Decay constants and spectroscopy of mesons in lattice QCD using domain-wall fermions

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JLQCD Collaboration

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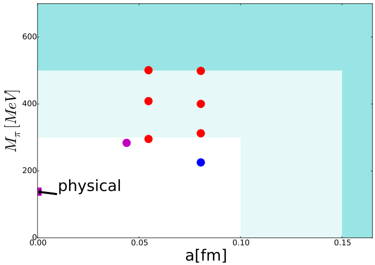
Project Overview

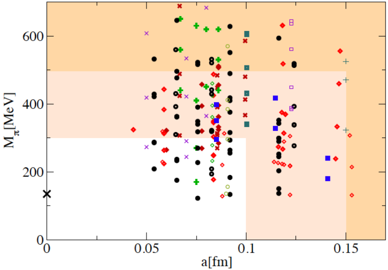
- $N_f = 2 + 1$ simulations on 15 Esnambles with $10,000$ MD times for each.
- Simulations at three lattice spacing $a^{-1} \approx 2.4, 3.6$ and 4.5GeV
- Pion masses from 230 MeV to 500 MeV
- Domain-Wall (Möbius) fermions
  - Good chiral symmetry with $m_{\text{res}} \ll m_{ud}$. $m_{\text{res}} \approx 1MeV$ on our coarsest lattice; ≈ 0 on the finer lattices.
  - Small residual mass is achieved by the Möbius representation and using stout link-smearing
  - Simpler Renormalization $Z_V = Z_A$
  - Topological charge not fixed
- Light and charmed meson correlators produced using domian-wall to analyze masses and pseudoscalar decay constants.
- **Fine lattices for heavy quarks: Are the discretization effect under control at the level of a few MeV**

Related talks using the same ensembles

- Jul 14th
  - **Fukaya 17:30** Extracting the eta-prime meson mass from gluonic correlators in lattice QCD
- Jul 15th
  - **Tomii 16:30** Analysis of short distance current correlators using OPE
  - **Nakayama 16:50** Charmonium current-current correlators with Mobius domain-wall fermion
  - **Hashimoto POSTER** Stochastic calculation of the QCD Dirac operator spectrum with Mobius domain-wall fermion
- Jul 16th
  - **Suzuki 11:20** D meson semileptonic decays from lattice QCD with chiral fermions

Ensambles





Our ensembles (Left) compared to various other groups (Right) image from Hoelbling, 1410.3403

- Red = Two ensembles at different values of m_s
- Blue = Two ensembles at different volumes
- Magenta = One ensemble

Ensambles

	L	$\#m_s$	m_π[MeV]	$m_\pi L$
$\beta = 4.17$ $1/a = 2.45$ GeV	$32^3 \times 64$ $(L = 2.6$ fm$)$	1	230	3.0
		2	310	4.0
		2	400	5.2
		2	500	6.5
	$48^3 \times 96$ $(L = 3.9$ fm$)$	1	230	4.4
$\beta = 4.35$ $1/a = 3.61$ GeV	$48^3 \times 96$ $(L = 2.6$ fm$)$	2	300	3.9
		2	410	5.4
		2	500	6.6
$\beta = 4.47$ $1/a = 4.50$ GeV	$64^3 \times 128$ $(L = 2.1$ fm$)$	2	285	4.1

Table: Lattices

$10,000$ MD times for each ensemble.

