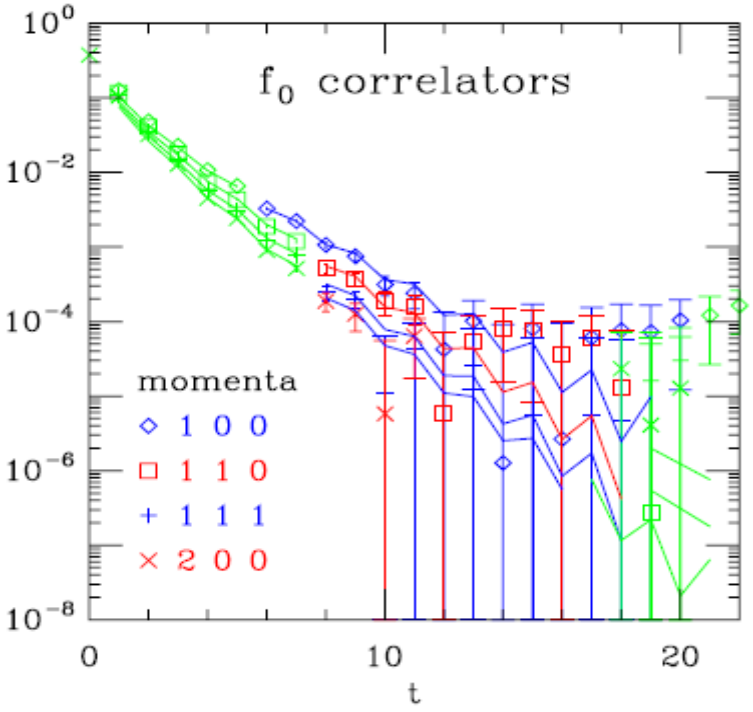
Y. Kuramashi et al, Phys. Rev. Lett. **71** 2387 (1993).

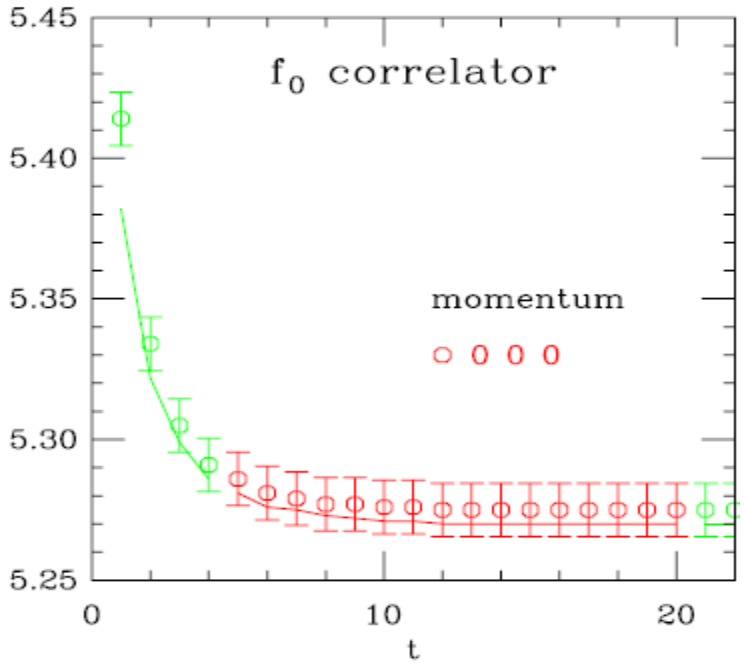
M. Fukugita et al, Phys. Rev. D **52** 3003 (1995).


NSE
nSOFT
NGB
30m SANS
aCORN
PGAA
MAGIk
PBR
HFBS
DCS
SPINS
CNDP
PHYS
MDM
NG7
30m SANS
NIOF
NIOFa
HOR
REFL
NGA
NGBu
NGBl
NGC
NGD
NG1
NG2
NG3
NG4
NG5
NG6
NG7
BT9
MACS II
BT8
DARTS
BT7
3-AXIS
BT1
HRPD
BT5
USANS
BT4
FANS
BT2
NIF

Lattice determination of the disconnected quark diagram

Case 1: Two-point correlation





C. Bernard，C. DeTar, Ziwen Fu，S. Prelovsek， Phys. Rev. D 76, 094504 (2007)

510 $24^3 64$ m_π=250MeV a=0.12fm, MILC RevModPhys.82.1349

Coding: 2 Years, Calculation: 2 Years, Others: 2 Years. FFT

FFT Algorithm:

1) Z_2 Technique
2) Improve the Heller's code (100G Memory?)
3) Concrete code is in detail described in Dissertation

C. Bernard, C. DeTar, Ziwen Fu, S. Prelovsek, Phys. Rev. D 76, 094504 (2007)
510 $24^3 64$ m_π =250MeV a=0.12fm, MILC RevModPhys.82.1349
Calculation: 2 Years, 300MFlops(免费)
600MFlops MILC aim：800MFlops

Center for High-Performance Computing
© the University of Utah

2000年就开始了
"disconnected 情结"

计算资源

Currecntly work on:

$40^3 96 \quad m_\pi = 240\text{MeV}\ a = 0.09\,fm \quad am_\pi = 0.105$

$48^3 144 \quad m_\pi = 300\text{MeV}\ a = 0.06\,fm \quad am_\pi = 0.094$

$56^3 144 \quad m_\pi = 260\text{MeV}\ a = 0.06\,fm \quad am_\pi = 0.078$

$64^3 144 \quad m_\pi = 230\text{MeV}\ a = 0.06\,fm \quad am_\pi = 0.0667$

MILC work： 2 Years （100 年）

Now： 2 Year

内存？ （DDR4）

- 四川大学高性能计算中心(SCU_HPC)
- 辐射物理国家重点实验室计算中心(ITER)
- 等离子体重点实验室计算中心(ITER苟富均)
- 格点工作站（傅子文）
- 其他
- 2GFlops ~ 10GFlops

四川大学高性能计算中心

Welcome to HPC Center !!!

login node

node17	16 cores 64G mem
node18	16 cores 64G mem

compile node

node201	16 cores 64G mem

computing nodes

node19-20	28 cores 128G mem 2*K80
node21-53	28 cores 192G mem
node61-67	56 cores 512G mem

100 Jobs
1/3 内存

辐射物理国家重点实验室计算中心

computing nodes			
Node 类1	（若干）	36 cores	128G mem 2*K80
Node 类2	（若干）	36 cores	256G mem 2*K80
Node 类3	（若干）	72 cores	512G mem 最新GPU

