Light meson decay constants from Möbius domain-wall fermions on gradient flowed HISQ ensembles

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LATTICE 2023
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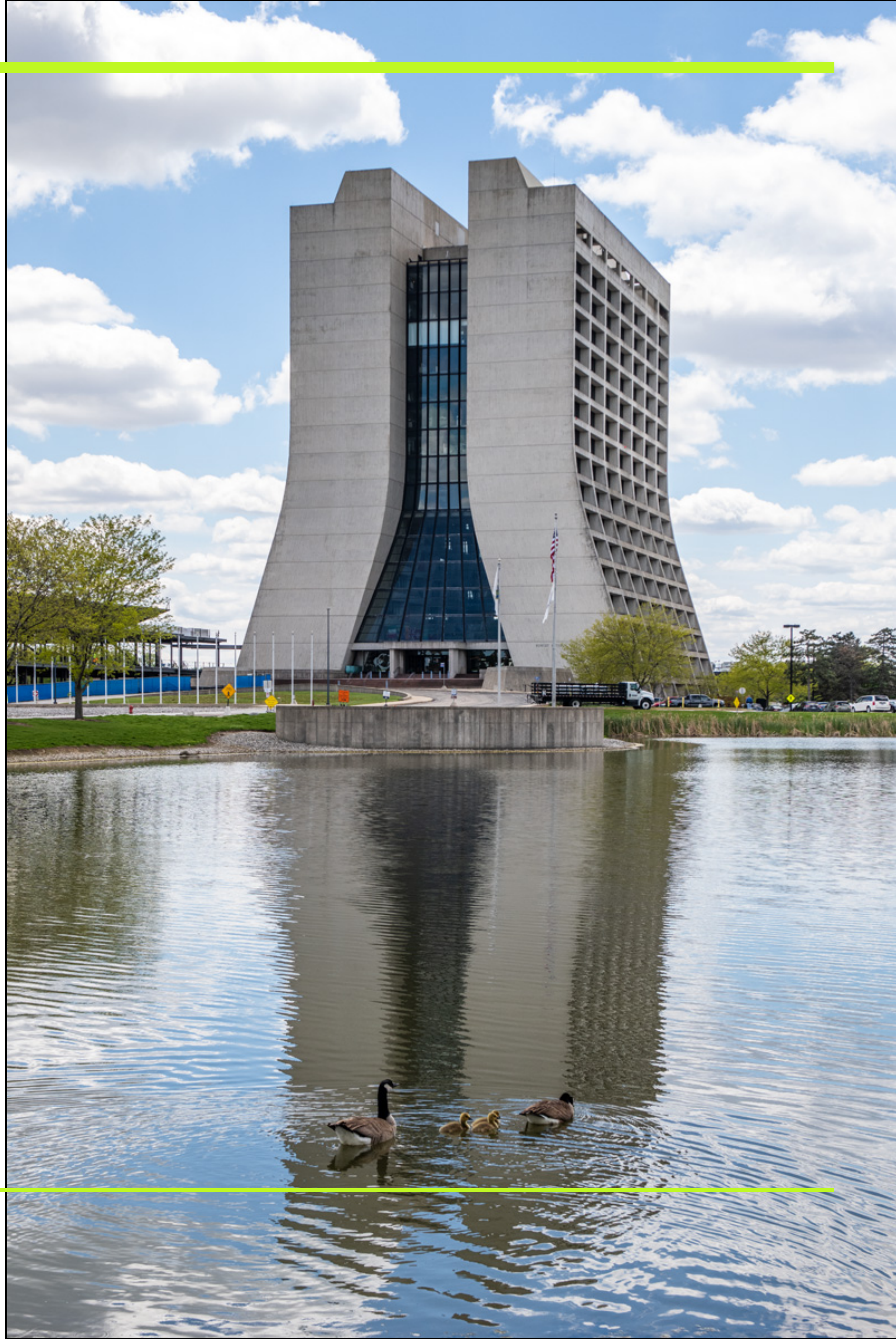
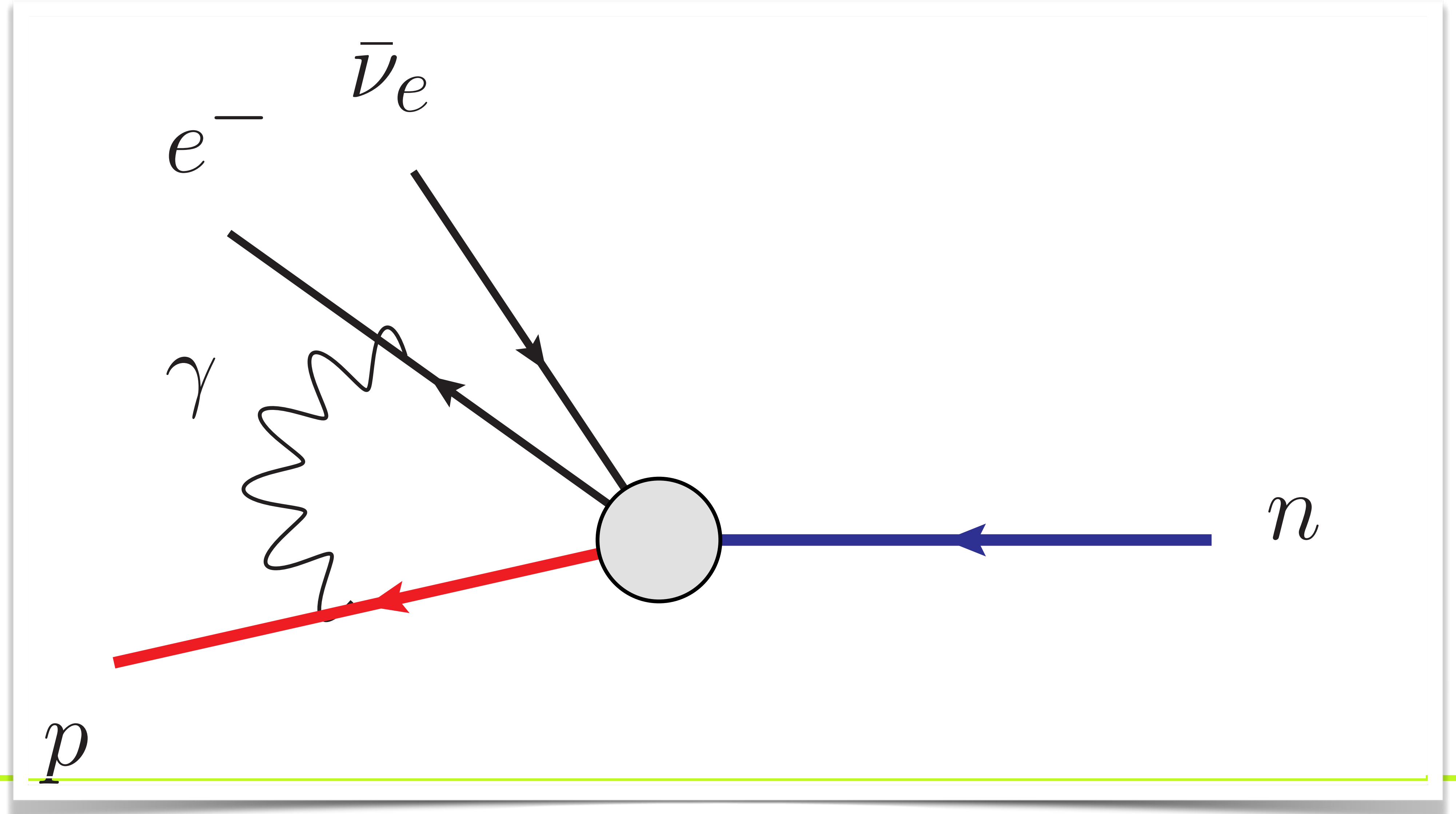


