B5: Exotic States from Lattice QCD

Ying Chen, **Marcus Petschlies**, Carsten Urbach

HISKP, University of Bonn
Bethe Center for Theoretical Physics,
European Twisted Mass Collaboration

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Personnel

- Principal Investigators:
  Ying Chen
  Carsten Urbach

- Students:
  Yunheng Ma
  Max Oehm
  Fernando Romero López
  Martin Ueding
  Marcus Werner
  Wei Sun

- Associate Professor:
  Zhaofeng Liu

- Post-Docs:
  Marcus Petschlies
  Liuming Liu
  Bartosz Kostrzewa

- External Collaborator:
  Bernard Metsch

ρ Meson Properties

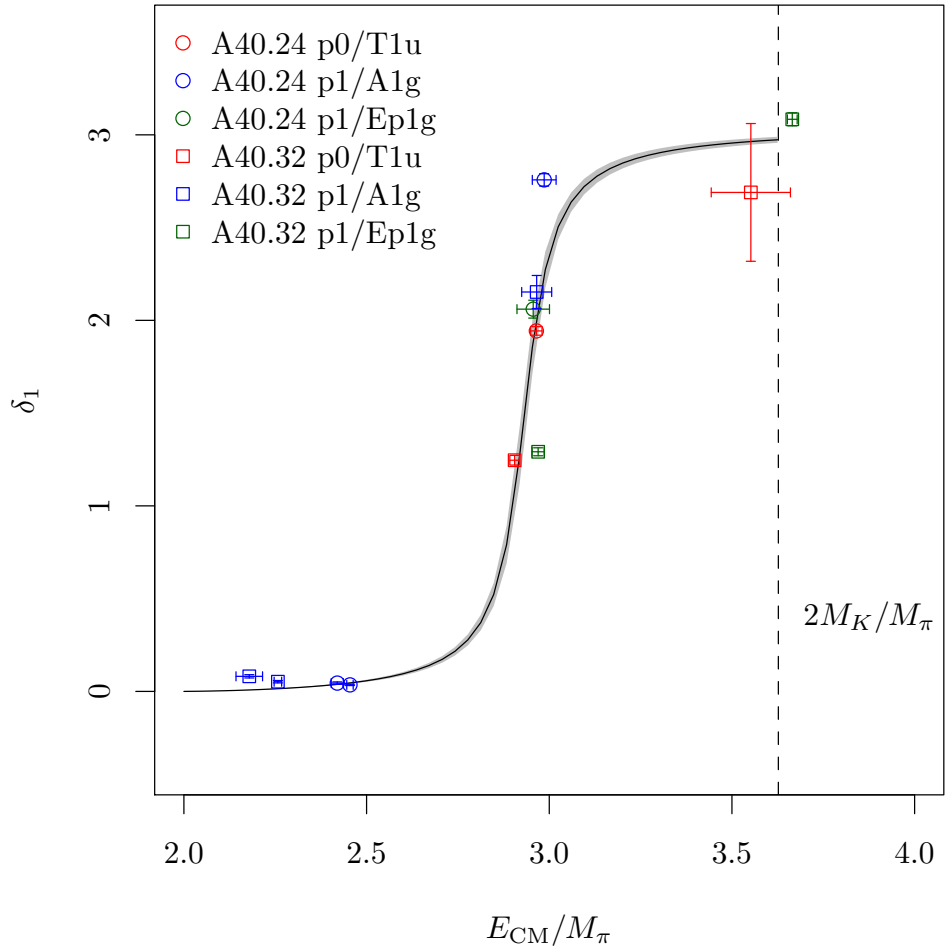
- reduced symmetries on the lattice

$\Rightarrow$ challenging Lüscher analysis

- have developed fully automatic
  - Clebsch-Gordan
  - subduction
  - induction
  - contraction

