Neutral D-Meson Mixing near the Charm Mass

Ava Khamseh

RBC and UKQCD Collaborations
Peter Boyle, Luigi Del Debbio, Andreas Jüttner,
Francesco Sanfilippo, Justus Tobias Tsang

July 15, 2015

RBC & UKQCD Members

BNL and RBRC
Tomomi Ishikawa
Taku Izubuchi
Chulwoo Jung
Christoph Lehner
Meifeng Lin
Shigemi Ohta (KEK)
Taichi Kawanai
Christopher Kelly
Amarjit Soni
Sergey Syritsyn

CERN
Marina Marinkovic

Columbia University
Ziyuan Bai
Norman Christ
Xu Feng
Luchang Jin
Bob Mawhinney
Greg McGlynn
David Murphy
Daiqian Zhang

University of Connecticut
Tom Blum

Edinburgh University
Peter Boyle
Luigi Del Debbio
Julien Frison
Richard Kenway
Ava Khamseh
Brian Pendleton
Oliver Witzel
Azusa Yamaguchi

Plymouth University
Nicolas Garron

University of Southampton
Jonathan Flynn
Tadeusz Janowski
Andreas Juettner
Andrew Lawson
Edwin Lizarazo
Antonin Portelli
Chris Sachrajda
Francesco Sanfilippo
Matthew Spraggs
Tobias Tsang

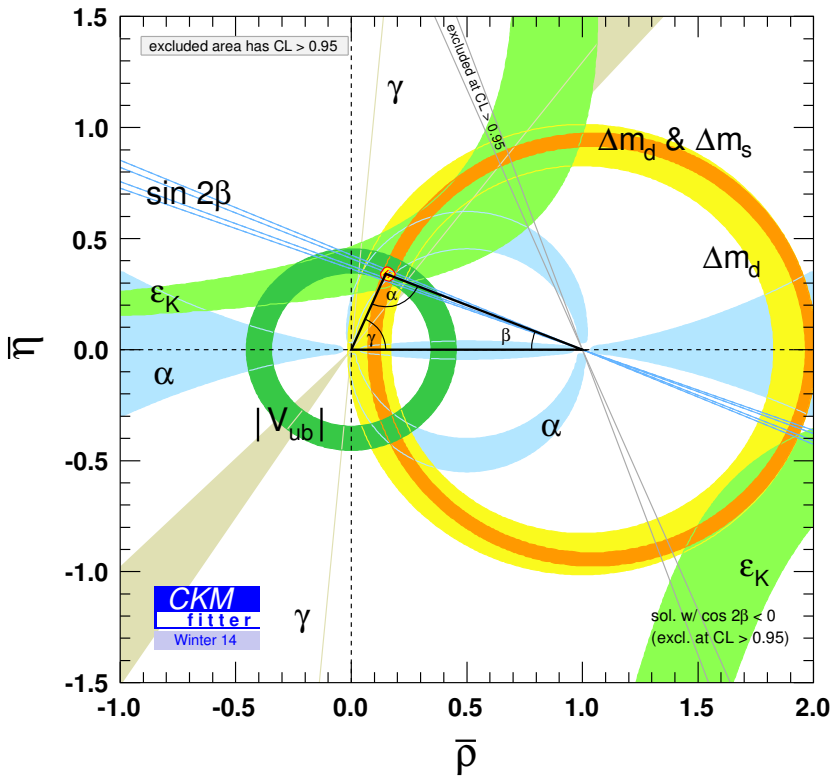
York University (Toronto)
Renwick Hudspith

Recent Results

- Motivation
- Masses and Decay Constants
- Bag Parameter
- ξ-Parameter
- Link Smearing and Run 2

Motivation

- Flavor physics plays an important role in testing the limits of SM and constraining BSM theories
- Precision measurements at LHCb and other B-factories in searches for New Physics
- Progress in Lattice QCD: Kaons $\rightarrow$ D-mesons $\rightarrow$ B-mesons