100 Jobs
80% 内存

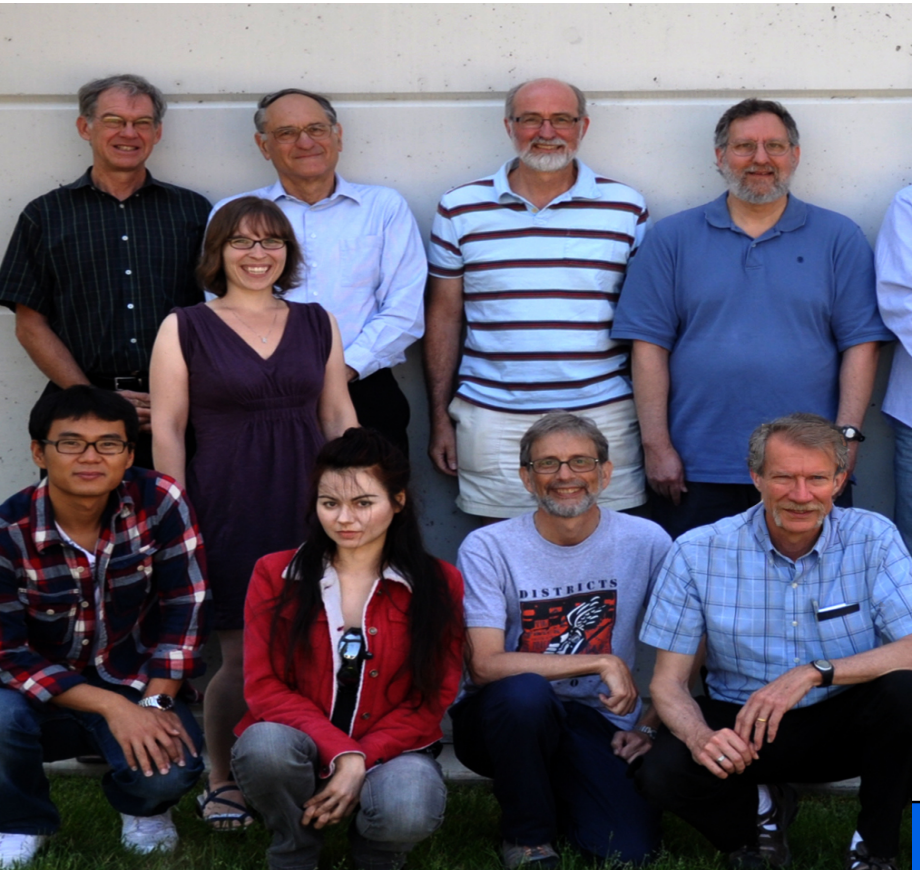
候氢：在编程序的时候，
幸福指数最高。

主要合作者 陈旭

2019年度四川省科技进步奖一等奖

多功能直线等离子体装置研制及应用　苟富均、陈旭、陈波、陈建军

等离子体重点实验室计算中心(ITER苟富均)

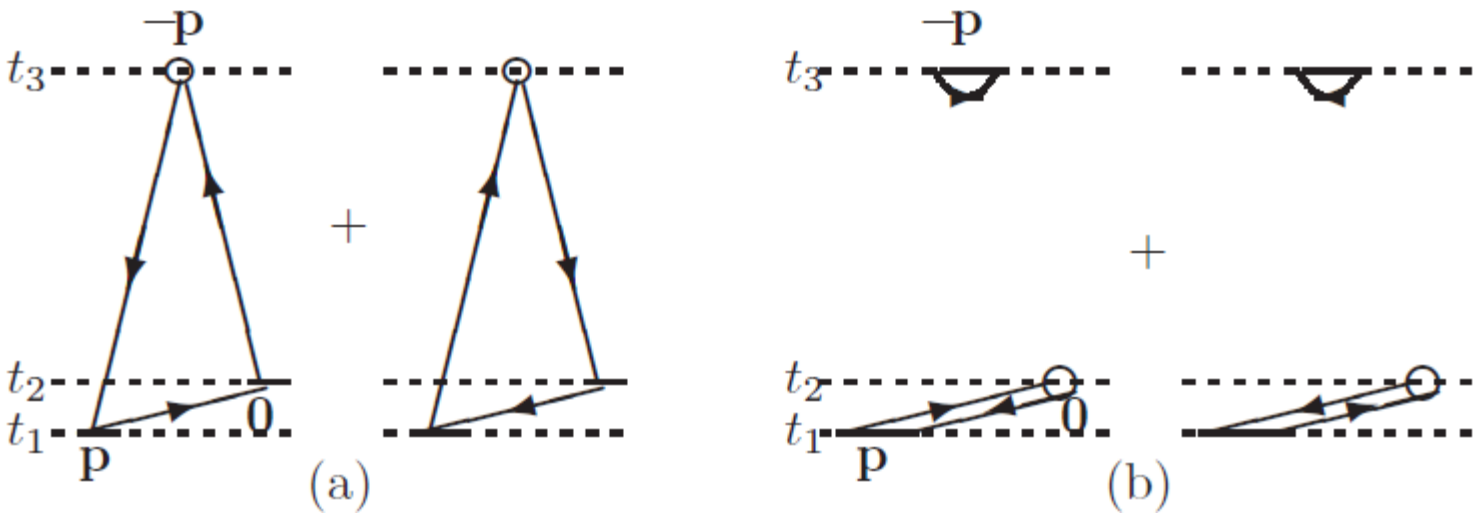


主要合作者 陈旭

计算工作？
10GFlops
普及格点QCD

Lattice determination of the disconnected quark diagram

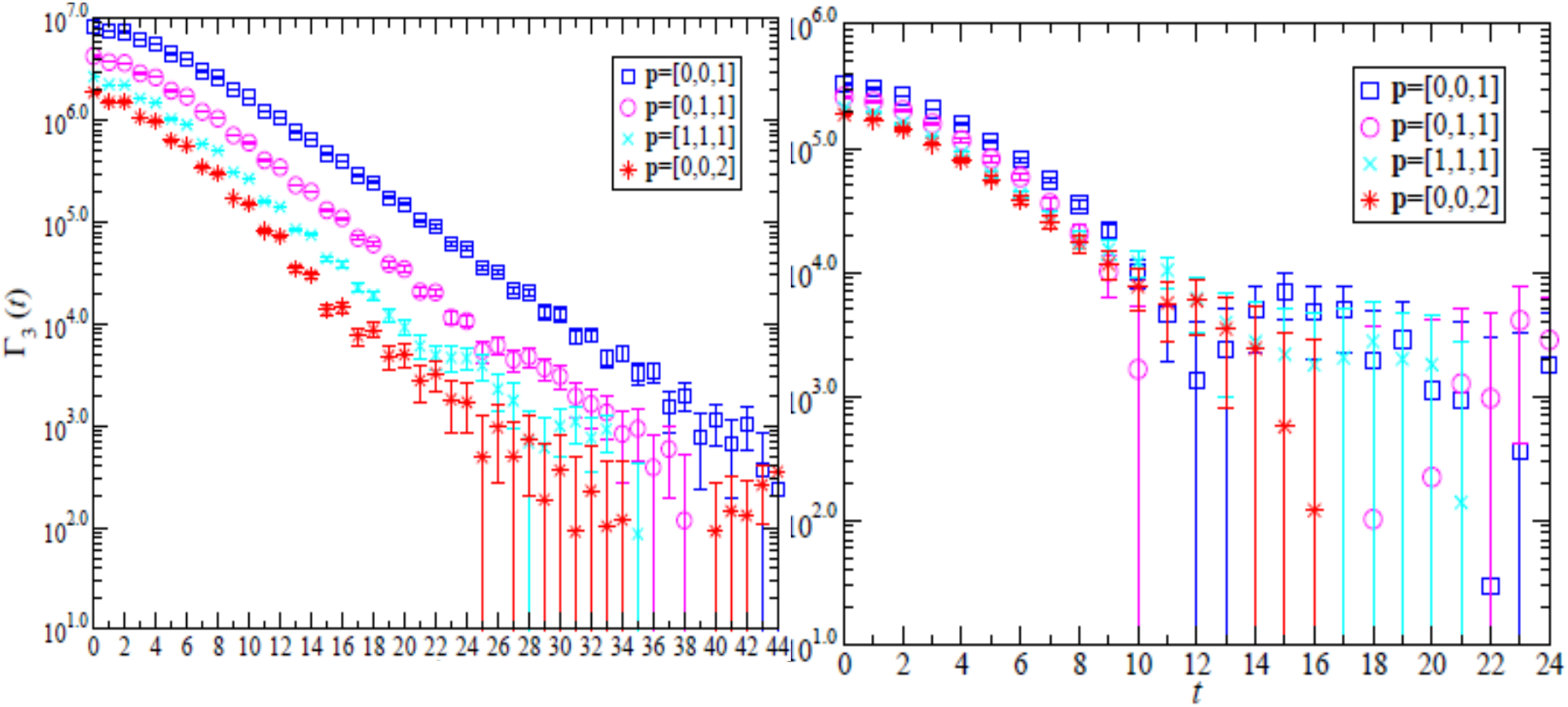
Case 2: Three-point correlation $\sigma \to \pi\pi$



