RBC-UKQCD Ensembles: Current and Planned

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RBC-UKQCD Ensembles

The gauge and fermion (G+F) action abbreviations used are:

- DWF = domain wall fermions
- MDWF = Mobius domain wall fermions,
- GMDWF = G-parity Mobius domain wall fermions,
- W = Wilson gauge action
- I = Iwasaki gauge action
- ID = Iwasaki plus Dislocation Suppressing Determinant Ratio (DSDR) gauge action.
- WE = Wilson plus Dislocation Enhancing Determinant (DED) gauge action.
- o following time extent = open boundary conditions in time

The total light quark mass (in lattice units) is $m_l + m_{\rm res}$ and the total strange quark mass is similarly $m_s + m_{\rm res}$.

2+1 Flavor RBC-UKQCD Ensembles

Early ensembles with heavy pions								
Ens.	Action (F+G)	$1/a$ (GeV)	Lattice volume	m_l (in lattice units)	m_s	$m_{\rm res}$	m_π (MeV)	Size (fm)
1	DWF+I	1.785(5)	$24^3\times64\times16$	0.005	0.04	0.00308	340	2.6
2	DWF+I	1.785(5)	$24^3\times64\times16$	0.01	0.04	0.00308	432	2.6
3	DWF+I	1.785(5)	$24^3\times64\times16$	0.02	0.04	0.00308	560	2.6
4	DWF+I	1.785(5)	$24^3\times64\times16$	0.03	0.04	0.00308	670	2.6
5	DWF+I	2.383(9)	$32^3\times64\times16$	0.004	0.03	0.000664	303	2.6
6	DWF+I	2.383(9)	$32^3\times64\times16$	0.006	0.03	0.000664	360	2.6
7	DWF+I	2.383(9)	$32^3\times64\times16$	0.008	0.03	0.000664	412	2.6
8	DWF+ID	1.378(7)	$32^3\times64\times32$	0.0042	0.045	0.00184	246	4.6
9	DWF+ID	1.378(7)	$32^3\times64\times32$	0.001	0.045	0.00184	171	4.6

Table 1: Early ensembles with heavy pions.

2+1 Flavor RBC-UKQCD Ensembles

Ensembles including those with physical pions								
Ens.	Action (F+G)	$1/a$ (GeV)	Lattice volume	m_l (in lattice units)	m_s	$m_{\rm res}$	m_π (MeV)	Size (fm)
10	MDWF+I	1.730(4)	$48^3 \times 96 \times 24$	0.00078	0.0362	0.000614	139	5.5
11	MDWF+I	2.359(7)	$64^3 \times 128 \times 12$	0.000678	0.02661	0.000314	139	5.4
12	DWF+I	3.15(2)	$32^3 \times 64 \times 12$	0.0047	0.0186	0.000631	371	2.0
13	MDWF+ID	0.98(4)	$32^3 \times 64 \times 24$	0.00022	0.05960	0.00217	117	3.8
14	MDWF+ID	2.02(1)	$32^3 \times 64 \times 24$	0.00478	0.03297	0.00447	401	6.2
15	GMDWF+ID	1.37(1)	$32^3 \times 64 \times 12$	0.0001	0.045	0.00184	141	4.6
16	MDWF+ID	0.98(4)	$32^3 \times 64 \times 24$	0.00107	0.0850	0.00217	137	6.4
17	MDWF+ID	0.98(4)	$24^3 \times 64 \times 24$	0.00107	0.0850	0.00217	137	4.8
18	MDWF+ID	0.98(4)	$48^3 \times 64 \times 24$	0.00107	0.0850	0.00217	137	9.6
19	MDWF+ID	1.37(1)	$32^3 \times 64 \times 12$	0.0001	0.045	0.00189	141	4.6
20	DWF+I	2.785	$48^3 \times 96 \times 12$	0.002144	0.02144	0.000968	267	3.5
21	MDWF+I	2.708	$32^3 \times 64 \times 12$	0.00054	0.02132	0.000233	140	2.3
22	MDWF+I	2.708	$96^3 \times 192 \times 12$	0.00054	0.02132	0.000233	140	6.9
23	MDWF+I	2.708	$48^3 \times 96 \times 12$	0.002144	0.02144	0.000236	232	3.5
24	GMDWF+ID	1.723	$40^3 \times 64 \times 12$	0.0003	0.0342	0.00101	135	4.6
25	GMDWF+ID	2.068	$48^3 \times 64 \times 12$	0.00074	0.02775	0.000276	135	4.6

Table 2: Ensembles including those with physical pions.