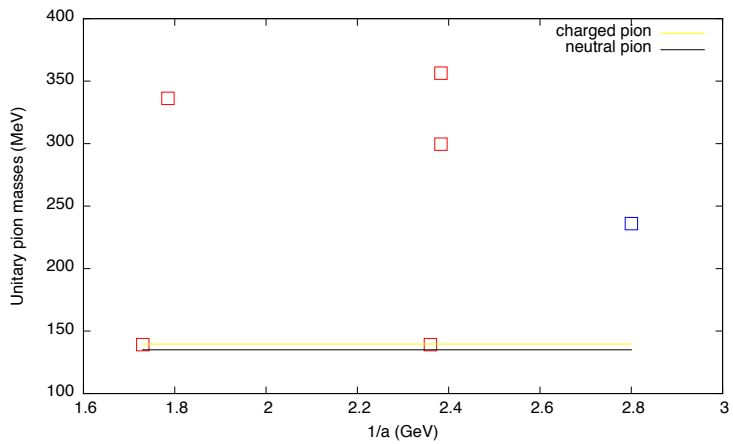
Run 1

Goal:

- HQ physics from 3 lattice spacings with a range of pion and charm masses
- Initially two lattice spacings at physical pion mass. (this talk + **Tobi Tsang**)

In progress: add

- Third $a^{-1} \approx 2.8$ GeV, $M_\pi \approx 230$ MeV
- Heavier M_π data
- Mass and lattice spacing dependence: simultaneous fit, continuum extrapolation (Rome-ETMC Method)



Lattice Parameters

Lattice	$48^3 \times 96$	$64^3 \times 128$
$1/a$ (GeV)	1.73	2.36
No. of Configs	88	80
am_l	0.00078	0.000678
am_s	0.0362	0.02661
am_h	0.3, 0.35, 0.4, 0.45	0.22, 0.28, 0.34, 0.4
Simulated M_π	139.25(22) MeV	139.33(26) MeV

- PDG $M_{\pi^+} = 139.57018(35)$ MeV, $M_{\pi^0} = 134.9766(6)$ MeV

Results: M_π, f_π, M_K, f_K

Meson	Mass 48^3 MeV	Mass 64^3 MeV	PDG Mass MeV
π	139.25(22)	139.33(26)	134.9766(6)
K	499.16(24)	507.80(94)	497.614(24)

After a short $\mathcal{O}(3)\%$ extrapolation agrees with the physical values:

$f_\pi = 130.19 \pm 0.89$ [130.4(0.04)(0.2)] MeV

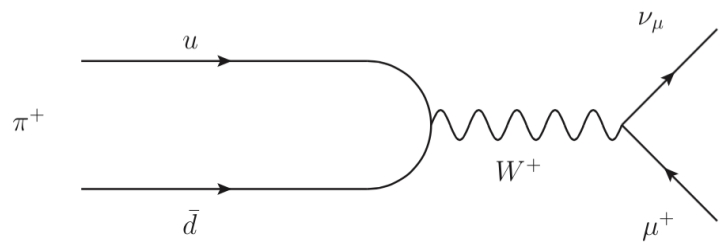
$f_K = 155.51 \pm 0.83$ [156.2(0.2)(0.6)(0.3)] MeV

RBC/UKQCD, Nov 2014, http://arxiv.org/pdf/1411.7017v1.pdf

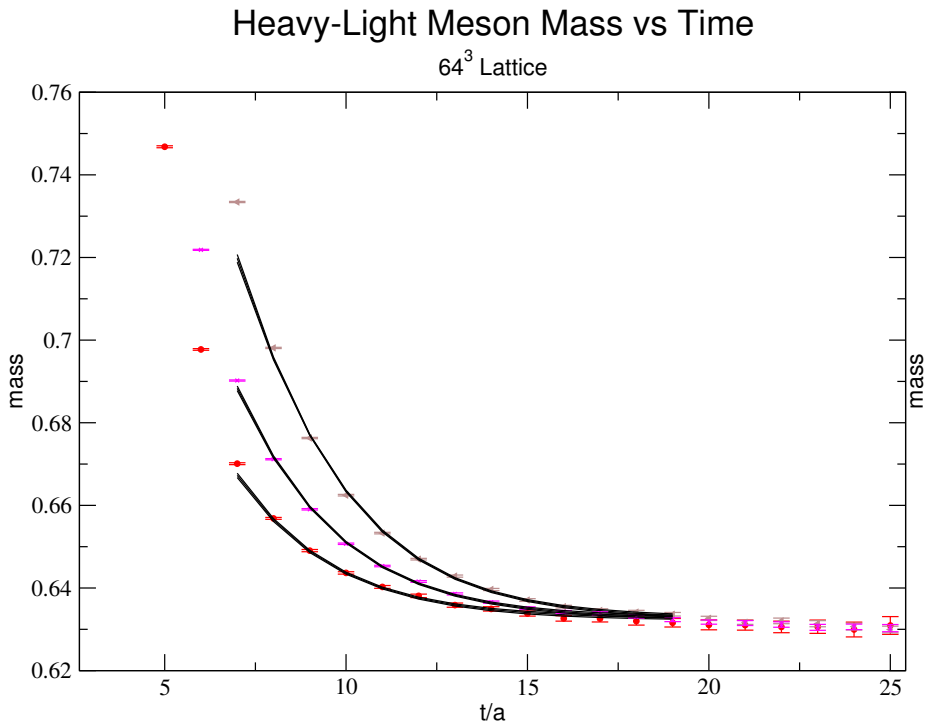
$f_D \rightarrow$ see talk by **Tobi Tsang**