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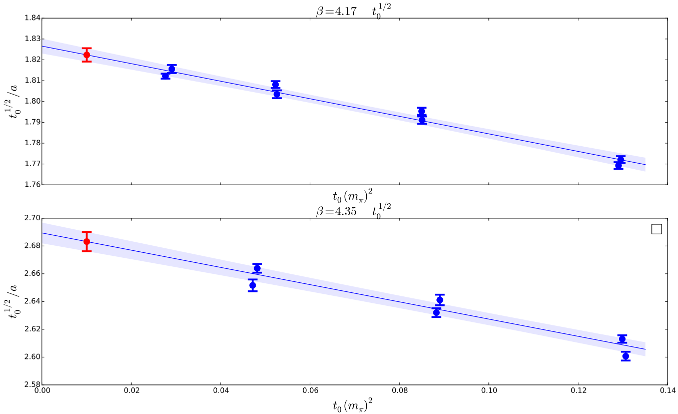
Measurements

- Correlators measured on each lattice for both smeared and unsmeared point sources
- Gauge invariant smearing of two different types for each source/sink
- Measurements done using 4 source points on 100 configurations for each ensemble
- Fits performed to two correlators simultaneously using the combination unsmeared-smeared and smeared-smeared to reduce variance of the unsmeared source
- Charmed correlator measured using 3 values of the charm mass which were then interpolated in m_c to match the masss of the spin averaged $c\bar{c}$

Scale Setting using Wilson Flow (t_0)

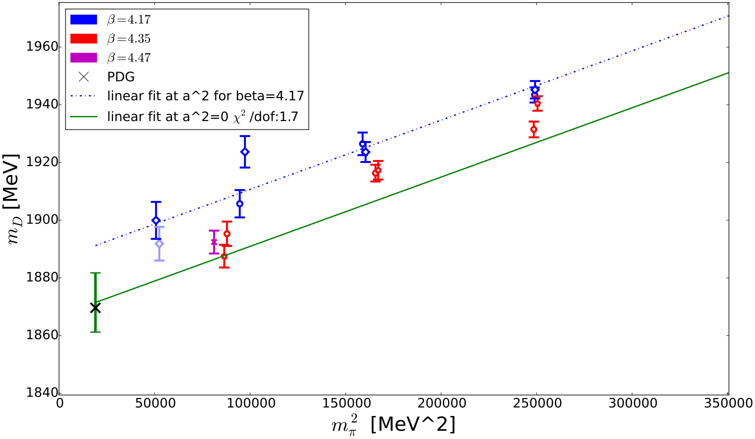


- Scale was set using t_0 from wilson flow
- Using $t_0 = 0.1465$ fm (BMW 2012)
  - $\beta = 4.17 \longrightarrow a^{-1} = 2453.1 \pm 4.0$ MeV
  - $\beta = 4.35 \longrightarrow a^{-1} = 3609.7 \pm 8.9$ MeV
  - $\beta = 4.47 \longrightarrow a^{-1} = 4496.1 \pm 9.2$ MeV

Physical Limit

- We have many ensembles and would like the physical point extrapolation
- Simple linear fits were used to interpolate/extrapolate to the physical point.
- Mistuning of the strange mass was interpolated using $2m_K^2 - m_\pi^2 \propto m_s$
- Extrapolation to continuum limit in a^2.
- Linear extrapolation in m_π^2.
- No cross terms introduced.
- Higher order χPT fitting (work in progress)