Wang, Lingyun; Fu, Ziwen; **Chen, Hang**, **arXiv:1702.08337**

400 $40^3 96$ m_π=240MeV a=0.09fm

Preliminary results



Wang, Lingyun; Fu, Ziwen; **Chen, Hang**, **arXiv:1702.08337**

400 $40^3 96$ m_π =240MeV a=0.09fm 187 $40^3 96$

相差1~2个数量级

Cheng Hang

Wang, Lingyun, Fu, Ziwen, Cheng Hang, arXiv:1702.08337

$$\Gamma_3 = f_{SA\pi}\big[P(E_S, E_\pi + E_A)e^{-E_\pi(t_S-t_\pi)}e^{-E_A(t_S-t_A)} + P(E_A, E_S + E_\pi)e^{-E_S(t_S-t_A)}e^{-E_\pi(t_\pi-t_A)} + P(E_\pi, E_S - E_A)e^{-E_S(t_S-t_\pi)}e^{-E_A(t_\pi-t_A)}\big],$$

$$f_{SA\pi} \equiv g_{SA\pi}\frac{\sqrt{Z_S(\mathbf{q}_S)Z_A(\mathbf{q}_A)Z_\pi(\mathbf{q}_\pi)}}{8E_S(\mathbf{q}_S)E_A(\mathbf{q}_A)E_\pi(\mathbf{q}_\pi)}. \qquad P(\omega, E) \equiv \frac{\sinh(\omega)}{\cosh(\omega)-\cosh(E)}.$$

Raul A. Briceño, Jozef J. Dudek, Robert G. Edwards, and David J. Wilson,
Isoscalar ππ Scattering and the σ Meson Resonance from QCD
PRL 118, 022002 (2017)

$$g^2_{\sigma\pi\pi} = \lim_{s\to s_0}(s_0 - s)t(s)$$

$$g^2_{\sigma\pi\pi} = \lim_{s\to s_0}\frac{s_0 - s}{4\pi\, t(s)}$$

Improve the signals?

Phys. Rev. D 94, 034505 (2016)

$$R_{NS}^2 \propto \sqrt{\frac{1}{N_{\rm cfg} N_{\rm slice} L^3}} \exp[(E_M - m_\pi)t].$$

$$R_{NS}^4 \propto \sqrt{\frac{1}{N_{\rm cfg} N_{\rm slice} L^3}} \exp[(E_\pi(\mathbf{p}) + E_\pi(\mathbf{q}) - 2m_\pi)t],$$

- Gauge Configurations (N=1000)
- Time slices (T=96,144,192.,etc)
- Big lattice (L=64?)
- Fine lattice (a=0.06fm, 0.045fm)
- Others (杨一玻, etc）

Currecntly work on:

$L^3T = 40^3 96$ $am_\pi = 0.105$

$L^3T = 48^3 144$ $am_\pi = 0.094$

$L^3T = 56^3 144$ $am_\pi = 0.078$

$L^3T = 64^3 144$ $am_\pi = 0.0667$

FFT Algorithm:

1) Z_2 Technique + Moving wall source technique
2) Improve the Heller's code (100G Memory?)
3) Concrete code will be published soon…

Currecntly work on:

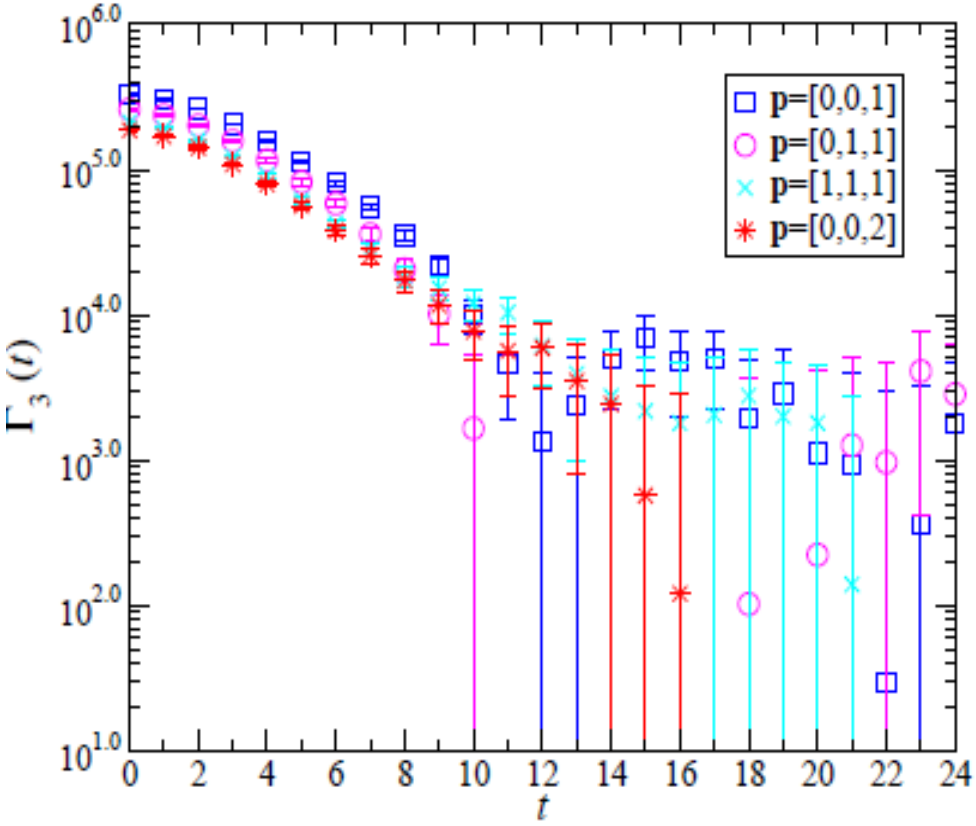
$40^3 96 \quad m_\pi = 240\text{MeV}\ a = 0.09\,fm \quad am_\pi = 0.105$

$48^3 144 \quad m_\pi = 300\text{MeV}\ a = 0.06\,fm \quad am_\pi = 0.094$

$56^3 144 \quad m_\pi = 260\text{MeV}\ a = 0.06\,fm \quad am_\pi = 0.078$

$64^3 144 \quad m_\pi = 230\text{MeV}\ a = 0.06\,fm \quad am_\pi = 0.0667$

To be published soon?