2+1 Flavor RBC-UKQCD Ensembles

G-Parity ensembles for K → ππ

Ensembles including those with physical pions								
Ens.	Action (F+G)	$1/a$ (GeV)	Lattice volume	m_l (in lattice units)	m_s	m_{res}	m_π (MeV)	Size (fm)
10	MDWF+I	1.730(4)	$48^3\times96\times24$	0.00078	0.0362	0.000614	139	5.5
11	MDWF+I	2.359(7)	$64^3\times128\times12$	0.000678	0.02661	0.000314	139	5.4
12	DWF+I	3.15(2)	$32^3\times64\times12$	0.0047	0.0186	0.000631	371	2.0
13	MDWF+ID	0.98(4)	$32^3\times64\times24$	0.00022	0.05960	0.00217	117	3.8
14	MDWF+ID	2.02(1)	$32^3\times64\times24$	0.00478	0.03297	0.00447	401	6.2
15	GMDWF+ID	1.37(1)	$32^3\times64\times12$	0.0001	0.045	0.00184	141	4.6
16	MDWF+ID	0.98(4)	$32^3\times64\times24$	0.00107	0.0850	0.00217	137	6.4
17	MDWF+ID	0.98(4)	$24^3\times64\times24$	0.00107	0.0850	0.00217	137	4.8
18	MDWF+ID	0.98(4)	$48^3\times64\times24$	0.00107	0.0850	0.00217	137	9.6
19	MDWF+ID	1.37(1)	$32^3\times64\times12$	0.0001	0.045	0.00189	141	4.6
20	DWF+I	2.785	$48^3\times96\times12$	0.002144	0.02144	0.000968	267	3.5
21	MDWF+I	2.708	$32^3\times64\times12$	0.00054	0.02132	0.000233	140	2.3
22	MDWF+I	2.708	$96^3\times192\times12$	0.00054	0.02132	0.000233	140	6.9
23	MDWF+I	2.708	$48^3\times96\times12$	0.002144	0.02144	0.000236	232	3.5
24	GMDWF+ID	1.723	$40^3\times64\times12$	0.0003	0.0342	0.00101	135	4.6
25	GMDWF+ID	2.068	$48^3\times64\times12$	0.00074	0.02775	0.000276	135	4.6

Table 2: Ensembles including those with physical pions.

2+1 Flavor RBC-UKQCD Ensembles

Iwasaki Physical Point Ensembles

Ensembles including those with physical pions

Ens.		Action (F+G)	$1/a$ (GeV)	Lattice volume	m_l	m_s	m_{res}	m_π (MeV)	Size (fm)
					(in lattice units)				
10	48I	MDWF+I	1.730(4)	$48^3\times96\times24$	0.00078	0.0362	0.000614	139	5.5
11	64I	MDWF+I	2.359(7)	$64^3\times128\times12$	0.000678	0.02661	0.000314	139	5.4
12		DWF+I	3.15(2)	$32^3\times64\times12$	0.0047	0.0186	0.000631	371	2.0
13		MDWF+ID	0.98(4)	$32^3\times64\times24$	0.00022	0.05960	0.00217	117	3.8
14		MDWF+ID	2.02(1)	$32^3\times64\times24$	0.00478	0.03297	0.00447	401	6.2
15		GMDWF+ID	1.37(1)	$32^3\times64\times12$	0.0001	0.045	0.00184	141	4.6
16		MDWF+ID	0.98(4)	$32^3\times64\times24$	0.00107	0.0850	0.00217	137	6.4
17		MDWF+ID	0.98(4)	$24^3\times64\times24$	0.00107	0.0850	0.00217	137	4.8
18		MDWF+ID	0.98(4)	$48^3\times64\times24$	0.00107	0.0850	0.00217	137	9.6
19		MDWF+ID	1.37(1)	$32^3\times64\times12$	0.0001	0.045	0.00189	141	4.6
20		DWF+I	2.785	$48^3\times96\times12$	0.002144	0.02144	0.000968	267	3.5
21		MDWF+I	2.708	$32^3\times64\times12$	0.00054	0.02132	0.000233	140	2.3
22	96I	MDWF+I	2.708	$96^3\times192\times12$	0.00054	0.02132	0.000233	140	6.9
23		MDWF+I	2.708	$48^3\times96\times12$	0.002144	0.02144	0.000236	232	3.5
24		GMDWF+ID	1.723	$40^3\times64\times12$	0.0003	0.0342	0.00101	135	4.6
25		GMDWF+ID	2.068	$48^3\times64\times12$	0.00074	0.02775	0.000276	135	4.6

Table 2: Ensembles including those with physical pions.