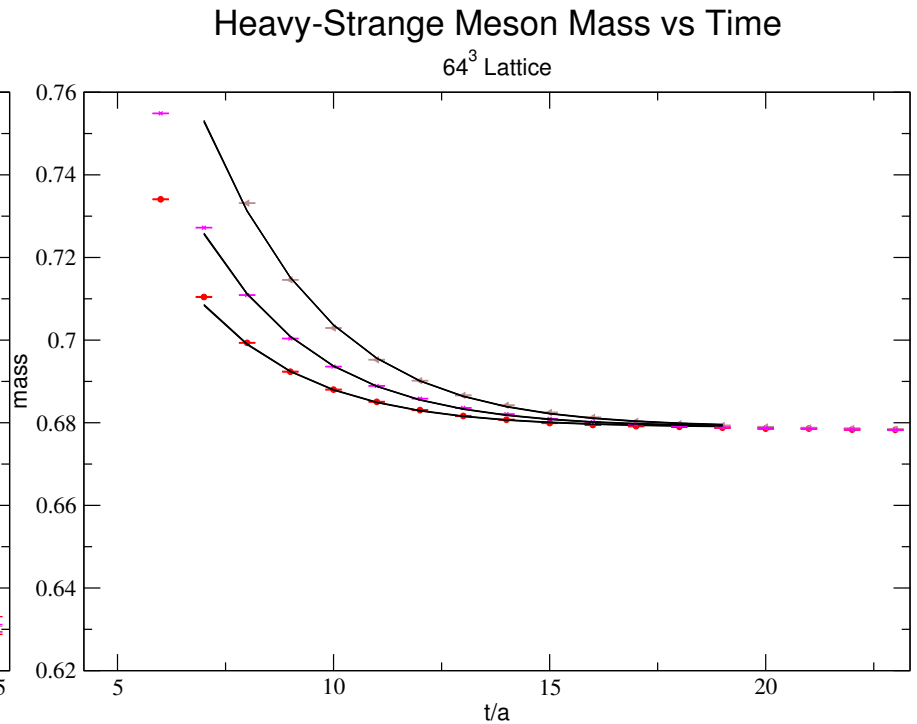
$$\langle 0|A_0(0)|\pi, \mathbf{p}=0\rangle = f_{\mathrm{PS}} M_{\mathrm{PS}}$$

$$f_{\mathrm{PS}} = \sqrt{\frac{2N_{AA}}{M_{\mathrm{PS}}}} = \frac{\sqrt{2N_{AP}^2}}{\sqrt{M_{\mathrm{PS}} \times N_{PP}}}$$