Ph.D 陈旭论文

$40^3 96$ m_π =240MeV a=0.09fm

Currecntly work on:

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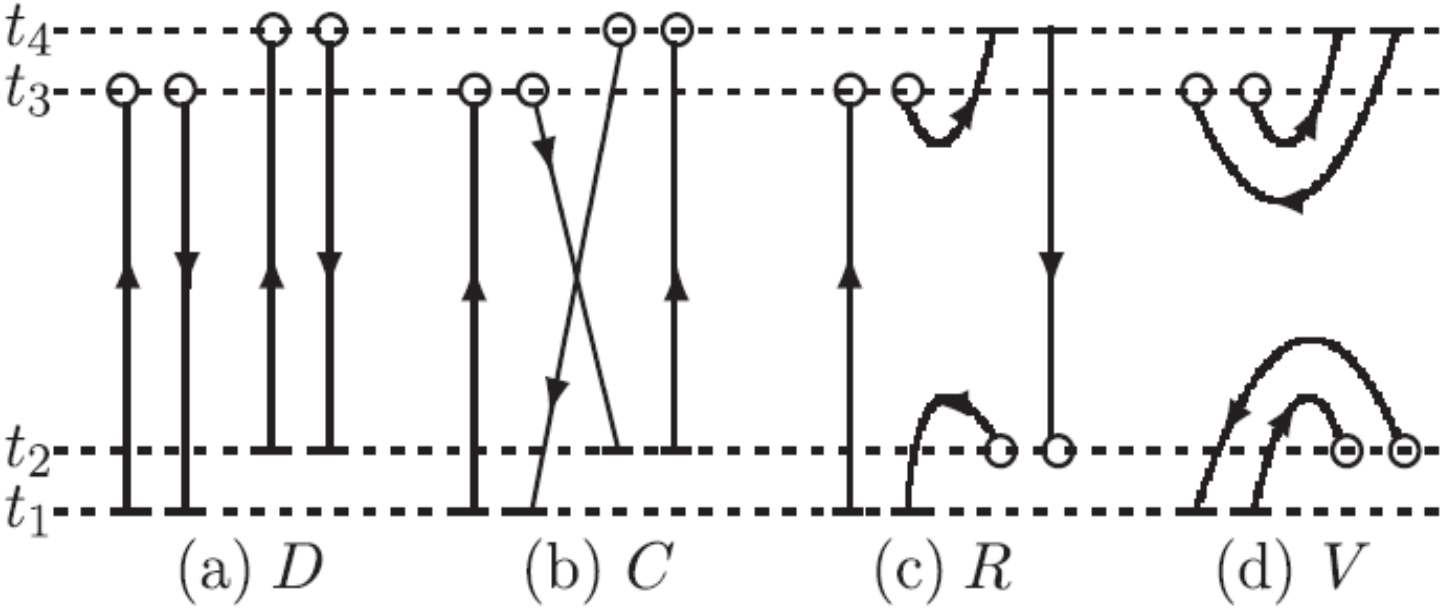
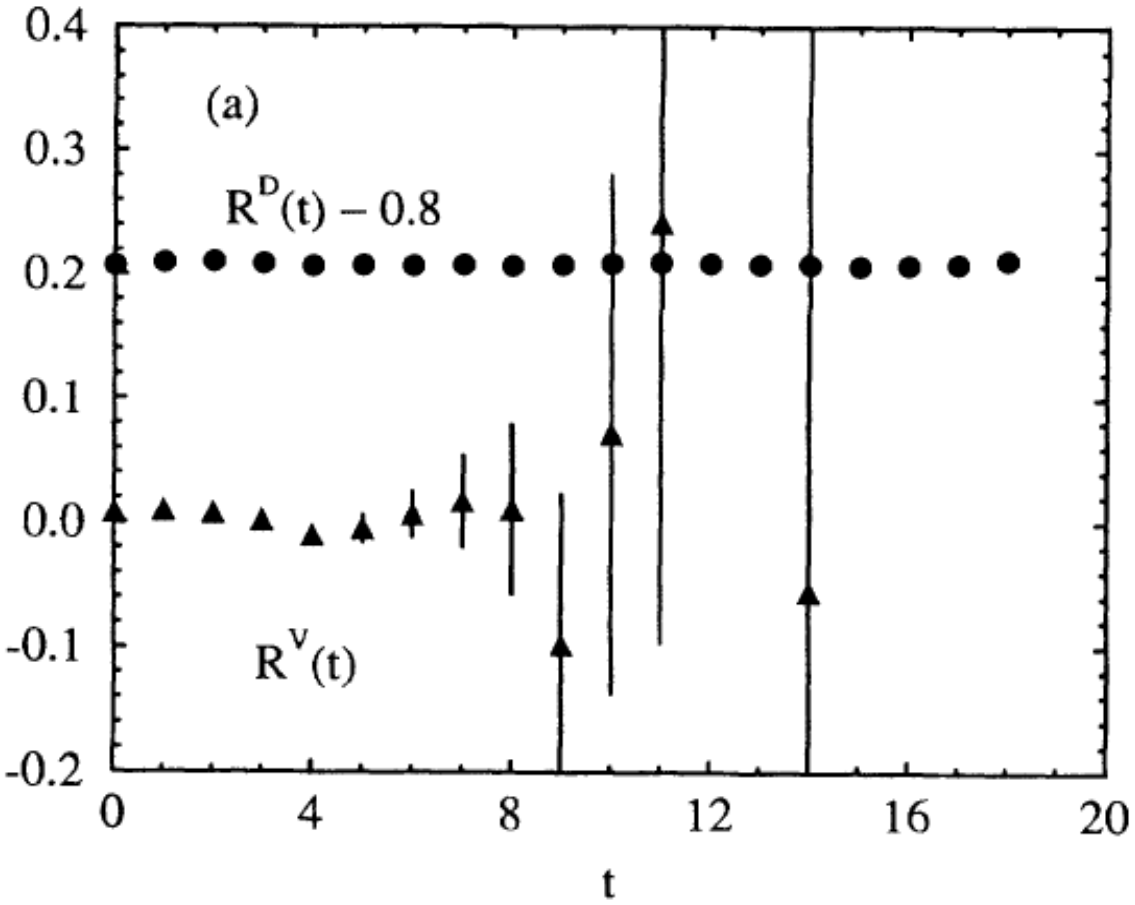
Lattice determination of the disconnected quark diagram