Motivation

- Particle-decay processes are some of the most promising methods of testing the Standard Model
  - β-decay experiments are how we know the *weak*-interactions are V-A (left handed)
  - Precise measurements are used to search for small corrections to V-A structure
  - Decays are used to determine elements of the quark mixing matrix (CKM)

- With current limits, our understanding of β-decay must be controlled with a precision of $O(10^{-4})$
  - The main challenge is understanding electromagnetic (QED) corrections often denoted *radiative* or *radiative QED* corrections
  - As part of our larger research program we seek to add QED for precision studies, yet the correlated correction need only be at 10^{-4} / α_{fs} ~ 10^{-2} level



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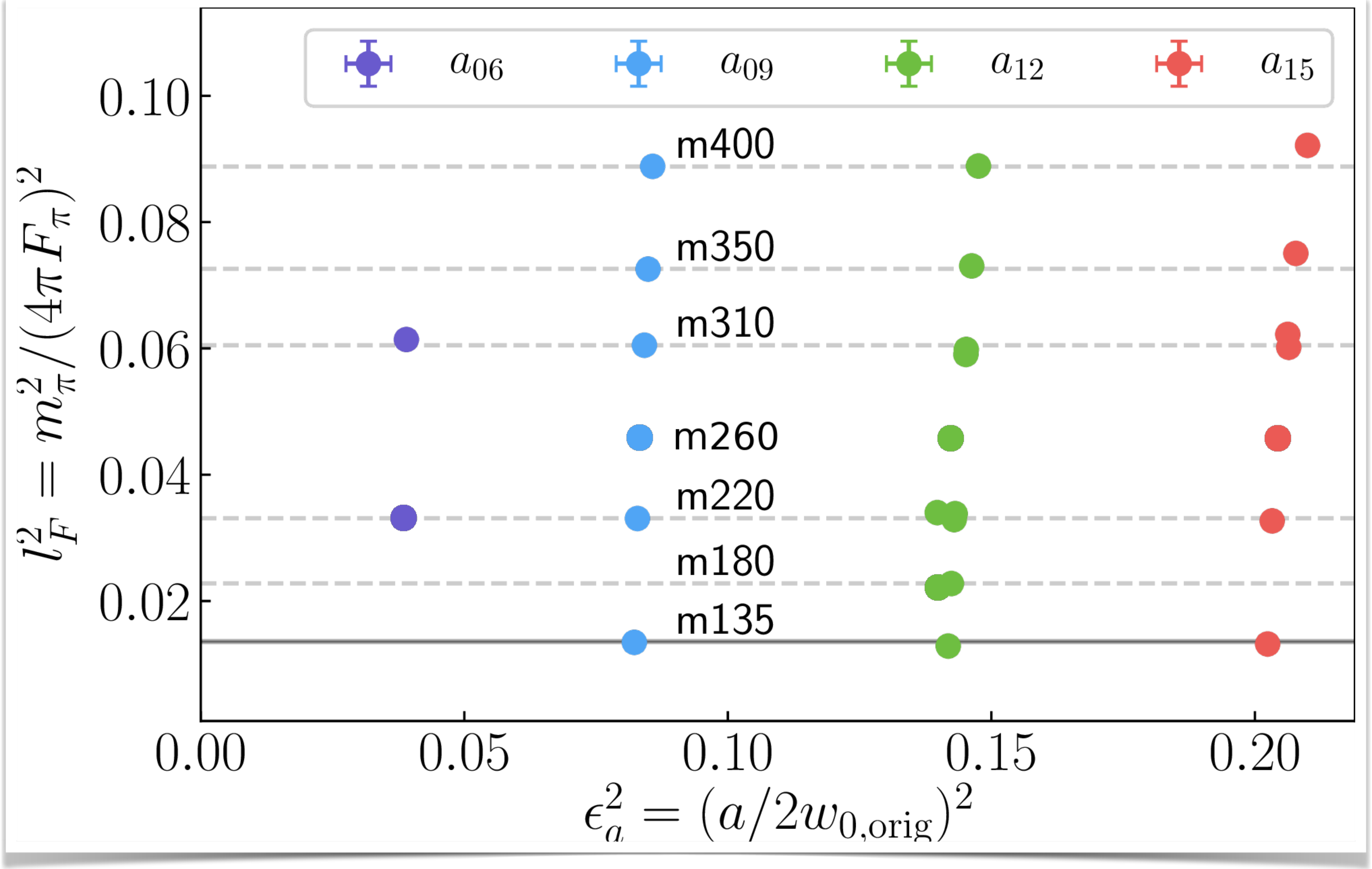
  - As part of our larger research program we seek to a QED for precision studies, yet the correlated correction need only be at $10^{-4} / \alpha_{fs} \sim 10^{-2}$ level
  - Therefore, we need to make sure our systematics are controlled in the QCD sector and decay constants act as “gold-plated” benchmarks

Lattice Setup



PHYSICAL REVIEW D **102,** 034507 (2020)

F_K/F_π from Möbius domain-wall fermions solved on gradient-flowed HISQ ensembles

Nolan Miller,[1] Henry Monge-Camacho,[1] Chia Cheng Chang (張家丞),[2,3,4] Ben Hörz,[3] Enrico Rinaldi,[5,2] Dean Howarth,[6,3] Evan Berkowitz,[7,8] David A. Brantley,[6] Arjun Singh Gambhir,[9,3] Christopher Körber,[4,3] Christopher J. Monahan,[10,11] M. A. Clark,[12] Bálint Joó,[13] Thorsten Kurth,[12] Amy Nicholson,[1] Kostas Orginos,[10,11] Pavlos Vranas,[6,3] and André Walker-Loud[3,6,4]

