Rho meson resonances with the stochastic LapH method

Lattice 2016 Southampton
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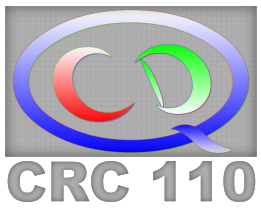

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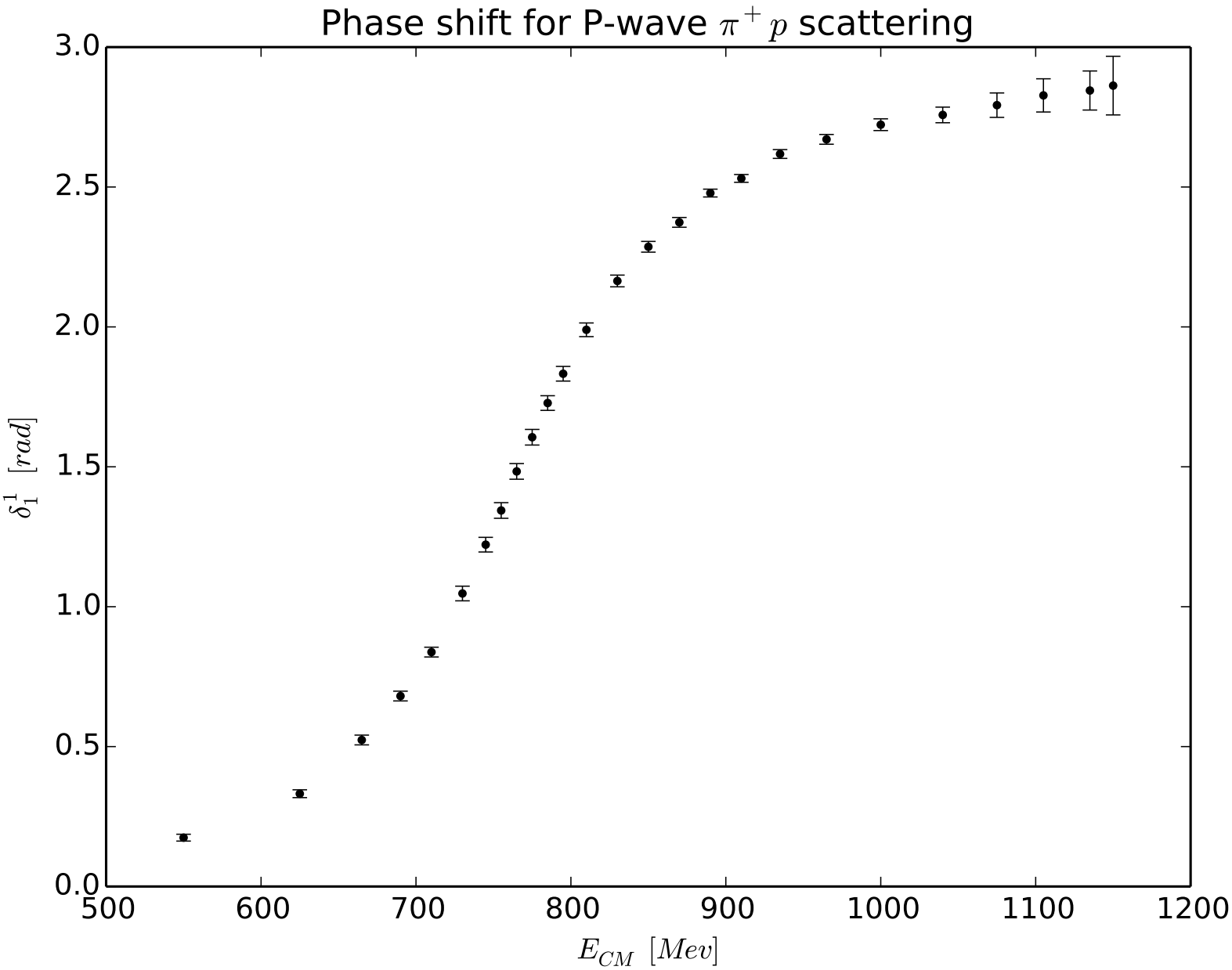
Introduction

- Experimentally ρ is P-wave resonance with $\Gamma_{\pi^+\pi^-}/\Gamma \sim 1$
- For ρ^0 from hadronic channels, PDG quotes:

$$M_\rho = 769.0(9)\,\text{MeV} \quad \Gamma = 151.7(2.6)\,\text{Mev}$$

- Recent experiments study leptonic channels e. g. $e^+e^- \to \pi\pi$ or $\tau \to \pi\pi\mu$
- Last hadronic experiments have been performed in the 70s

Experimental data S. D. Protopopescu *et al.*, Phys. Rev. D **7** (1973) 1279.