Case 3: Four-point correlation $\pi\pi \to \pi\pi$



Y. Kuramashi et al, Phys. Rev. Lett. **71** 2387 (1993).
M. Fukugita et al, Phys. Rev. D **52** 3003 (1995).

Individual amplitude ratios



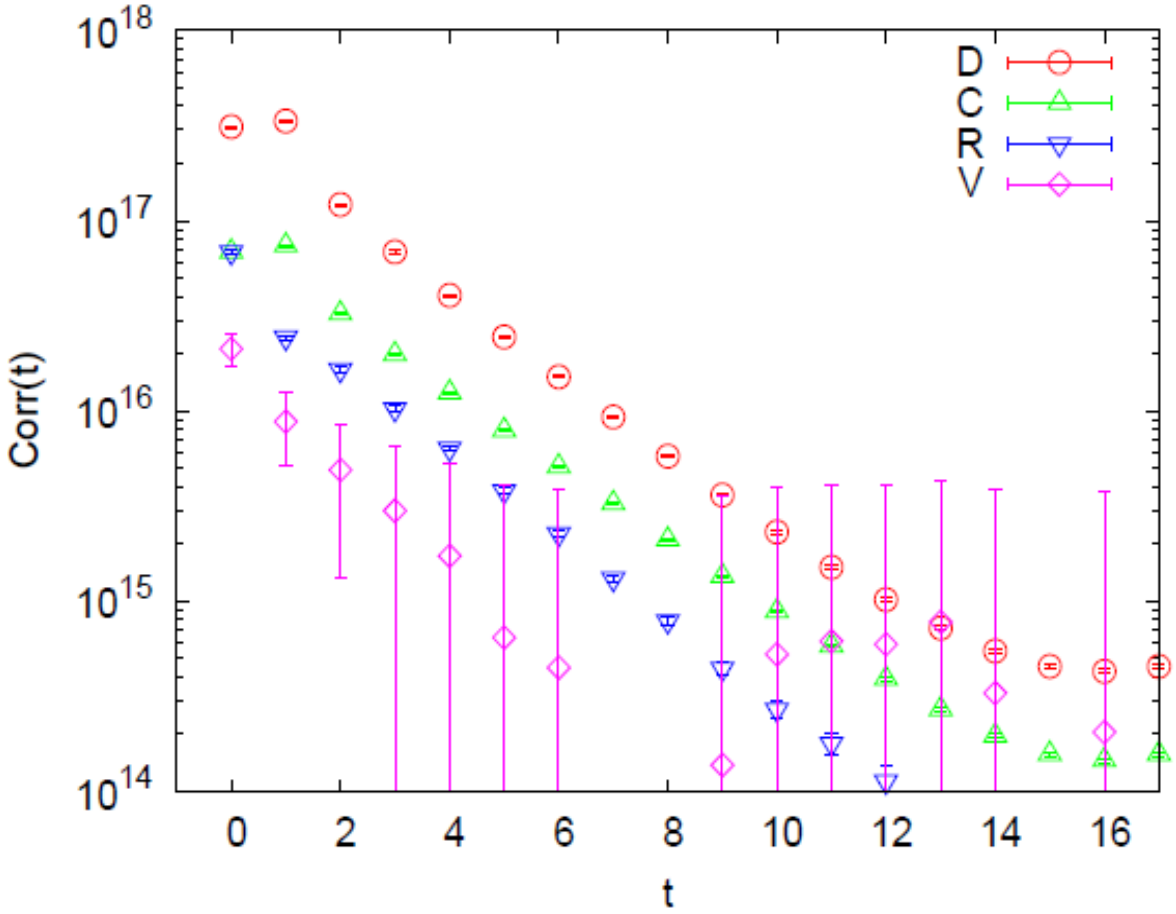
$12^3 20$ $am_\pi = 0.29$

Y. Kuramashi et al, Phys. Rev. Lett. **71** 2387 (1993).
M. Fukugita et al, Phys. Rev. D **52** 3003 (1995).

$$R^X(t) = \frac{C^X(0,1,t,t+1)}{C_\pi(0,t)C_\pi(1,t+1)}$$

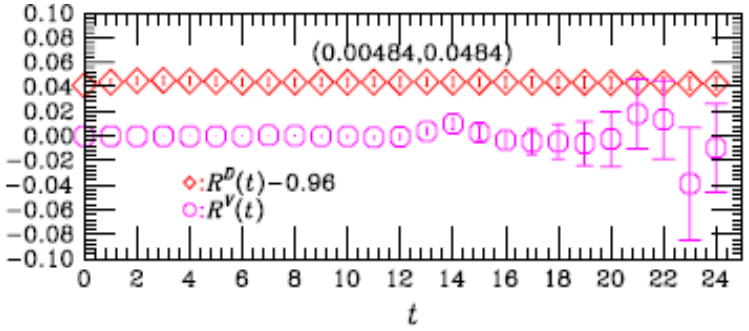
Individual amplitude ratios

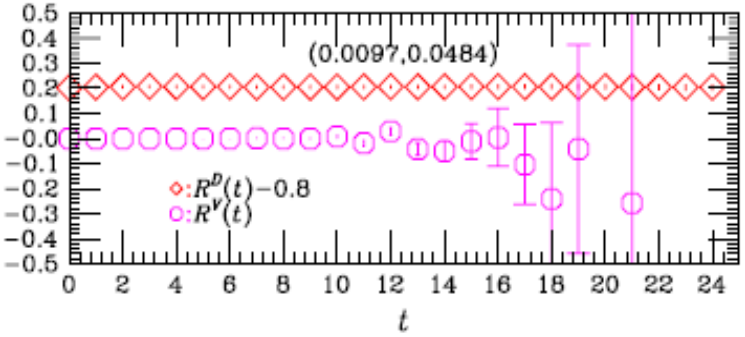
●**Q. Liu**, PoS **LAT2009**, 101 (2009)