2+1 Flavor RBC-UKQCD Ensembles

ID Physical Point Ensembles

Ensembles including those with physical pions								
Ens.	Action (F+G)	$1/a$ (GeV)	Lattice volume	m_l (in lattice units)	m_s	m_{res}	m_π (MeV)	Size (fm)
10	MDWF+I	1.730(4)	$48^3\times96\times24$	0.00078	0.0362	0.000614	139	5.5
11	MDWF+I	2.359(7)	$64^3\times128\times12$	0.000678	0.02661	0.000314	139	5.4
12	DWF+I	3.15(2)	$32^3\times64\times12$	0.0047	0.0186	0.000631	371	2.0
13	MDWF+ID	0.98(4)	$32^3\times64\times24$	0.00022	0.05960	0.00217	117	3.8
14	MDWF+ID	2.02(1)	$32^3\times64\times24$	0.00478	0.03297	0.00447	401	6.2
15	GMDWF+ID	1.37(1)	$32^3\times64\times12$	0.0001	0.045	0.00184	141	4.6
16	MDWF+ID	0.98(4)	$32^3\times64\times24$	0.00107	0.0850	0.00217	137	6.4
17	MDWF+ID	0.98(4)	$24^3\times64\times24$	0.00107	0.0850	0.00217	137	4.8
18	MDWF+ID	0.98(4)	$48^3\times64\times24$	0.00107	0.0850	0.00217	137	9.6
19	MDWF+ID	1.37(1)	$32^3\times64\times12$	0.0001	0.045	0.00189	141	4.6
20	DWF+I	2.785	$48^3\times96\times12$	0.002144	0.02144	0.000968	267	3.5
21	MDWF+I	2.708	$32^3\times64\times12$	0.00054	0.02132	0.000233	140	2.3
22	MDWF+I	2.708	$96^3\times192\times12$	0.00054	0.02132	0.000233	140	6.9
23	MDWF+I	2.708	$48^3\times96\times12$	0.002144	0.02144	0.000236	232	3.5
24	GMDWF+ID	1.723	$40^3\times64\times12$	0.0003	0.0342	0.00101	135	4.6
25	GMDWF+ID	2.068	$48^3\times64\times12$	0.00074	0.02775	0.000276	135	4.6

Table 2: Ensembles including those with physical pions.

2+1 Flavor RBC-UKQCD Ensembles

Ensembles probing effects near physical pion ensembles								
Ens.	Action (F+G)	$1/a$ (GeV)	Lattice volume	m_l (in lattice units)	m_s	$m_{\rm res}$	m_π (MeV)	Size (fm)
26	MDWF+I	1.73	$32^3 \times 64 \times 24$	0.0025	0.0362	0.00063	208	3.7
27	MDWF+I	1.73	$24^3 \times 48 \times 32$	0.0055	0.0368	0.00046	284	2.8
28	MDWF+I	1.73	$32^3 \times 64 \times 24$	0.0025	0.05	0.00065	210	3.7
29	MDWF+I	1.74	$24^3 \times 48 \times 24$	0.0049	0.0362	0.00062	279	2.8
30	MDWF+I	2.37	$32^3 \times 64 \times 12$	0.00372	0.0257	0.00030	281	2.7
31	MDWF+I	1.76	$24^3 \times 48 \times 8$	0.002356	0.03366	0.00415	303	2.7
32	MDWF+I	1.73	$32^3 \times 64 \times 24$	0.00078	0.0362	0.00061	139	3.7
33	MDWF+I	1.73	$64^3 \times 128 \times 24$	0.00078	0.0362	0.00061	139	7.4
34	MDWF+I	1.74	$32^3 \times 64 \times 24$	0.0049	0.0362	0.00062	279	3.7
35	MDWF+I	3.50	$48^3 \times 192o \times 12$	0.0026	0.0176	0.00014	280	2.7