  codes

- applicable to arbitrary channels



- here: ρ meson phase shift for different lattice irreps

- analysis in progress

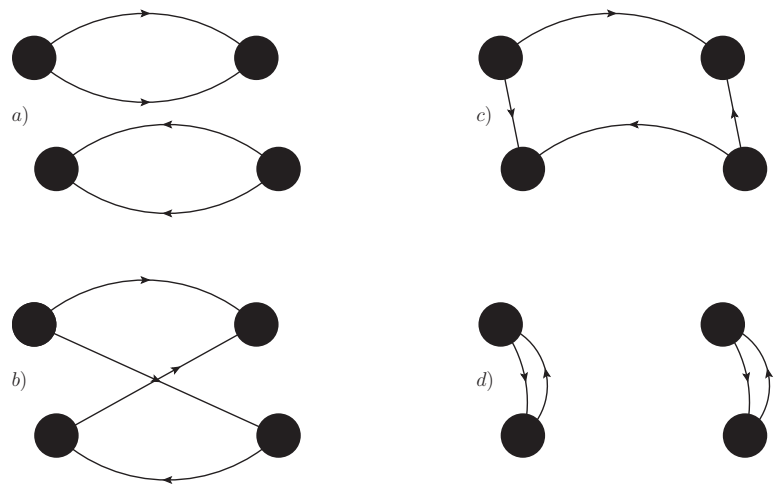
$\pi - \pi$ Scattering with $I = 0$: Topologies

- two-particle operator for $I = 0$ (with $\Gamma = \gamma_5, 1$):

$$\mathcal{O}_\Gamma^{I=0} = \frac{1}{\sqrt{3}}(\mathcal{O}_\Gamma^+\mathcal{O}_\Gamma^- + \mathcal{O}_\Gamma^-\mathcal{O}_\Gamma^+ + \mathcal{O}_\Gamma^0\mathcal{O}_\Gamma^0)\,, \quad \text{e.g.} \quad \mathcal{O}_{\gamma_5}^{\pm,0} \equiv \pi^{\pm,0}$$

- isospin limit: only four diagrams contribute

$$C_{\pi\pi}(t-t') = \langle \mathcal{O}_{\gamma_5}^{I=0}(t')(\mathcal{O}_{\gamma_5}^{I=0})^\dagger(t)\rangle$$
$$= D(t) + \frac{1}{2}X(t) - 3B(t) + \frac{3}{2}V(t)$$



- in the elastic region sufficient to determine δE from $C_{\pi\pi}$!
- $a_0^{I=0}$ in principle from same analysis as for $I = 2$

$I = 0$ in Twisted Mass Lattice QCD

- Twisted Mass Lattice QCD explicitly breaks isospin symmetry at finite lattice spacing values

$\Rightarrow$ cannot project to states with $I = 0$

see also [Buchoff et al., (2009)]

- way out $\Rightarrow$ valence action with explicit isospin symmetry

- con: have to deal with lattice artefacts from unitarity violations
  here: mixing with lower lying states (due to vacuum diagram)