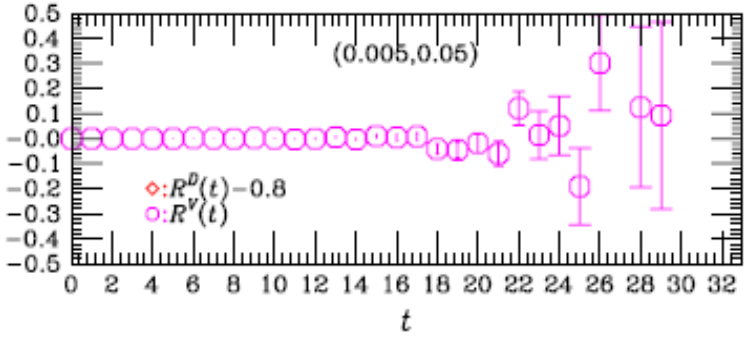


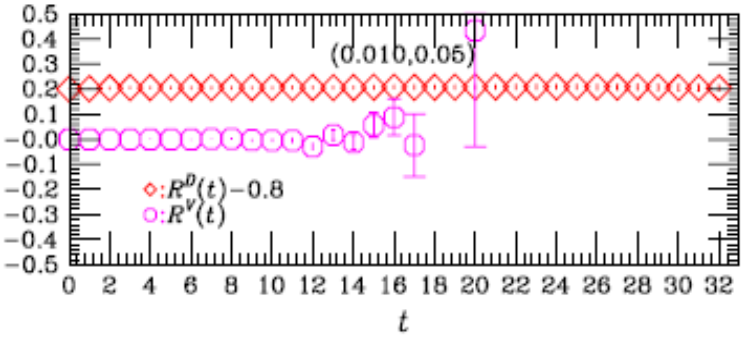
$16^3 32$ $am_\pi = 0.247$

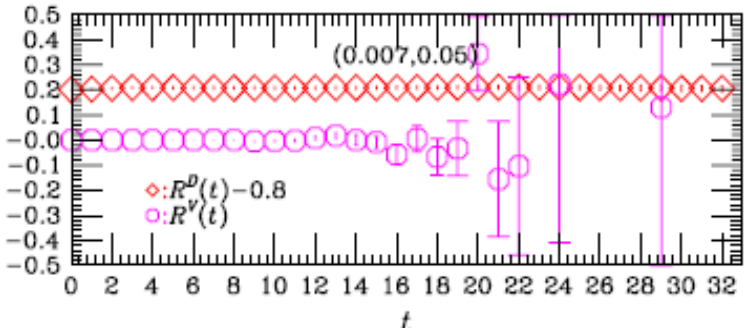
Individual amplitude ratios

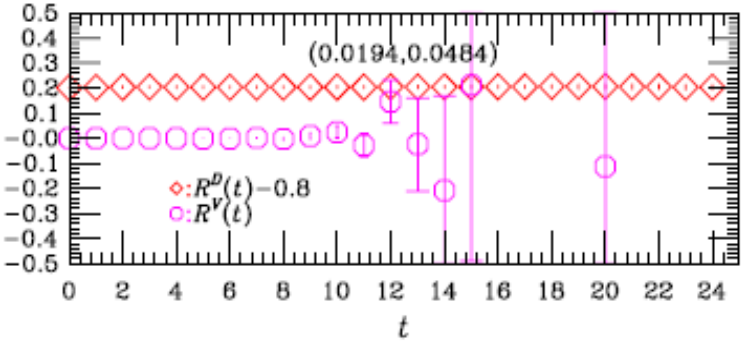






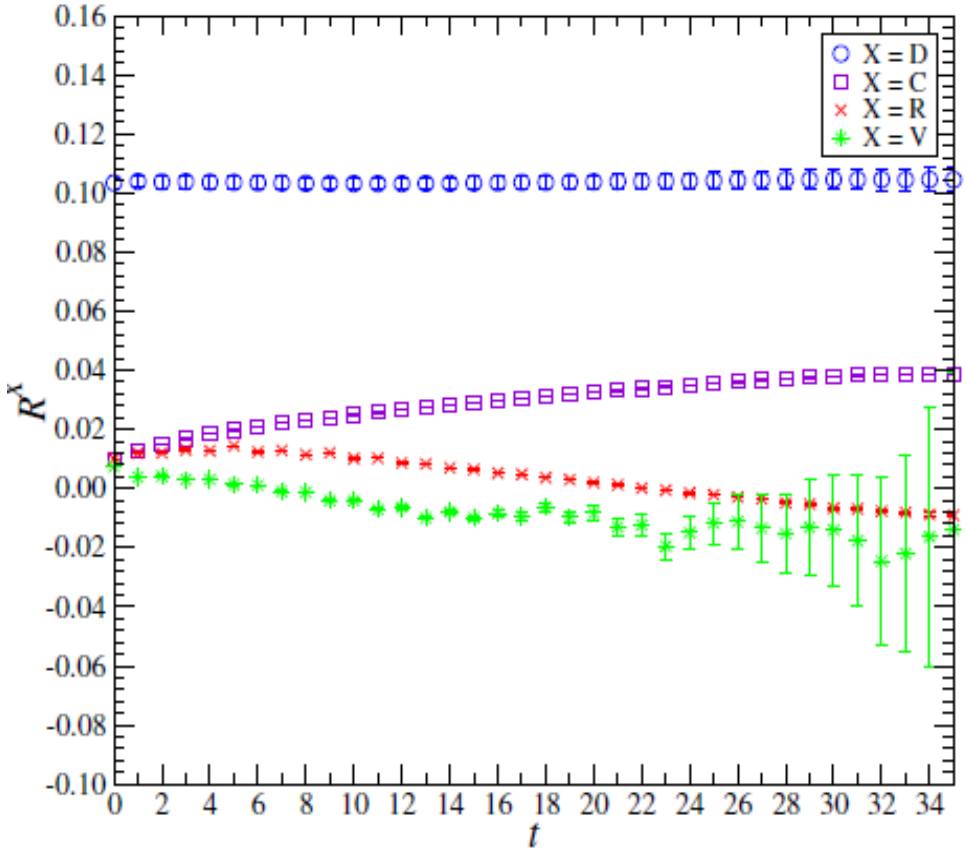




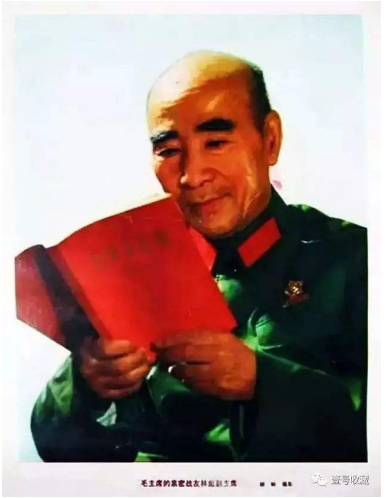


PHYSICAL REVIEW D 87, 074501 (2013)

Individual amplitude ratios



Phys. Rev. D **98** 014514 (2018)



604 $40^3 96$ a $m_\pi = 0.105$

$$R^4_{NS} \propto \sqrt{\frac{1}{N_{\rm cfg} N_{\rm slice} L^3}} \exp[(E_\pi(\mathbf{p}) + E_\pi(\mathbf{q}) - 2m_\pi)t],$$

FFT Algorithm:

1) Moving wall source technique
2) Improve the Heller's code (100G Memory?)
3) Concrete algorithm is published in Phys. Rev. D **98** 014514 (2018)

Currecntly work on:

$40^3 96 \quad m_\pi = 240\ MeV \quad a = 0.09\ fm$

$48^3 144 \quad m_\pi = 300\ MeV \quad a = 0.06\ fm$

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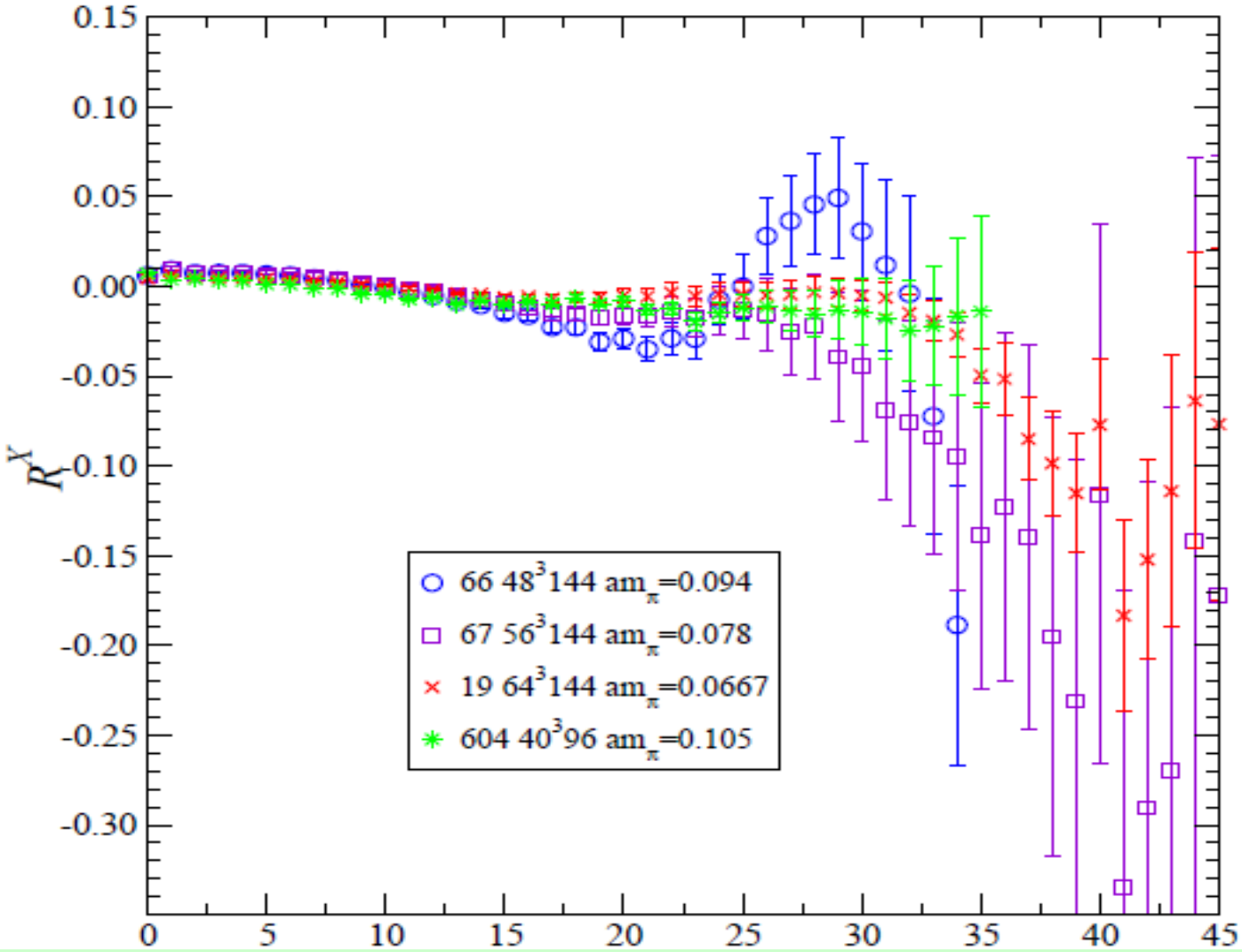
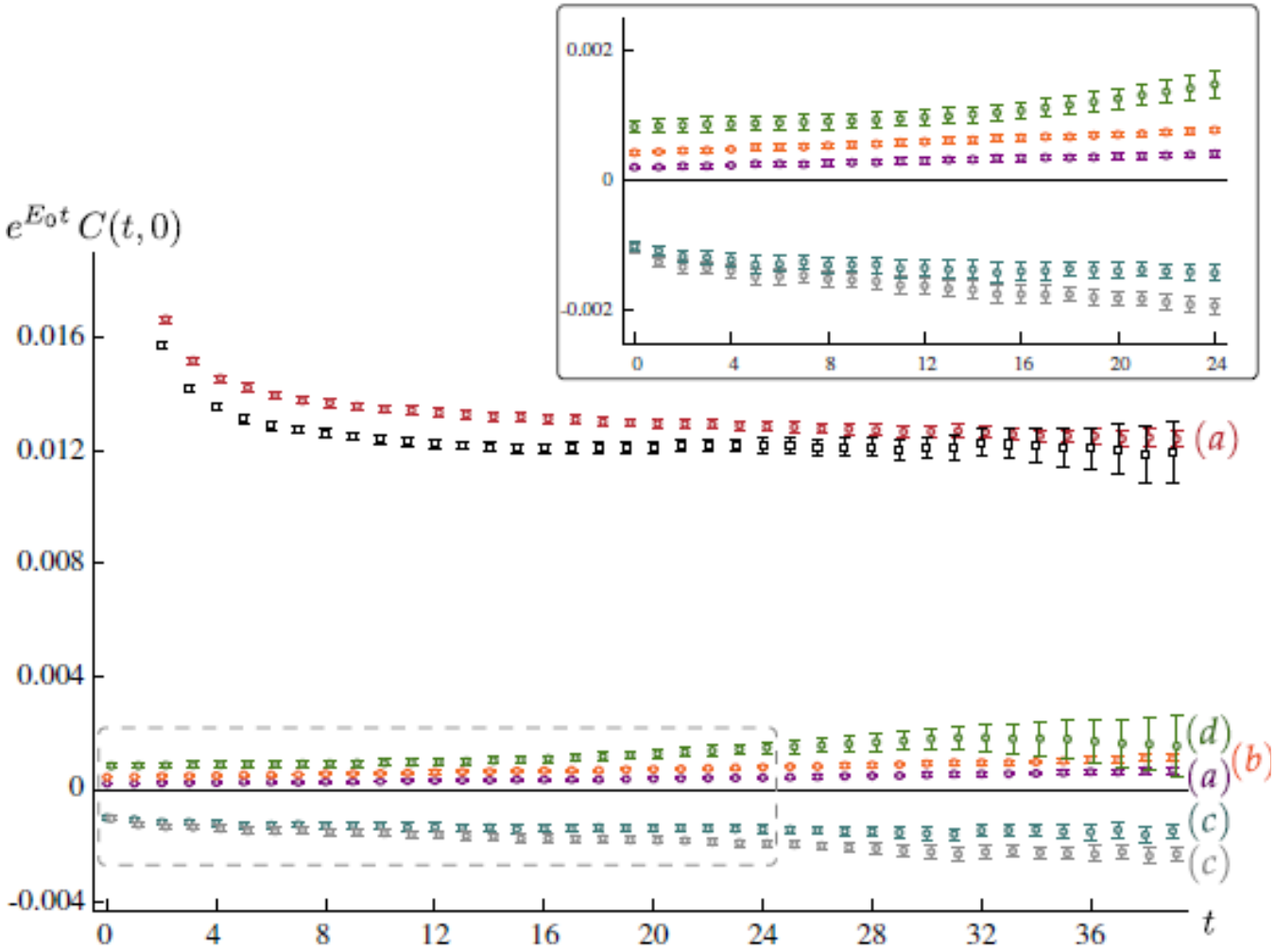
Toward the precise determination of the disconnected quark diagram



Phys. Rev. D **98** 014514 (2018) (000) Center-of-mass Frame

Comparable to HSC



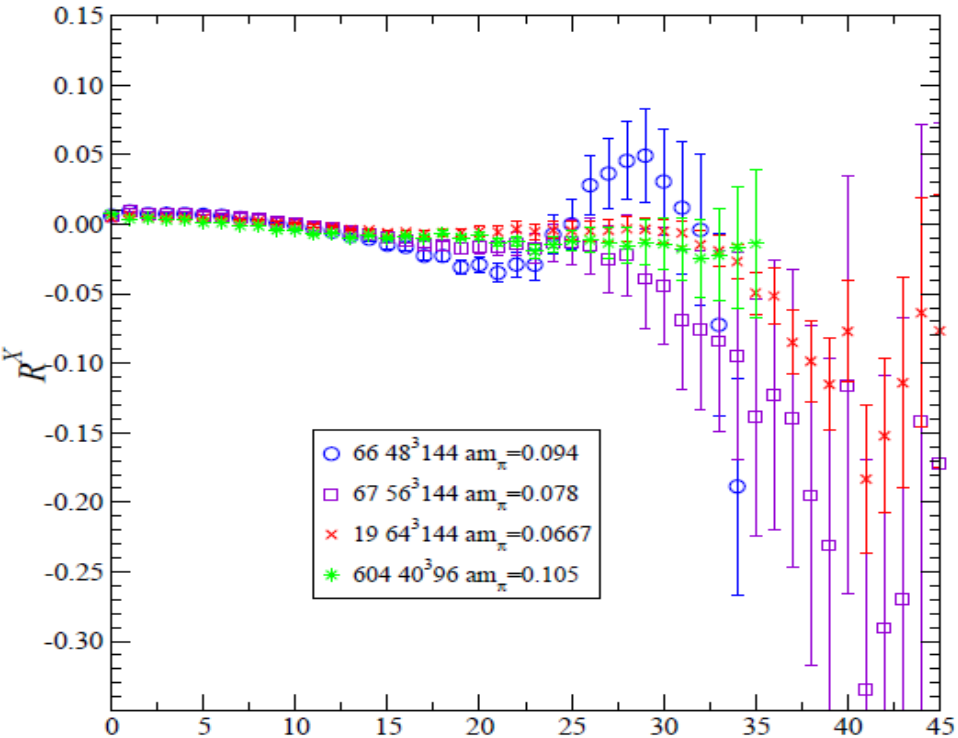
Raul A. Briceño, etc (Hadron Spectrum Collaboration), Isoscalar ππ Scattering and the σ Meson Resonance from QCD PRL 118, 022002 (2017)