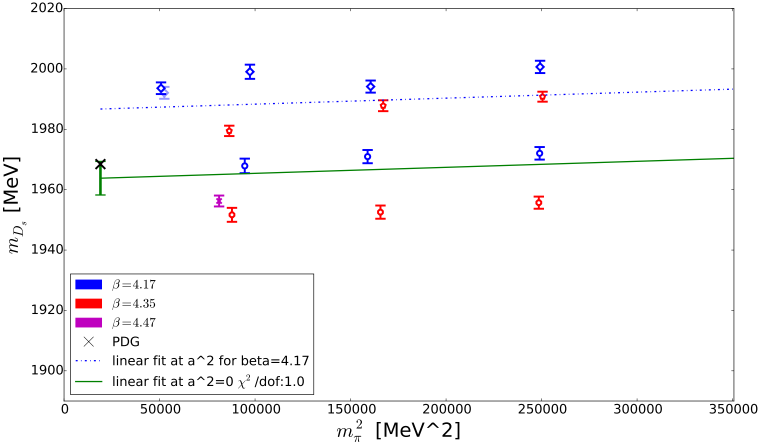
D meson masses



Physical point extrapolation $m_D = 1871 \pm 10$ MeV
PDG 1868.02 ± 0.10 MeV

D_s meson masses

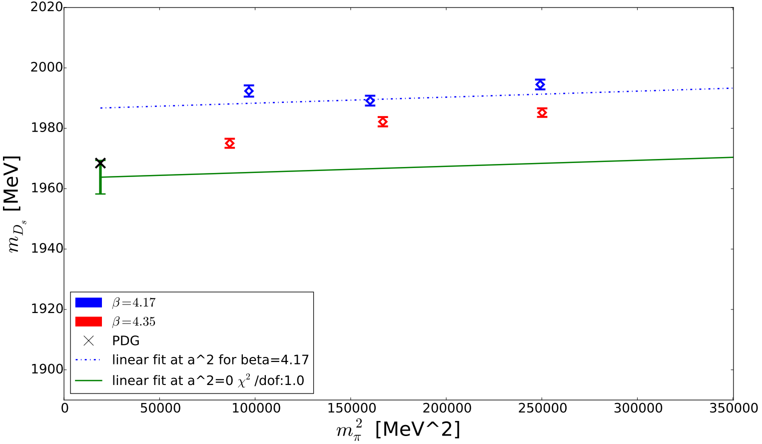
Before m_s interpolation



Physical point extrapolation $m_{D_s} = 1963.8 \pm 5.5$ MeV
PDG 1968.30 ± 0.11 MeV

D_s meson masses

After m_s interpolation



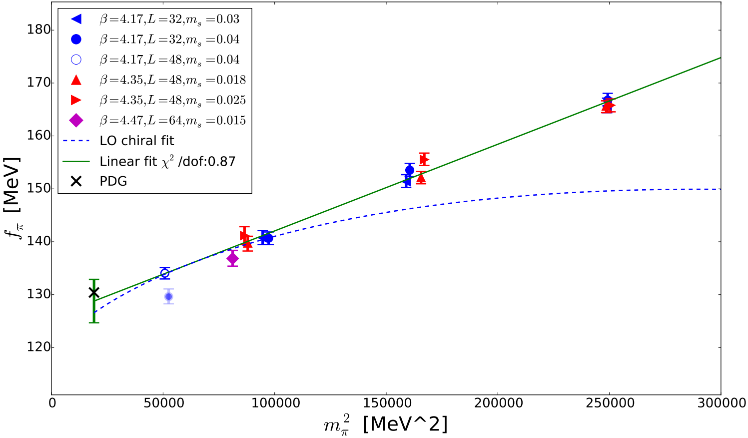
Physical point extrapolation $m_{D_s} = 1963.8 \pm 5.5$ MeV

PDG 1968.30 ± 0.11 MeV

Pseudoscalar decay constants

- Because we have chiral fermions the psudoscalar decay constants can be computed using the PCAC relation $m_\pi Z_A \langle 0|A_4|\pi\rangle = (m_q + m_q)\langle 0|P|\pi\rangle$.
- Fit correlator to $C = \underbrace{\frac{1}{2m_\pi}\langle 0|P|\pi\rangle\langle\pi|P|0\rangle}_{A_{PP}} e^{-m_\pi t}$
- Decay constant computed using $f_\pi = (m_q + m'_q)\sqrt{\frac{2A_{PP}}{m_\pi^3}}$. Residual mass is added to the quark mass (minor effect of 1 MeV or less)
- This does not require renormalization factor Z_A