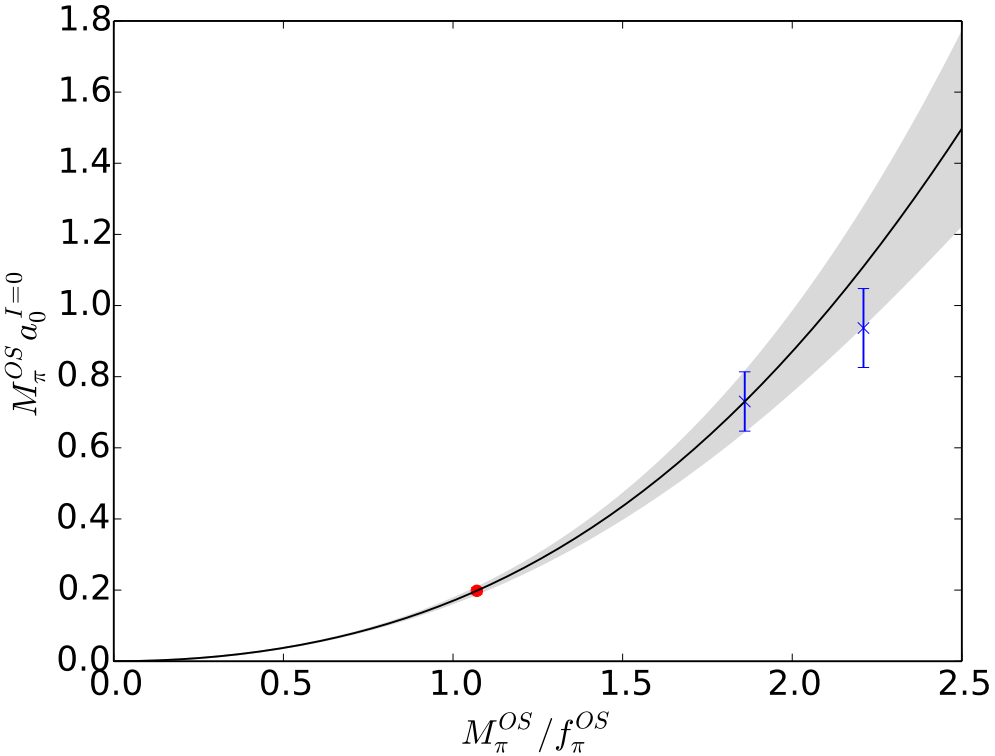
- use different discretisation with reduced isospin splitting

- apply generalized eigenvalue problem (GEVP) to identify state of interest

[Michael and Teasdale (1983); Lüscher and Wolff (1990)]

$\pi - \pi$ Scattering with $I = 0$

- much more difficult due to disconnected contributions
- $I = 0$ channel with the σ resonance
- weakly attractive interaction
- only one lattice spacing value



- we obtain (see arXiv:1701.08961)

$$M_\pi a_0^{\mathrm{I}=0} = 0.198(9)_{\mathrm{stat}}(6)_{\mathrm{sys}}$$

- compare to NA48-2 result $M_\pi a_0^{\mathrm{I}=0} = 0.220(3)(2)$

[NA48-2, (2010)]

Generation of Gauge Configurations

Lessons learned from $I = 0$ investigation:

- in principle possible with twisted mass
- but very hard to control systematic uncertainties
- and very hard to compute the phase shift

We decided to generate new gauge configurations, requiring

- physical point possible at $a \approx 0.1$ fm
- parameters known from the literature
- simulation software available and tested
- no isospin breaking
- not too expensive to simulate

Generation of Gauge Configurations

$\Rightarrow$ Wilson-clover with $6\times$ stout smearing with $N_f = 2 + 1$

[BMW (2013)]