PHYSICAL REVIEW D **103,** 054511 (2021)

Scale setting the Möbius domain wall fermion on gradient-flowed HISQ action using the omega baryon mass and the gradient-flow scales t_0 and w_0

Nolan Miller,[1] Logan Carpenter,[2] Evan Berkowitz,[3,4] Chia Cheng Chang (張家丞),[5,6,7] Ben Hörz,[6] Dean Howarth,[8,6] Henry Monge-Camacho,[9,1] Enrico Rinaldi,[10,5] David A. Brantley,[8] Christopher Körber,[7,6] Chris Bouchard,[11] M. A. Clark,[12] Arjun Singh Gambhir,[13,6] Christopher J. Monahan,[14,15] Amy Nicholson,[1,6] Pavlos Vranas,[8,6] and André Walker-Loud[6,8,7]

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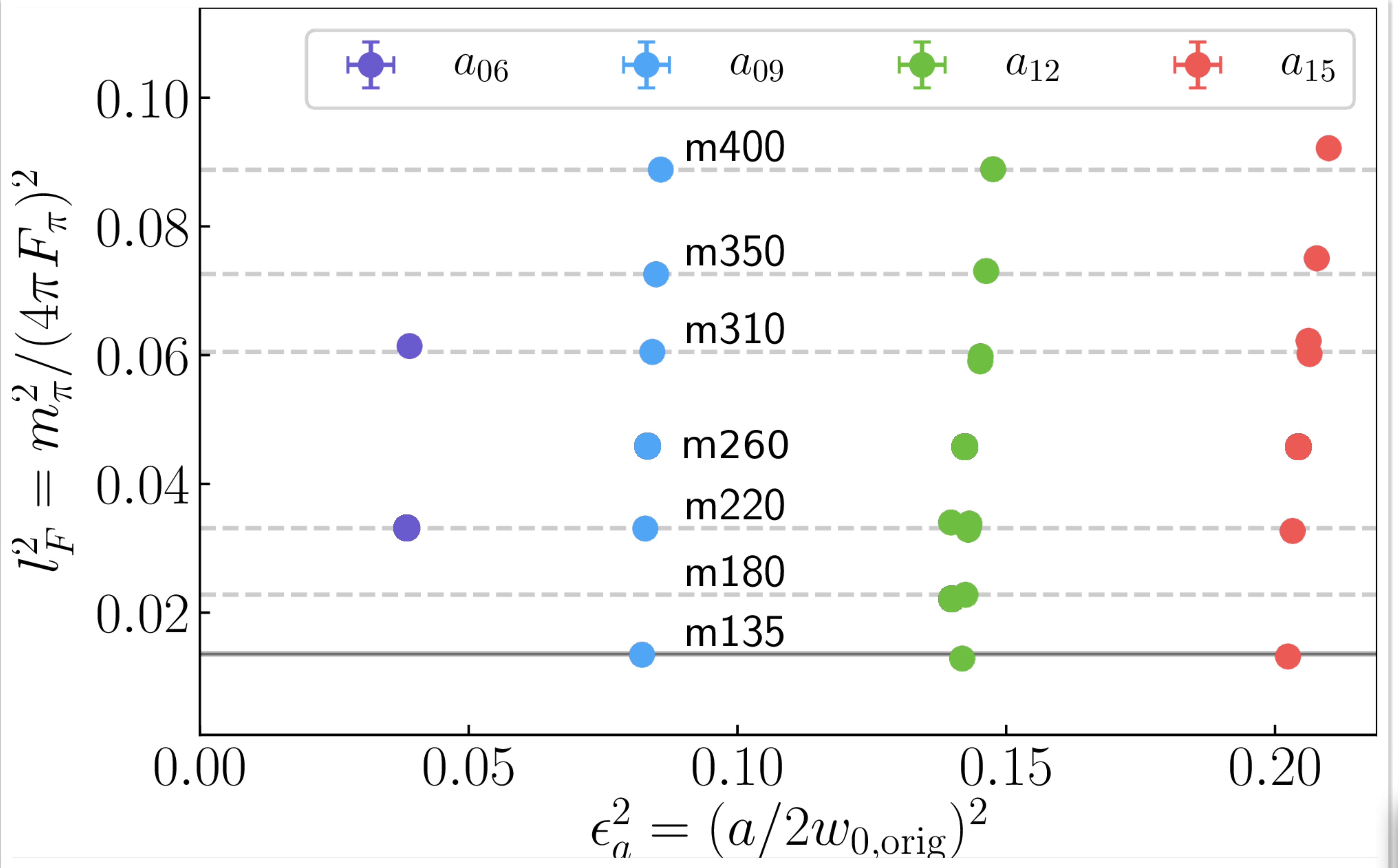