$32^3 256$ $a_t m_\pi = 0.069$ Anisotropic configurations (500) $m_\pi = 236\text{MeV}$ (011)

Toward the precise determination of the disconnected quark diagram

$$C^V_{\pi\pi}(\mathbf{p}, t_4, t_3, t_2, t_1) = \sum_{\mathbf{x}_2,\mathbf{x}_3} \cos(\mathbf{p}\cdot(\mathbf{x}_2-\mathbf{x}_3))\langle \mathrm{Tr}[G^\dagger_{t_1}(\mathbf{x}_2,t_2)G_{t_1}(\mathbf{x}_2,t_2)]\mathrm{Tr}[G^\dagger_{t_4}(\mathbf{x}_3,t_3)G_{t_4}(\mathbf{x}_3,t_3)]\rangle$$
$$- \delta_{\mathbf{p},0}\sum_{\mathbf{x}_2,\mathbf{x}_3}\langle \mathrm{Tr}[G^\dagger_{t_1}(\mathbf{x}_2,t_2)G_{t_1}(\mathbf{x}_2,t_2)\rangle\langle \mathrm{Tr}[G^\dagger_{t_4}(\mathbf{x}_3,t_3)G_{t_4}(\mathbf{x}_3,t_3)]\rangle,$$

Phys. Rev. D **98** 014514 (2018)



其它动量（001）???
无背景噪声

敬请期待

Calculation Time

```
processing t=41
CG: time:4.06e+04 iters:3509 GFLOPS:3.87 at c=0
CG: time:4.07e+04 iters:3555 GFLOPS:3.92 at c=1
CG: time:4.02e+04 iters:3494 GFLOPS:3.89 at c=2
processing t=42
CG: time:4.05e+04 iters:3557 GFLOPS:3.94 at c=0
CG: time:4.09e+04 iters:3572 GFLOPS:3.91 at c=1
CG: time:4.04e+04 iters:3529 GFLOPS:3.91 at c=2
processing t=43
CG: time:4.05e+04 iters:3476 GFLOPS:3.84 at c=0
CG: time:4.01e+04 iters:3505 GFLOPS:3.92 at c=1
CG: time:4.10e+04 iters:3589 GFLOPS:3.92 at c=2
processing t=44
CG: time:4.01e+04 iters:3484 GFLOPS:3.89 at c=0
CG: time:4.04e+04 iters:3540 GFLOPS:3.92 at c=1
CG: time:4.03e+04 iters:3528 GFLOPS:3.92 at c=2
processing t=45
CG: time:4.07e+04 iters:3536 GFLOPS:3.89 at c=0
CG: time:4.12e+04 iters:3610 GFLOPS:3.92 at c=1
CG: time:4.01e+04 iters:3513 GFLOPS:3.93 at c=2
processing t=46
CG: time:4.03e+04 iters:3522 GFLOPS:3.91 at c=0
```

$$L^3T = 64^3144$$

$64144f21b746m0018m018a.1062$

144*3*40000 ~ **250天**

十年磨一剑
砺得梅花香

2000~2019　20年
2009~2019　10年
再战10年

情怀
QING HUAI

格点QCD计算三部曲

规范场组态
Gauge Configuration

下载(MILC)
自己产生？

传播子
(90%)

储存
>500T

两点关联函数
（质量、胶球）

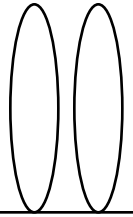
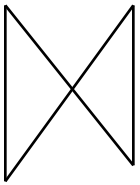
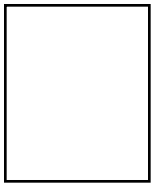
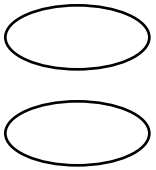
三点关联函数
（衰变）

四点关联函数
（介子散射）

四点关联函数
（介子-重子散射）

……

Takeshi YAMAZAKI，University of Tsukuba （10年前）

通道					共振态
$I=2\ \pi\pi$	O	O	X	X	
$I=1\ \pi\pi$	O	O	O	X	ρ
$I=0\ \pi\pi$	O	O	O	O	σ
$I=3/2\ \pi K$	O	O	X	X	
$I=1/2\ \pi K$	O	O	O	X	κ
$I=1\quad KK$	O	O	X	X	
$I=1\quad K\bar{K}$	O	O	O	X	
$I=0\quad K\bar{K}$	O	O	O	O	
	Easy	Easy	Hard	impossible	

- **HSC不答应（非常出色）**
- **进一步研究I=0 $K\bar{K}$散射**

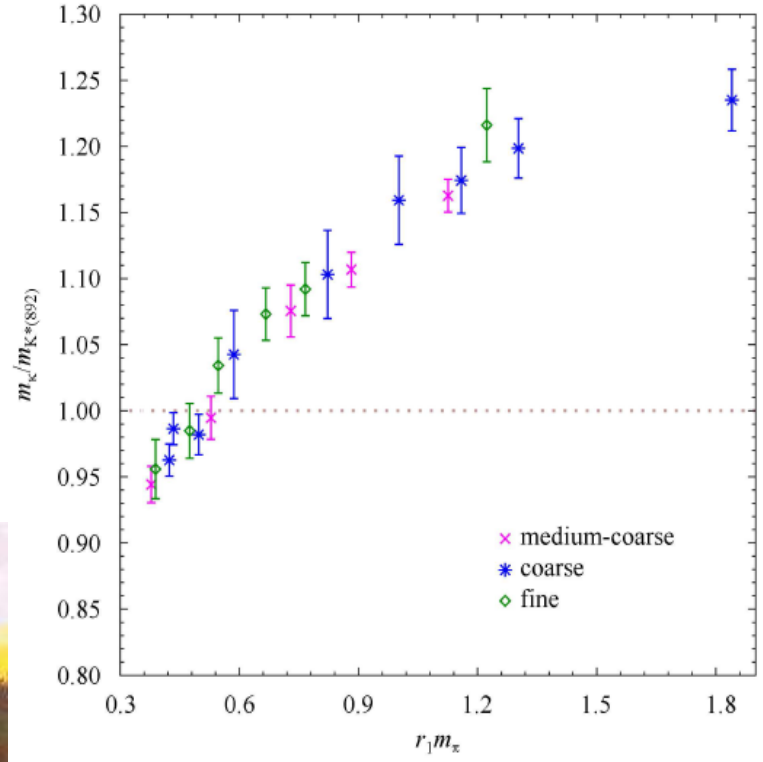
计算量太大，如何克服

- 软件 (候氢GPU等, 几十倍？）
- 硬件 (1T内存，陈旭，预计计算缩短到一年以)
- 与兄弟单位合作（585等）

更大的格点计算（64^3 192）在进行中….

总结与展望

- 积累的数据可以做点其它事情：
  - -标量介子共振态参数的有效确定？
  - -中子散射
  - -天体物理（宇宙学）
  - -其它



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总结与展望

- 与兄弟单位合作
  - -核反应截面（九院：可控核反应）