- Resonances nonperturbative problem

- To describe them with lattice QCD needs at least operators interpolating ρ and $\pi\pi$
  - S. Aoki *et al.* [CP-PACS Collaboration], Phys. Rev. D **76** (2007) 094506 [arXiv:0708.3705 [hep-lat]]
  - X. Feng, K. Jansen and D. B. Renner, Phys. Rev. D **83** (2011) 094505
  - C. B. Lang, D. Mohler, S. Prelovsek and M. Vidmar, Phys. Rev. D **84** (2011) no.5, 054503

    Erratum: [Phys. Rev. D **89** (2014) no.5, 059903]
  - S. Aoki *et al.* [CS Collaboration], Phys. Rev. D **84** (2011) 094505

- Calculation of phase shift with Lüschers formula
  - M. Luscher, Commun. Math. Phys. **105** (1986) 153

- Systematic study of possible operators with 3 volumes, 250 ρ- and 33 $\pi\pi$-operators
  - J. J. Dudek *et al.* [Hadron Spectrum Collaboration], Phys. Rev. D **87** (2013) no.3, 034505

    Erratum: [Phys. Rev. D **90** (2014) no.9, 099902]

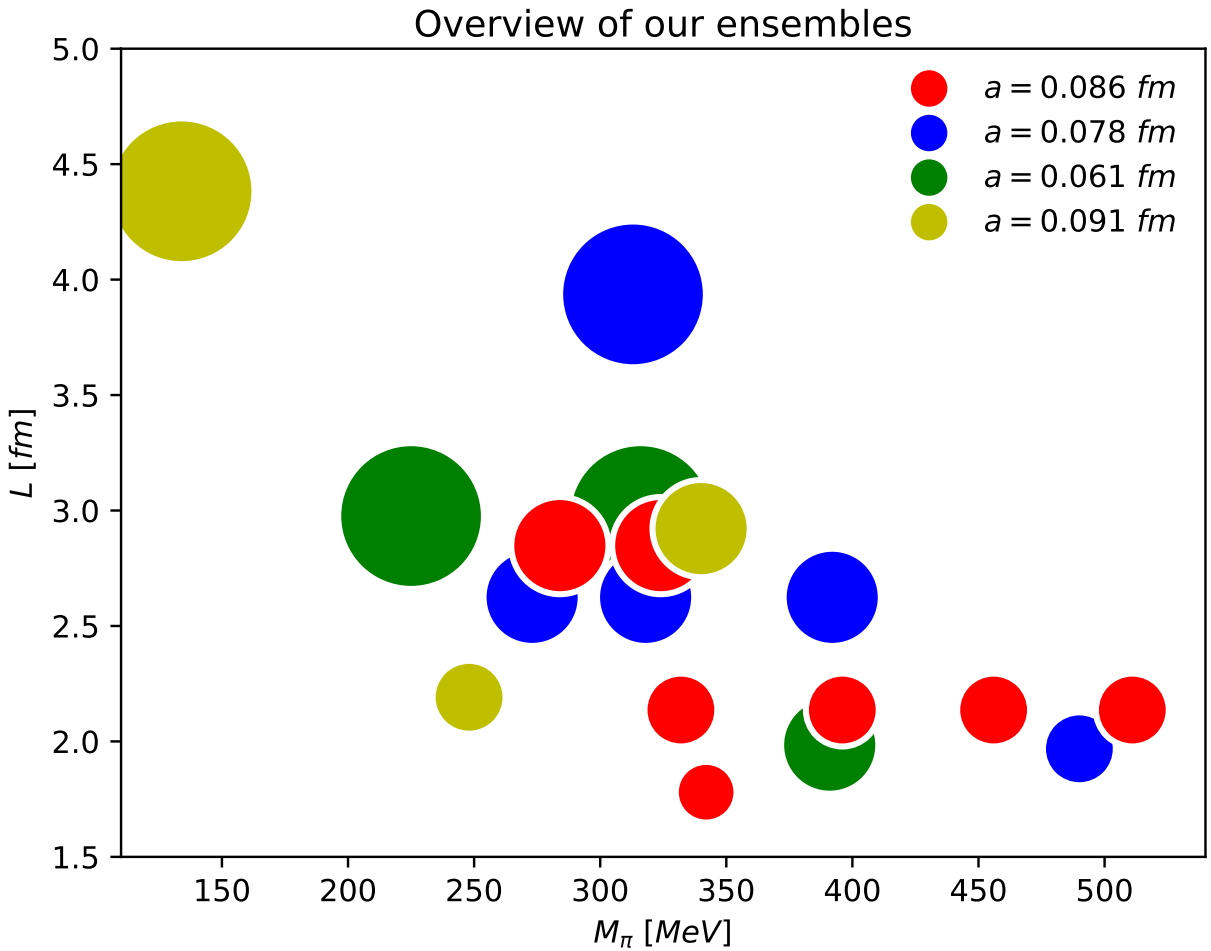
State of the art 2016

- Physical point
  - G. S. Bali *et al.* [RQCD Collaboration], Phys. Rev. D **93** (2016) no.5, 054509
- Elongated lattices