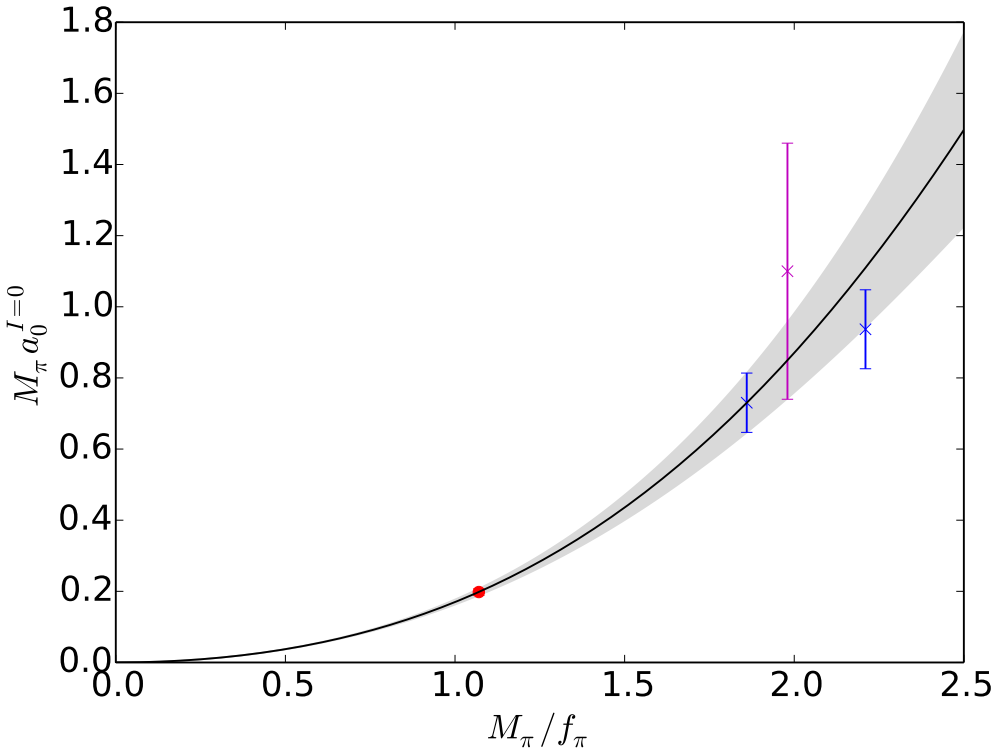
- can be simulated using chroma
- simulation parameters available in the literature

[BMW, (2013)]

- we have slightly re-tuned the strange quark mass
- use extra-long time extend to avoid unwanted pollution
- currently running $M_\pi \approx 270\ \mathrm{MeV}$ with $L/a = 24$ and $L/a = 32$ with $T/a = 96$

First Results on new Ensemble

- first $I = 0$ result on new ensemble
- limited statistics
- single volume
- compared to twisted-clover result



$\Rightarrow$ on a good track

- optimistic to deliver the milestones with this action!