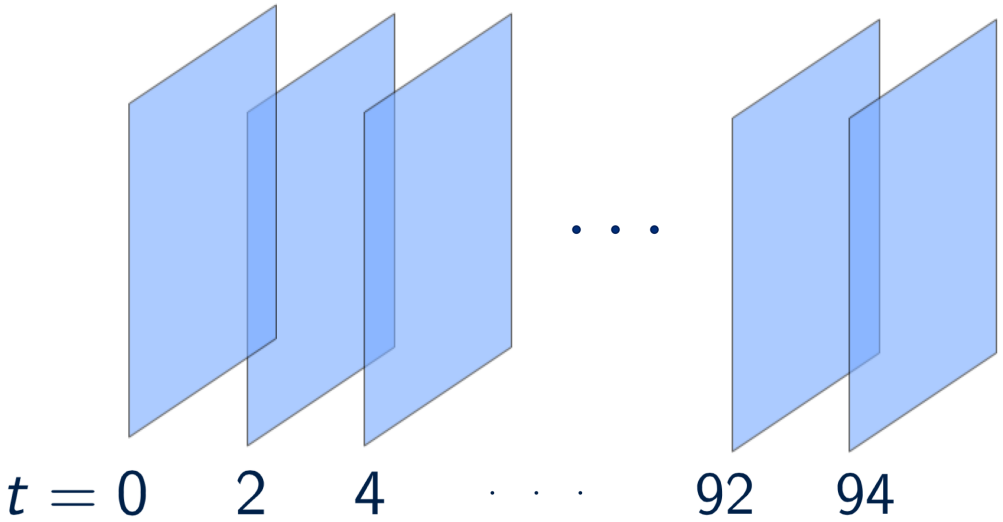
Fit Strategy

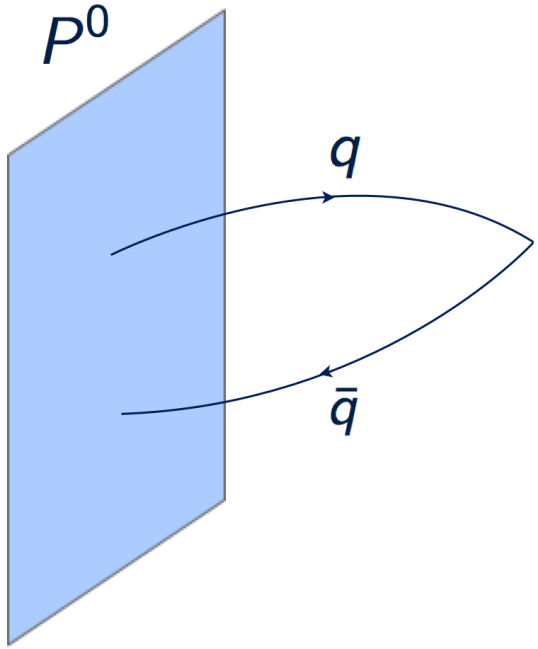


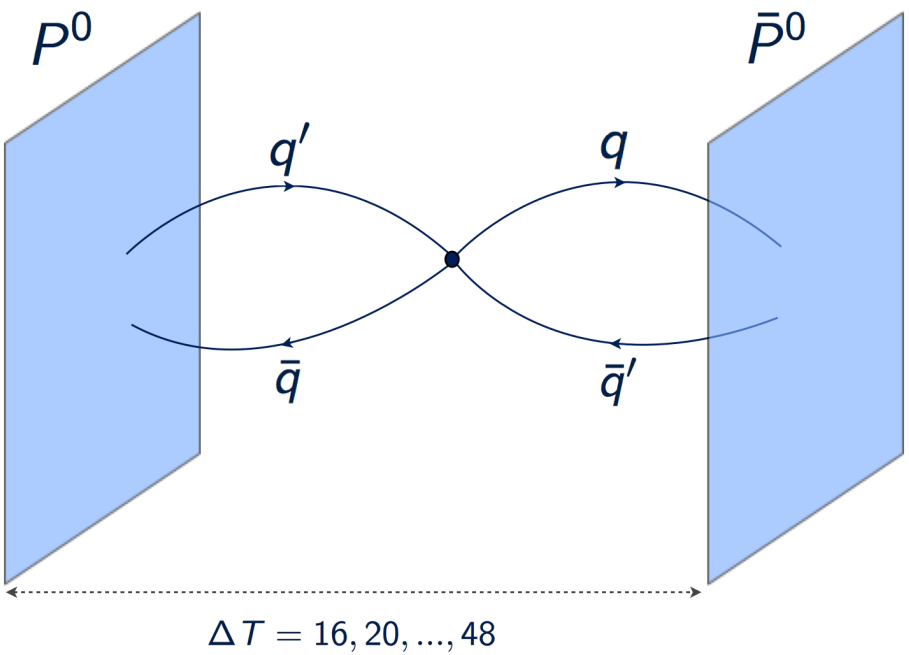


- Excited states
- Simultaneous fit from different Γ-channels

Z2Wall Source

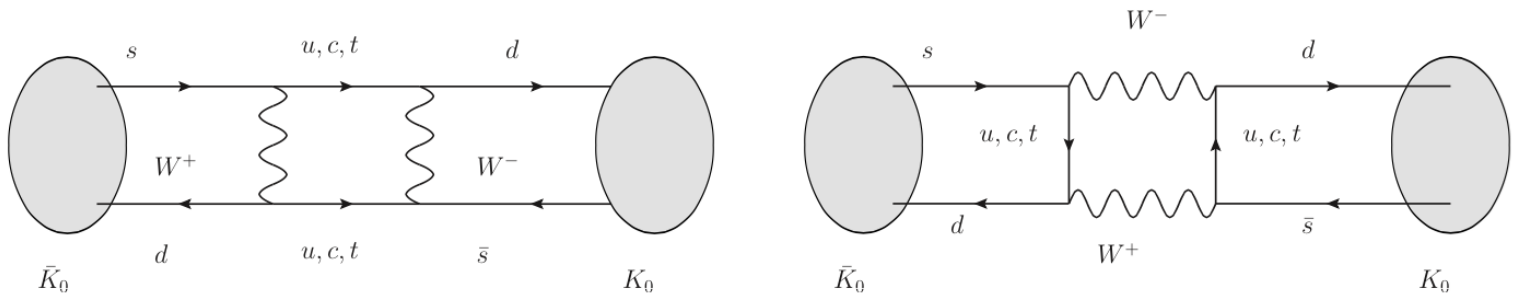






The Bag Parameter