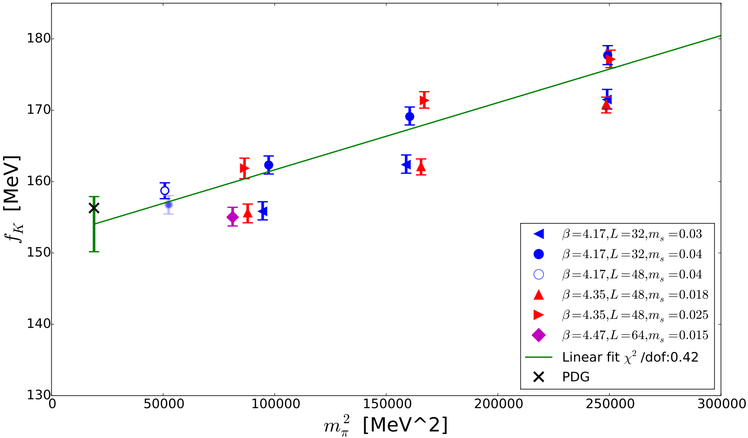
Pion pseudoscalar decay constants



One-Loop chiral log fit (with fixed $F_\pi = 130$ MeV) for $m_\pi < 400$ MeV vs Linear extrapolation. Difference of 2.2 MeV
Physical point linear extrapolation $f_\pi = 128.8 \pm 4.1^{+0}_{-2.2}$ MeV
PDG 130.41 ± 0.2 MeV