  - D. Guo, A. Alexandru, R. Molina and M. Doering, arXiv:1605.03993 [hep-lat]
- Large operator basis
  - J. Bulava, B. Fahy, B. Hörz, K. J. Juge, C. Morningstar and C. H. Wong, arXiv:1604.05593 [hep-lat]
  - D. J. Wilson, R. A. Briceno, J. J. Dudek, R. G. Edwards and C. E. Thomas, Phys. Rev. D **92** (2015) no.9, 094502

BUT: No calculation with large operator basis
and
full control of chiral limit and continuum limit

Our goal

- We want to extrapolate to the physical point with all systematics under control



- 15 $N_f = 2 + 1 + 1$ Ensembles
  - 3 lattice spacings
  - M_π from 225 to 511 MeV
- 3 $N_f = 2$ Ensembles
  - M_π from 134 to 340 MeV

sLapH method

- Use the stochastic Laplacian Heaviside method to generate all-to-all Correlators [1] [2]

T/a	L/a	N_{rnd}	N_{ev}	dil_T	dil_E	dil_D
48	24	6	120	B2	I6	F4
64	32	5-7	220	B2	I4	F4
96	48	6	660	B3	I4	F4

- $\sim$ 3000 inversions per configuration

[1] M. Peardon *et al.* [Hadron Spectrum Collaboration], Phys. Rev. D **80** (2009) 054506

[2] C. Morningstar, J. Bulava, J. Foley, K. J. Juge, D. Lenkner, M. Peardon and C. H. Wong, Phys. Rev. D **83** (2011) 114505