The η' in $N_f = 2$ QCD at the physical point

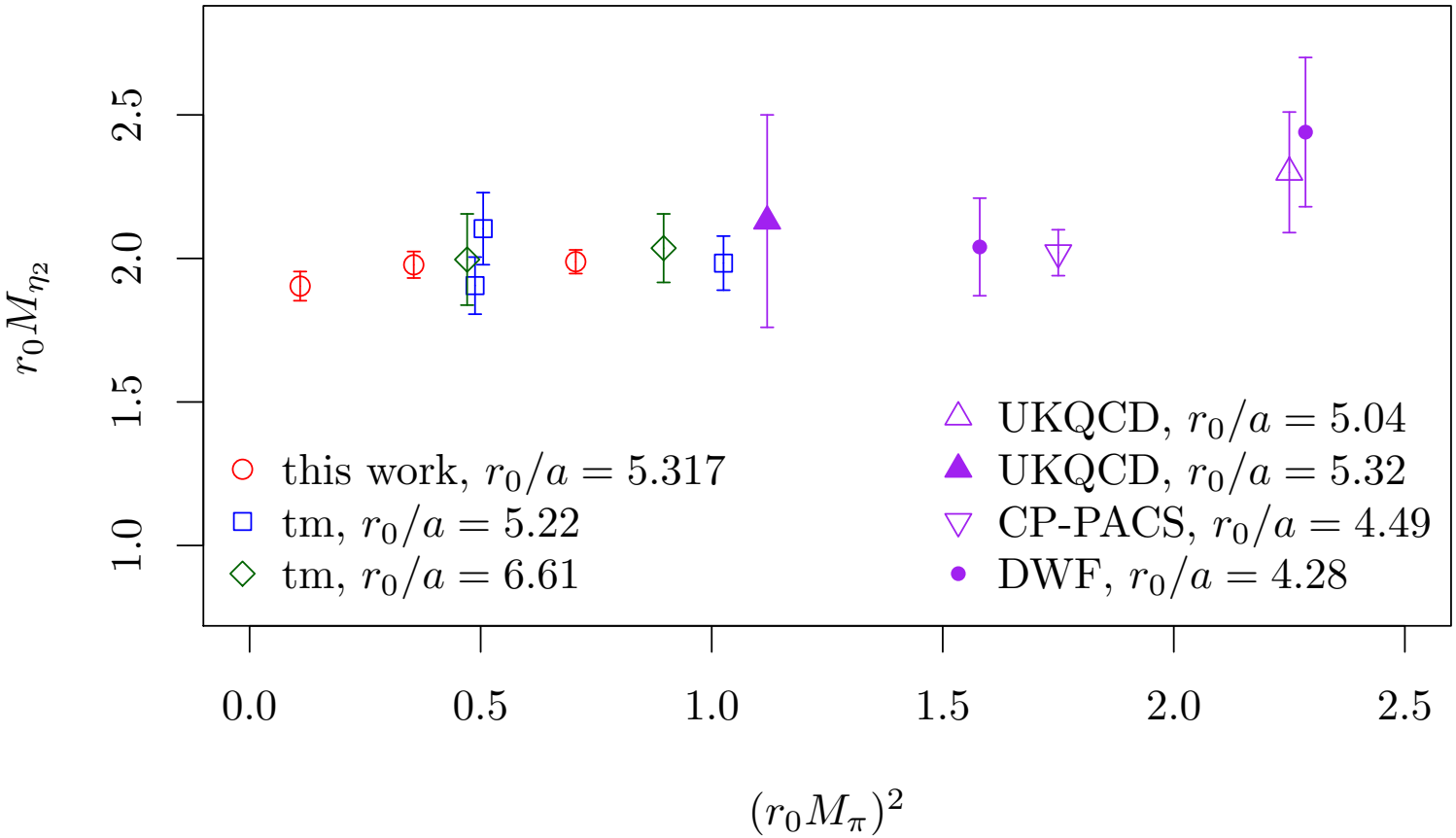
- $U(1)$ axial anomaly thought to be responsible for large η' mass

$$\partial^\mu J^q_{\mu 5} = 2m_q(\bar{q} i\gamma_5 q) + \frac{\alpha_s}{4\pi} F\tilde{F}$$

- tightly connected to topology
- results at physical pion mass missing so far
- how do errors scale towards the physical point?
- $N_f = 2$ technically easier: no mixing of η–η'
- Glueball spectrum? Mixing of η' with Glueballs?