- Dominant contribution comes from indirect CP violation through state-mixing, mediated by the imaginary part of the box diagram:



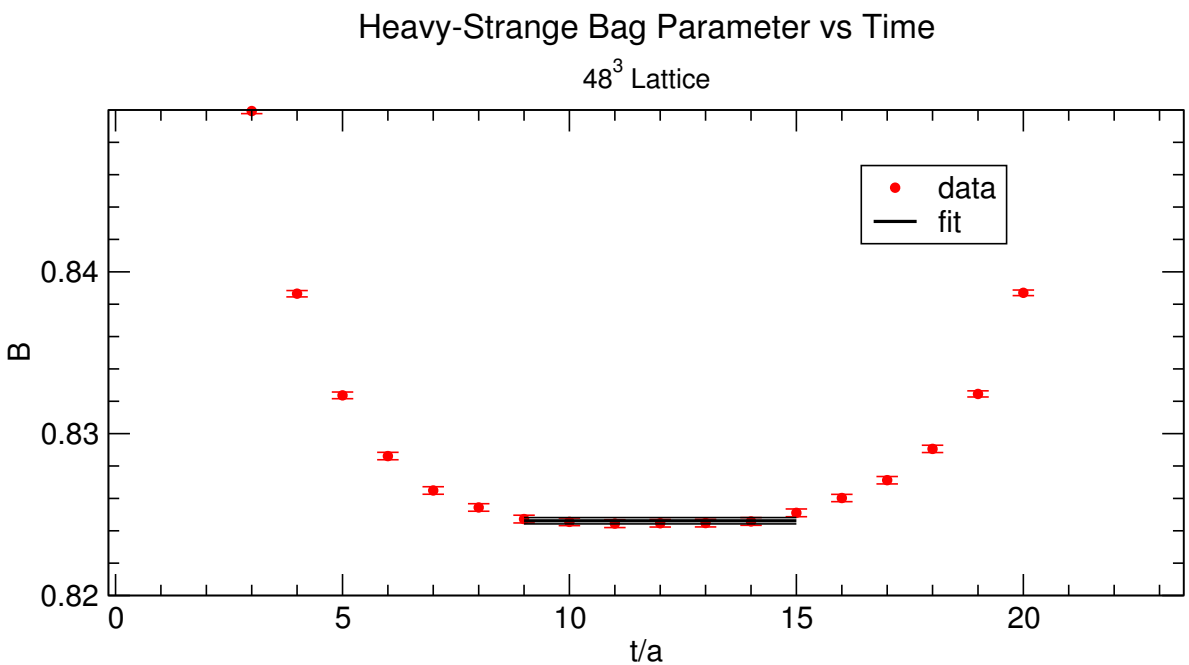
- Define "Bag Parameter" to parametrise neutral meson mixing due to weak interactions:

$$B_P = \frac{\langle P^0 | O_{VV+AA} | \bar{P}^0 \rangle}{\frac{8}{3} f_P^2 M_P^2}$$