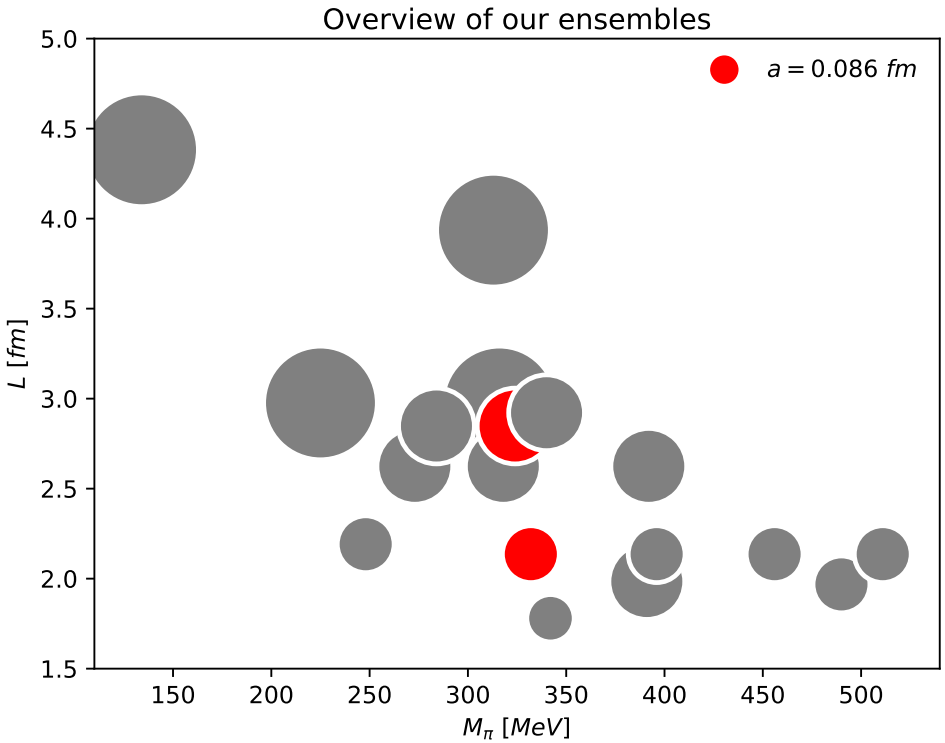
Part of the Bonn scattering project

- 16:30: Kaon Kaon scattering at maximal isospin from $N_f = 2 + 1 + 1$ twisted mass lattice QCD by Christopher HELMES

- 17:10: The isospin-0 pion-pion scattering length from twisted mass lattice QCD by Liuming LIU