$\Rightarrow$ see the talk of Wei Sun

The η' in $N_f = 2$ QCD at the physical point



- with $r_0 = 0.4907(5)$ fm we arrive at

$$M_{\eta_2}^{N_f=2} \;=\; 768(24)\ \text{MeV}$$

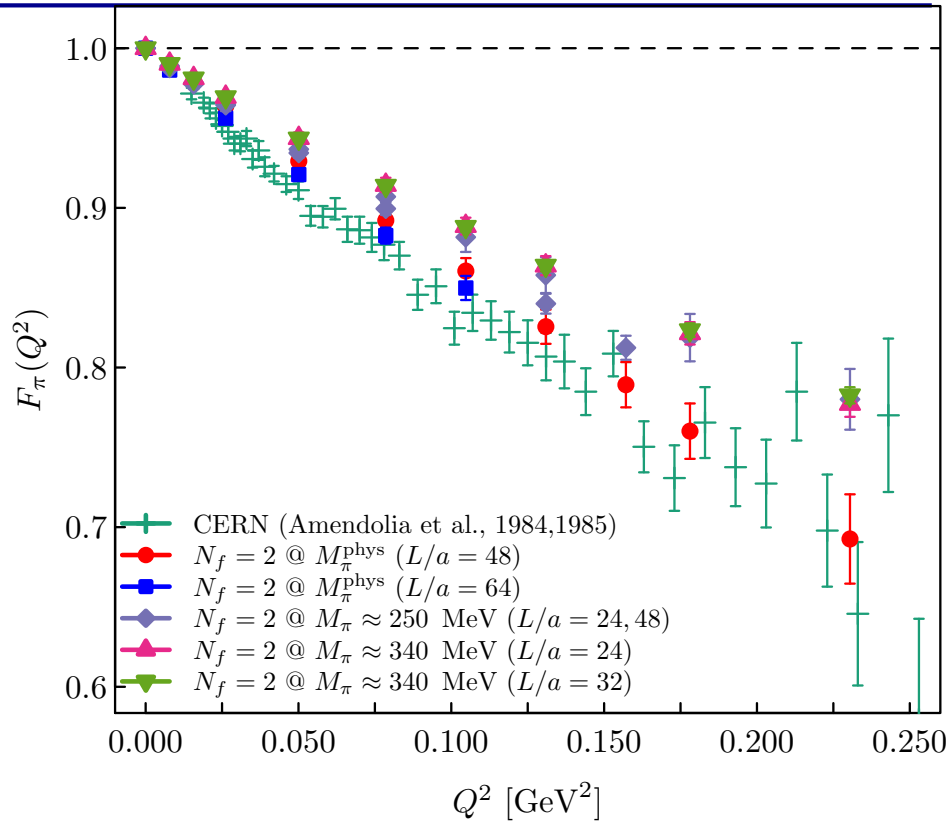
[B. Kostrzewa+, in preparation]

The Pion electromagnetic form factor at the physical point

- Electromagnetic pion form factor

$$F_\pi((p-p')^2)(p+p')_\mu = \langle \pi^+(p')|V_\mu(0)|\pi^+(p)\rangle$$

- two volumes at physical point
- additional ensembles at $M_\pi = 250$ MeV and $M_\pi = 340$ MeV
- two volumes each



$\Rightarrow$ result for the charge radius (ChPT in m_ℓ and for FS)

$$r_\pi^2 \;=\; 0.443\,(29)\ \text{fm}^2$$

[B. Kostrzewa+, in preparation]

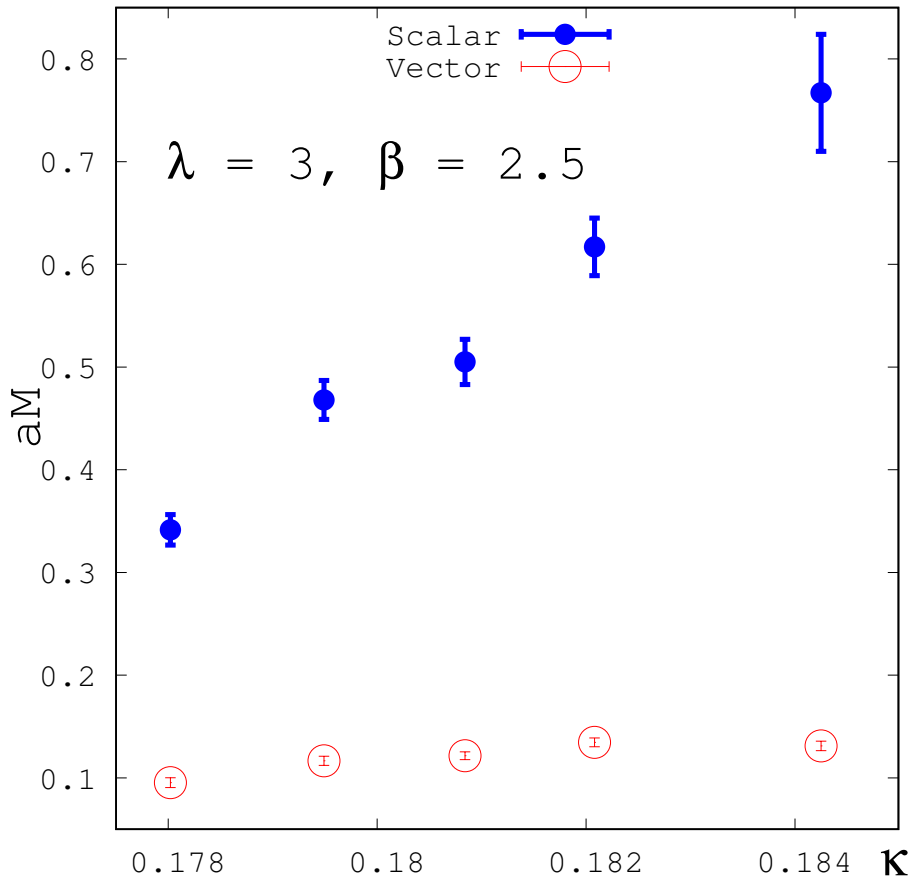
compare $(r_\pi^{\rm exp})^2 = 0.452(11)\ \text{fm}^2$