Kaon pseudoscalar decay constants

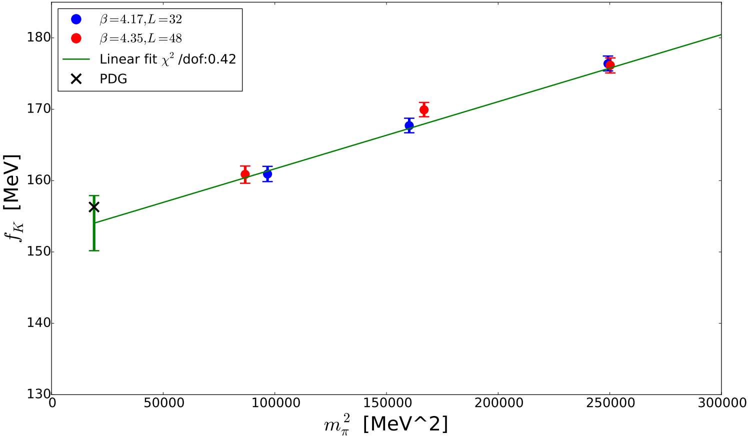
Before m_s interpolation



Physical point extrapolation $f_K = 154.0 \pm 3.9$ MeV. PDG 156.1 ± 0.8 MeV

Kaon pseudoscalar decay constants

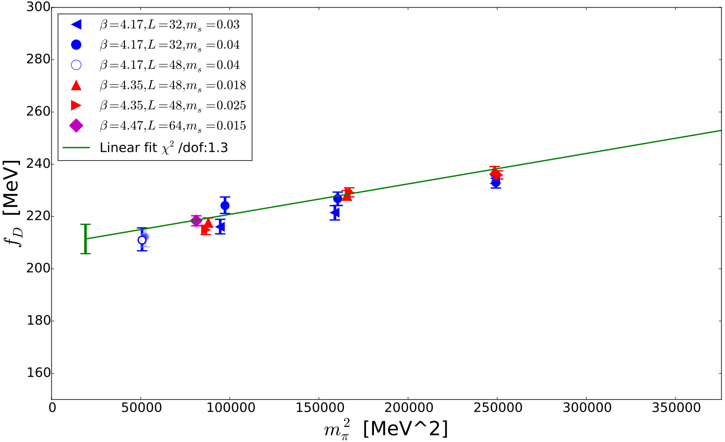
After m_s interpolation



Physical point extrapolation $f_K = 154.0 \pm 3.9$ MeV. PDG 156.1 ± 0.8 MeV

Ratio $f_K/f_\pi = 1.196 \pm 0.053$. PDG 1.1970 ± 0.0065

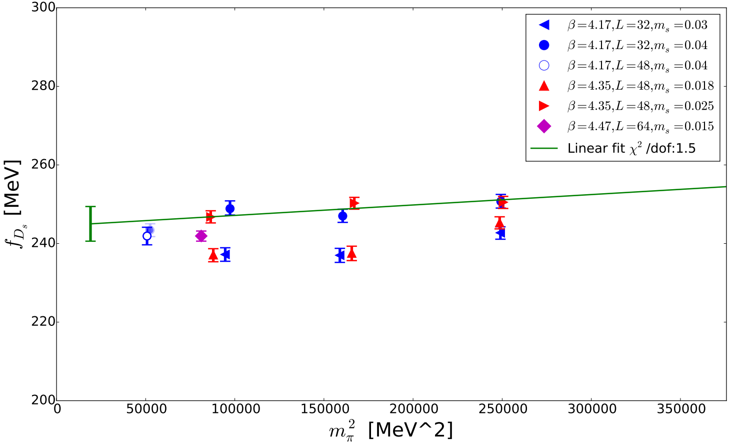
D pseudoscalar decay constants



Physical point extrapolation $f_D = 211.4 \pm 5.6$ MeV

D_s pseudoscalar decay constants

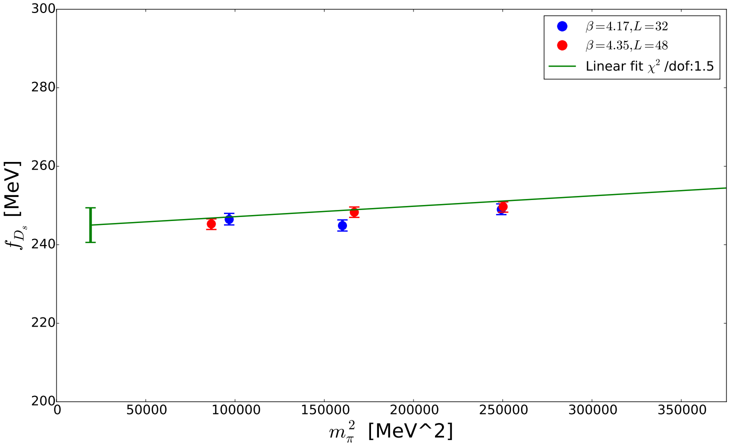
Before m_s interpolation



Physical point extrapolation $f_{D_s} = 245.0 \pm 4.4$ MeV

D_s pseudoscalar decay constants

After m_s interpolation



Physical point extrapolation $f_{D_s} = 245.0 \pm 4.4$ MeV
Ratio $f_{D_s}/f_D = 1.159 \pm 0.037$

Conclusions and Future work

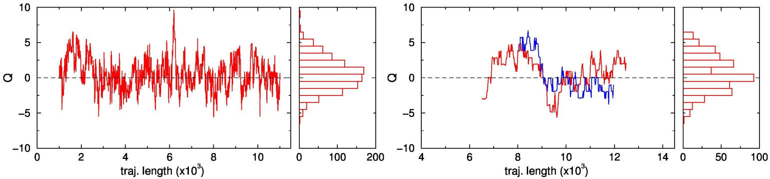
- First physical results from the JLQCD 2+1 domain wall ensembles with lattice spacing $1/a = 2.45 - 4.5$ GeV.
- We obtain the values of light and charmed decay constants with errors of order 1% after continuum extrapolation.
- Chiral fermions allow for computation of pseudoscalar decay constants without the need of renormalization factor Z_A. However, the calculation of Z_V, Z_A is on-going (see Tomii's talk)
- No substantial discretization effect for charm is observed.

- χPT analysis ongoing. Though no substantial effect is expected.
- Include heavier quark masses to extrapolate to B physics
- More physical quantities, including semi-leptonic D decays (on-going, see Suzuki's talk)

Thank You.

Backup Slides

Topological charge



Topological charge for $a^{-1} = 2.4$ GeV (left) and $a^{-1} = 3.6$ GeV (right)