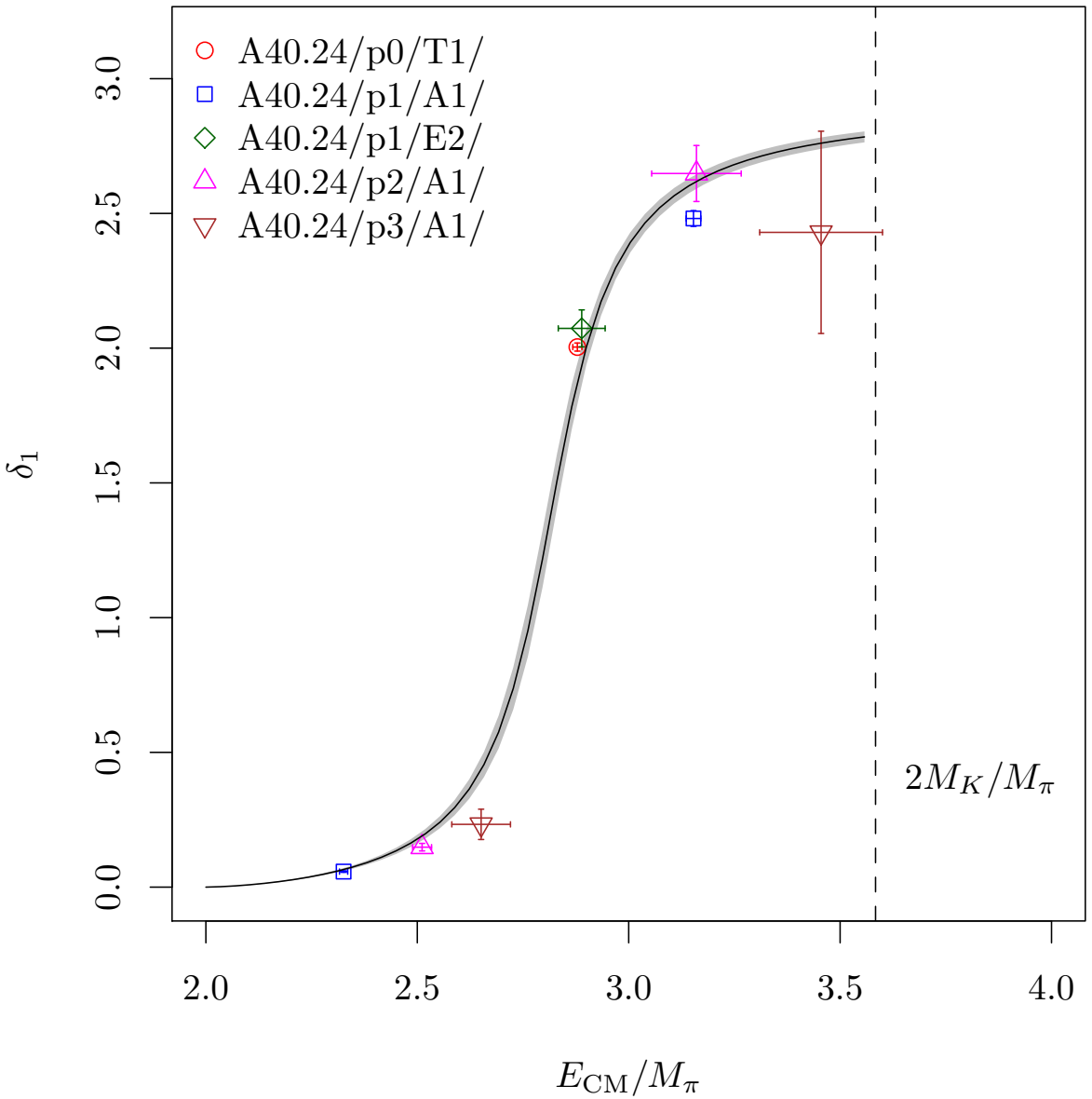
This talk

- First test method with high-statistics ensemble
- $L = 24 : N_{\text{config}} = 1018$
- $L = 32 : N_{\text{config}} = \ \ 250$



- Still in the process of enlarging operator basis. In this talk:
  - Moving frames with $|\vec{p}_{\text{CM}}| \leq |(1,1,1)|$
    - K. Rummukainen and S. A. Gottlieb, Nucl. Phys. B **450** (1995) 397)
    - M. Gockeler, R. Horsley, M. Lage, U.-G. Meissner, P. E. L. Rakow, A. Rusetsky, G. Schierholz and J. M. Zanotti, Phys. Rev. D **86** (2012) 094513
  - $|\vec{k}_\pi| \ \ \leq |(0,0,2)|$

$L = 24 \quad a = 0.086$ fm $\quad M_\pi = 332$ MeV



- CM and 3 moving frames
- Breaking of rotational symmetry splits spin triplett
- More irreps with larger $|\vec{k}_\pi|^2$

Fitprocedure and preliminary results

- Fully correlated fit to effective range formula
  - L. S. Brown and R. L. Goble, Phys. Rev. Lett. **20** (1968) 346