Table 3: Ensembles probing effects near physical pion ensembles

2+1+1 Flavor RBC-UKQCD Ensembles

2+1+1 flavor ensembles									
Ens.	Action (F+G)	$1/a$ (GeV)	Lattice volume	m_l (in lattice units)	m_s (in lattice units)	m_c (in lattice units)	m_{res}	m_π (MeV)	Size (fm)
1f	MDWF+WE	3.1	$32^3 \times 64 \times 32$	0.0001	0.0186	0.243	0.0008	160	1.7
2f	MDWF+WE	3.1	$80^2 \times 96 \times 192 \times 32$	0.0001	0.0186	0.243	0.0008	160	4.1
3f	MDWF+I	1.75	$24^3 \times 48 \times 24$	0.0049	0.0362	0.6679	0.00067	280	3.8
4f	MDWF+I	1.75	$24^3 \times 48 \times 24$	0.0049	0.0362	0.5	0.00067	280	3.8
5f	MDWF+I	1.75	$24^3 \times 48 \times 24$	0.0049	0.0362	0.35	0.00079	284	3.9
6f	MDWF+I	2.37	$32^3 \times 64 \times 12$	0.00372	0.0257	0.4539	0.00030	280	3.9
PROPOSED									
7f	MDWF+W	2.8	$96^3 \times 384o \times 24$					135	4.6
8f	MDWF+W	3.8	$128^3 \times 512o \times 16$					135	4.5
9f	MDWF+W	4.8	$160^3 \times 640o \times 12$					135	4.5

Table 4: 2+1+1 flavor ensembles. The precise values for the fifth dimensional extent, L_s, are to be determined and will depend on the gauge action used.

- Plan to use open boundary conditions to improve topological tunneling
- RBC-UKQCD working on many algorithmic ideas: DDHMC, trivializing maps, RMHMC, gauge fixed Fourier accelerated HMC, ...

96I on OLCF Summit

6 Nvidia V100 2 Power9 CPU, 512GB DDR4 + 96GB HBM2) $\times$ 4608 nodes
Möbius + Iwasaki ($\beta = 2.31$) 2+1 flavor physical , $96^3 \times 192 \times 12 (b+c=2)$,
$am_l = 0.00054, am_h = 0.02144$, $a \sim$0.07fm, $L \sim$ 7fm
$16 \times 12^3 \times 12$ on $(1 \times 8 \times 8 \times 16 = 1024)$ nodes $\times$ 6 GPUs
Evolution: CPS+ QUDA
Exact One Flavor Algorithm(EOFA) with Cayley Preconditioner: 1 flavor Möbius fermion action with

$$S_{pf} = \begin{pmatrix} 0 & \phi_1^\dagger \end{pmatrix} \left[I - k\Omega_-^T \frac{1}{H_T(m_1)} \Omega_- \right] \begin{pmatrix} 0 \\ \phi_1 \end{pmatrix} + \begin{pmatrix} \phi_2^\dagger & 0 \end{pmatrix} \left[I + k\Omega_+^T \frac{1}{H_T(m_2) - \Delta_+(m_1, m_2) P_+} \Omega_+ \right] \begin{pmatrix} \phi_2 \\ 0 \end{pmatrix},$$

Can be simulated with CG, avoids RHMC. Allow mixed precision, etc to reduce time on inversion.
Small memory footprint improve overall arithmetic intensity, especially significant on GPUs.
Multisplitting-preconditioned Conjugate Gradient
Additive Schwarz 'done right' for Möbius CG Utilize Tensor core for 5D part
Low Overhead Transparent Multilevel Checkpoint/Restart (VeloC)

From Chulwoo Jung

Summary

- Essentially physical point MDWF+I ensembles for 3 lattice spacings
  - * Ensembles away from physical point allow for ~5% adjustments in quark masses to reach truly physical results.
  - * For HVP project, additional "nearby" ensembles have recently been generated (Lehner).
- MDWF+ID ensembles at 1/a = 1 GeV at 3 different, large volumes
  - * Observables generally within 10% of continuum limit values
  - * Nice environment for testing finite volume effects, new methods...
- G-Parity MDWF+ID ensembles at physical pions for 3 lattice spacings
  - * Will allow a continuum extrapolation for $K \to \pi\pi$ calculations
- Most are available from Globus endpoint at Columbia. Newest ones can be posted there soon.
- Use and access allowed by non-collaboration members for non-competing projects. Generally available after first publication and may be available sooner. Contact us if interested.