[PDG]

Scattering of two Vector Particles

- motivation: Higgs a bound state of W bosons?
- derived formalism for scattering of vector particles in finite volume

  [see also: Briceno, (2014)]
- test in toy model: scalar QED
- allows variation of interaction strength



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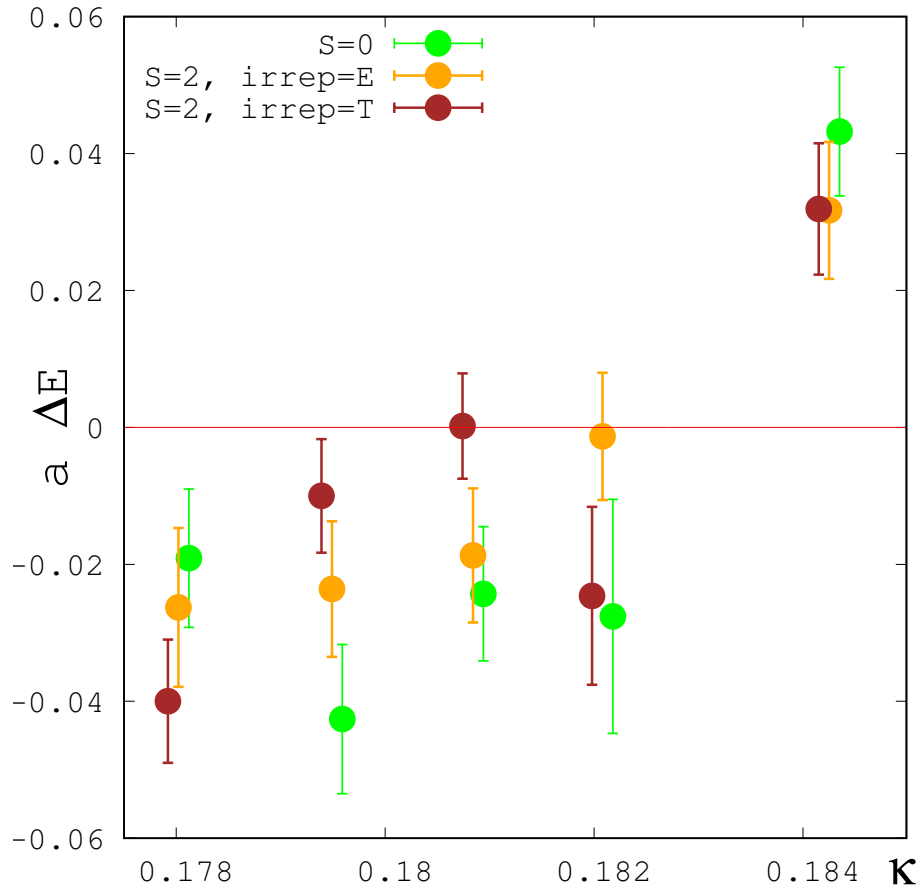
$\Rightarrow$ energy shift can be determined