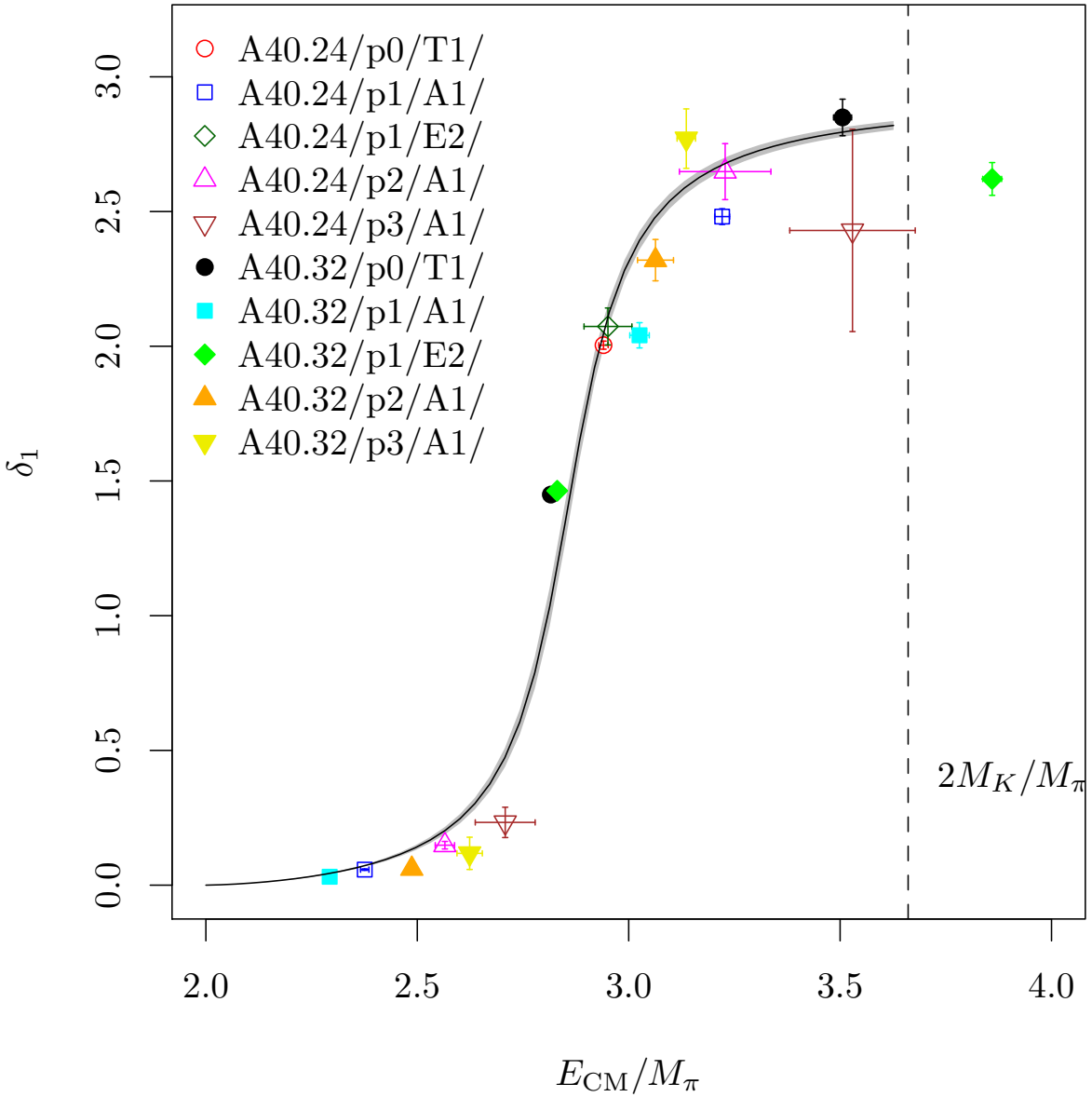
$$\delta_1(E_{\mathrm{CM}}) = \arctan\left(\frac{g_{\rho\pi\pi}^2}{6\pi}\frac{\tilde{q}^3}{E_{\mathrm{CM}}(M_\rho^2 - E_{\mathrm{CM}}^2)}\right), \qquad \tilde{q} = \sqrt{\left(\frac{E_{\mathrm{CM}}^2}{4} - M_\pi^2\right)}$$

- Fit results:

$$M_\rho = 914(37)\ \mathrm{MeV}$$

$$g_{\rho\pi\pi} = 6.02(20)$$

$L = 24, 32 \quad a = 0.086$ fm $\quad M_\pi = 332$ MeV, 324 MeV



- $M_\rho = 906(37)$ MeV
- $g_{\rho\pi\pi} = 5.68(16)$

Summary and Outlook

- LapH perambulators available, but ongoing analysis
- Investigate higher momenta, more irreps and derivative operators
- Perform a chiral extrapolation
- Perform a continuum extrapolation

Overview of Ensembles

- Ensembles are generated by the European Twisted Mass Collaboration[3]

name	L/a	T/a	N_{conf}	a[fm]	M_π[MeV]	
A40.20	20	48	557	0.086	342	(✓)
A100.24	24	48	626	0.086	511	(✓)
A80.24	24	48	307	0.086	456	(✓)
A60.24	24	48	314	0.086	396	(✓)
A40.24	24	48	1018	0.086	332	(✓)
A40.32	32	64	250	0.086	324	(...)
A30.32	32	64	281	0.086	284	(...)
B85.24	24	48	296	0.078	490	(✓)
B55.32	32	64	310	0.078	392	(...)
B35.32	32	64	250	0.078	318	(✓)
B25.32t	32	64	201	0.078	273	(✓)
B35.48	48	96	316	0.078	313	(✓)
D45.32	32	64	301	0.061	391	(✓)
D30.48	48	96	198	0.061	316	(...)
D15.48	48	96	321	0.061	225	(✓)
cA2.30.24	24	48	352	0.091	248	(✓)
cA2.60.32	32	64	209	0.091	340	(...)
cA2.09.48	48	96	440	0.091	134	(...)

[3] R. Baron *et al.*, PoS LATTICE **2010**, 123 (2010) and R. Baron *et al.*, JHEP **1006**, 111 (2010)