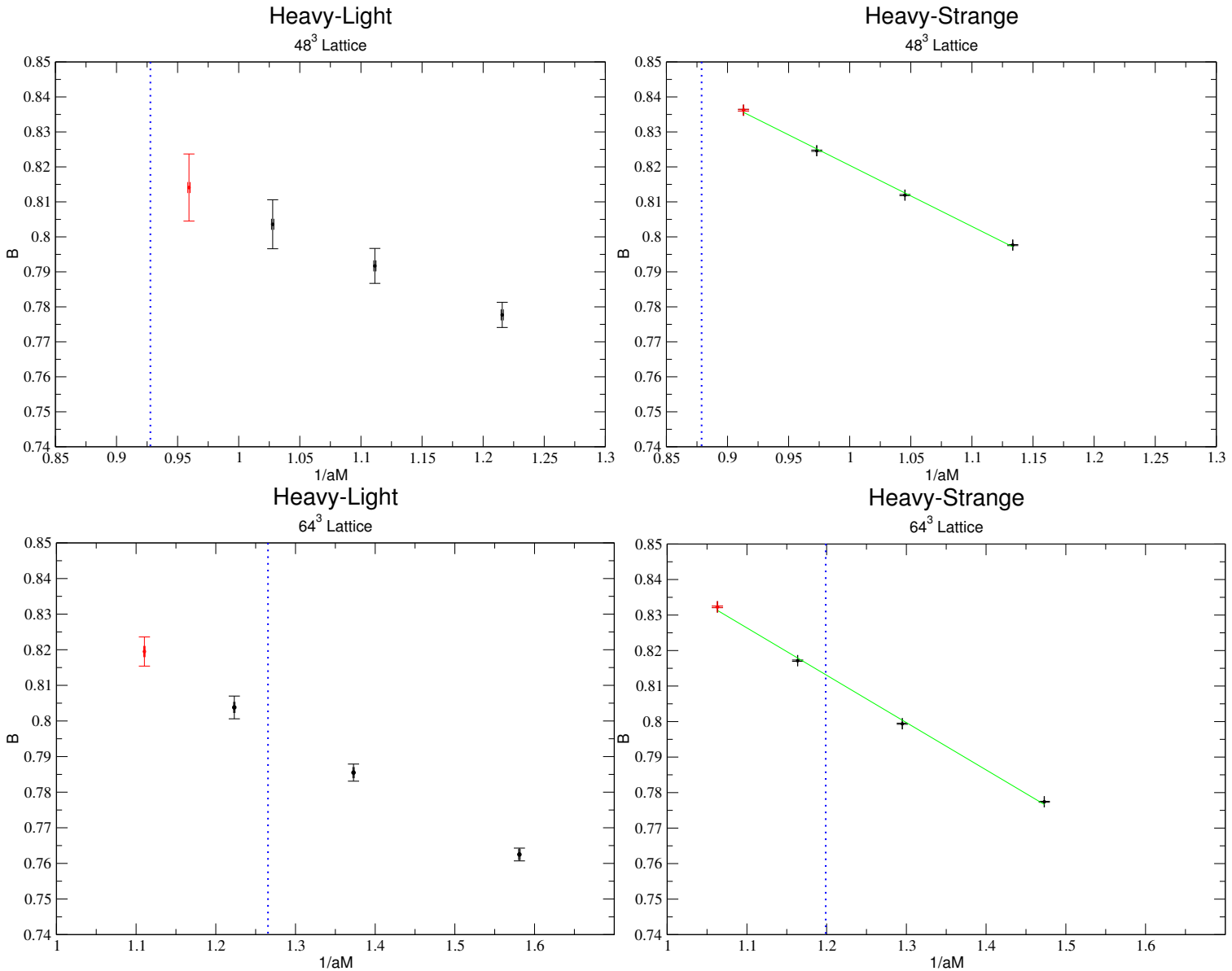
The Bare Bag Parameter

- Fit plateau to constant in region where time dependence cancels e.g. $B_P^{\text{bare}} = 0.82461(20)$

$$B_P^{\text{bare}} = \frac{\langle P^0(\Delta t)|O_{VV+AA}(t)|\bar{P}^0(0)\rangle}{\frac{8}{3}\langle P^0(\Delta t - t)|A_0(0)\rangle\langle A_0(t)|\bar{P}^0(0)\rangle}$$