QPhiX: Towards New Architectures

- new architecture pose significant challenges

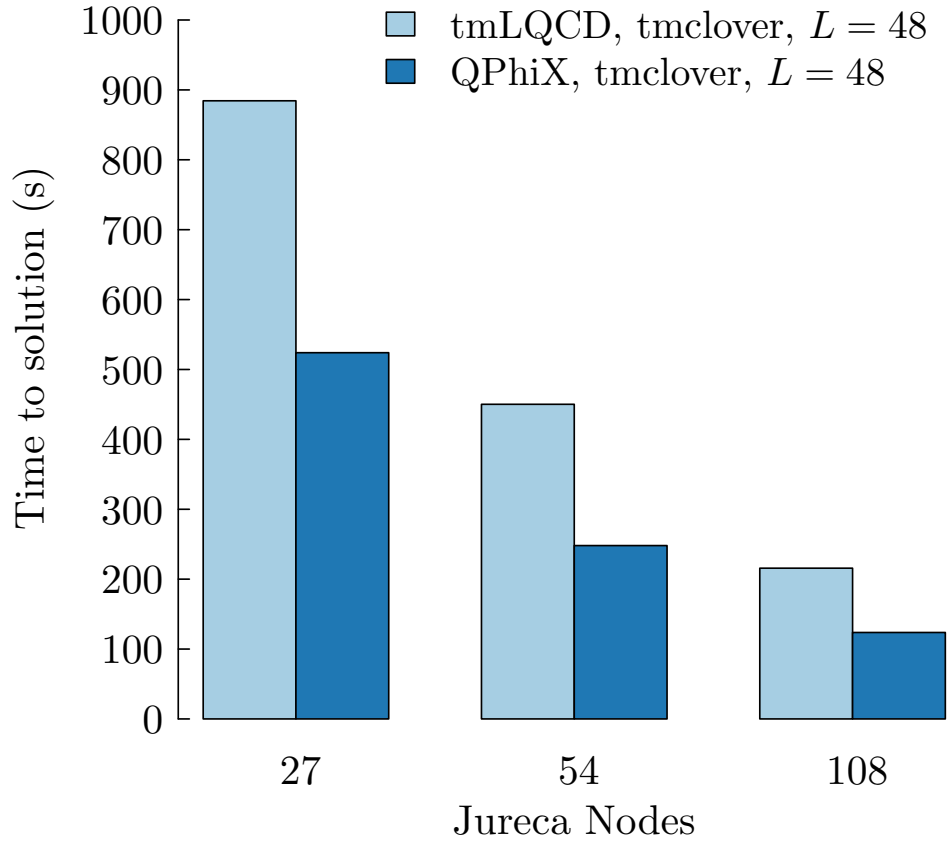
$\Rightarrow$ MPI

$\Rightarrow$ threading (OpenMP)

$\Rightarrow$ SIMD vector unit

- QPhiX: flexible C++ suite for Intel chips

[https://github.com/JeffersonLab/qphix]



$\Rightarrow$ significant speedup compared to standard kernel

$\Rightarrow$ speedup of 1.6 in our gauge configuration generation

Milestones

- 2016:
  - Spectrum of 1^{++} charmonium states on ensemble A40.24
  - Calculation of pion form factors as test of generalised perambulators

- 2017:
  - Spectrum of 1^{++} charmonium states and $X(3872)$
  - Exploratory study on the radiative transitions between charmonium and $X(3872)$ using distillation
  - The study of J/ψ radiatively decaying into the $s\bar{s}$ tensor meson
  - ρ meson properties on $N_f = 2$ physical point ensemble ✓
  - a_0, ... change of strategy, instead:

  $\Rightarrow$ Generate new gauge configurations first to avoid isospin breaking ✓