Results: Bare Bag Parameter near Charm Mass

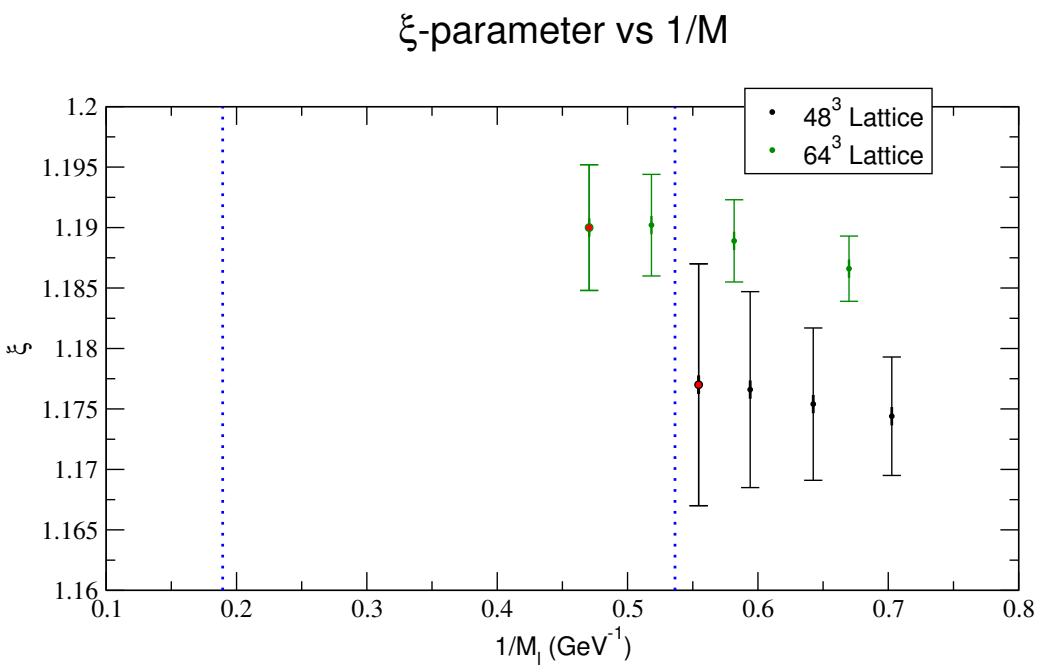


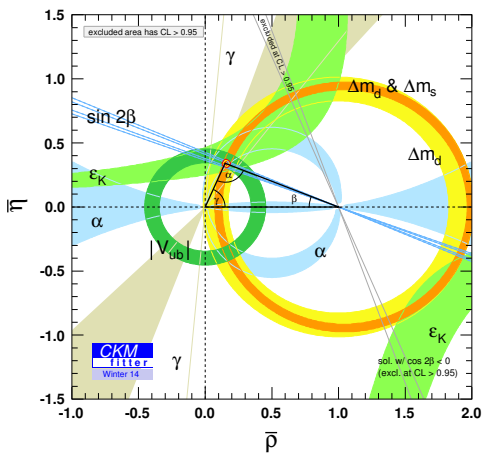
Results: ξ-parameter

- $B^0 - \bar{B}^0$ mixing provides information on the $|\frac{V_{td}}{V_{ts}}|$ through the parameter

$$\xi = \frac{f_{hs}\sqrt{B_{hs}}}{f_{hl}\sqrt{B_{hl}}}$$

- This constrains the orange circle centred at $\bar{\rho} = 1$

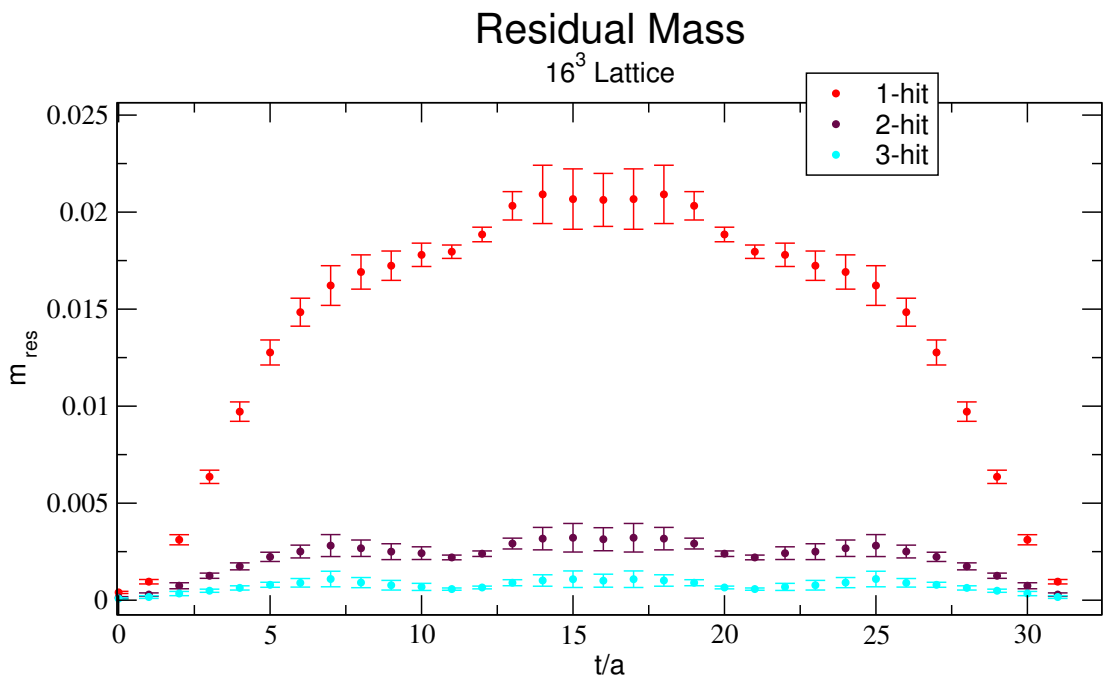




Gauge Link Smearing

- Stout Smearing
- Search for optimal parameters: Stout parameter, hits, M_5, ...

$$am_{res} = \frac{\sum_x \langle J_{5q}(x) P(0) \rangle}{\sum_x \langle P(x) P(0) \rangle}$$



Outlook: Run 2

- Gauge link smearing to save the heaviest data point
- Potentially go further towards B-mesons
- New action and the next run

Backup: Kaon Mixing and CP Violation

- CP is not an exact symmetry of weak interactions
- Experimental measure of indirect CP violation

$$\epsilon_K = \frac{A(K_L \to (\pi\pi))}{A(K_S \to (\pi\pi))}$$

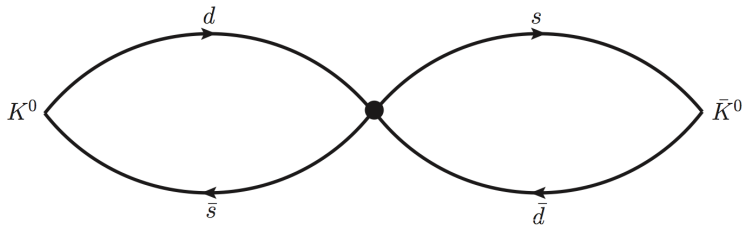
- Theoretically,

$$\epsilon_K \propto V_{xs}^* V_{xd} G_F^2 M_W^2 \times \langle K^0 | \underbrace{(\bar{s}\gamma_\mu d)(\bar{s}\gamma_\mu d) + (\bar{s}\gamma_5\gamma_\mu d)(\bar{s}\gamma_5\gamma_\mu d)}_{O_{VV+AA}} | \bar{K}^0 \rangle$$

non-perturbative hadronic matrix element is determined theoretically using lattice. This imposes constraints on unitarity triangle through $V_{xs}^* V_{xd} \to$ green hyperbola

B_K on the Lattice: The 3-point function

To determine the Bag Parameter, we integrate out M_W and heavy quark masses (EFT) and evaluate the following QCD diagram:



B_K can be found starting from the 3-point function on the lattice

$$\langle Q(t_2) O_{VV+AA}(t_1) Q(0) \rangle = \langle 0|O|\bar{P}^0\rangle \langle \bar{P}^0|Q|P^0\rangle \langle P^0|O|0\rangle e^{-(t_y - t_x)E_{\bar{P}^0}} e^{-t_x E_{P^0}} + \ldots$$

where the pseudo-scalar operator $Q = \bar{d}\gamma_5 s$ and $t_2 > t_1$. Time dependence is cancelled in this structure,

$$B_P^{\text{bare}} = \frac{\langle P^0(\Delta t)|O_{VV+AA}(t)|\bar{P}^0(0)\rangle}{\frac{8}{3}\langle P^0(\Delta t - t)|A_0(0)\rangle\langle A_0(t)|\bar{P}^0(0)\rangle}$$