Determine F_K, $F_\pi \rightarrow m_\pi$, $m_K \rightarrow m_q^l$, m_q^s

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Ensembles

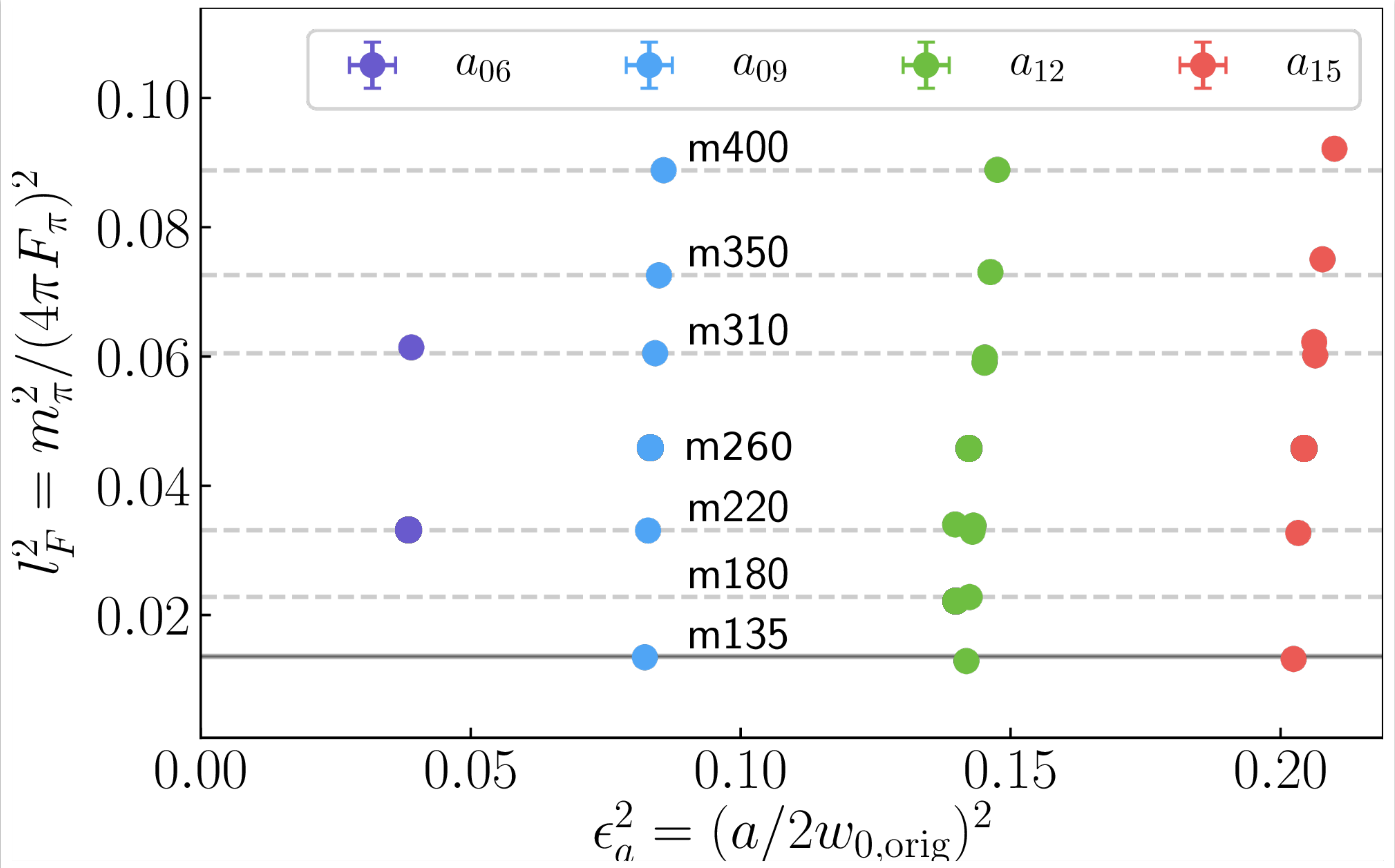
EFT

PHYSICAL REVIEW D **97,** 114004 (2018)

Analytic representations of m_K, F_K, m_η, and F_η in two loop $SU(3)$ chiral perturbation theory

B. Ananthanarayan,[1] Johan Bijnens,[2] Samuel Friot,[3,4] and Shayan Ghosh[1]

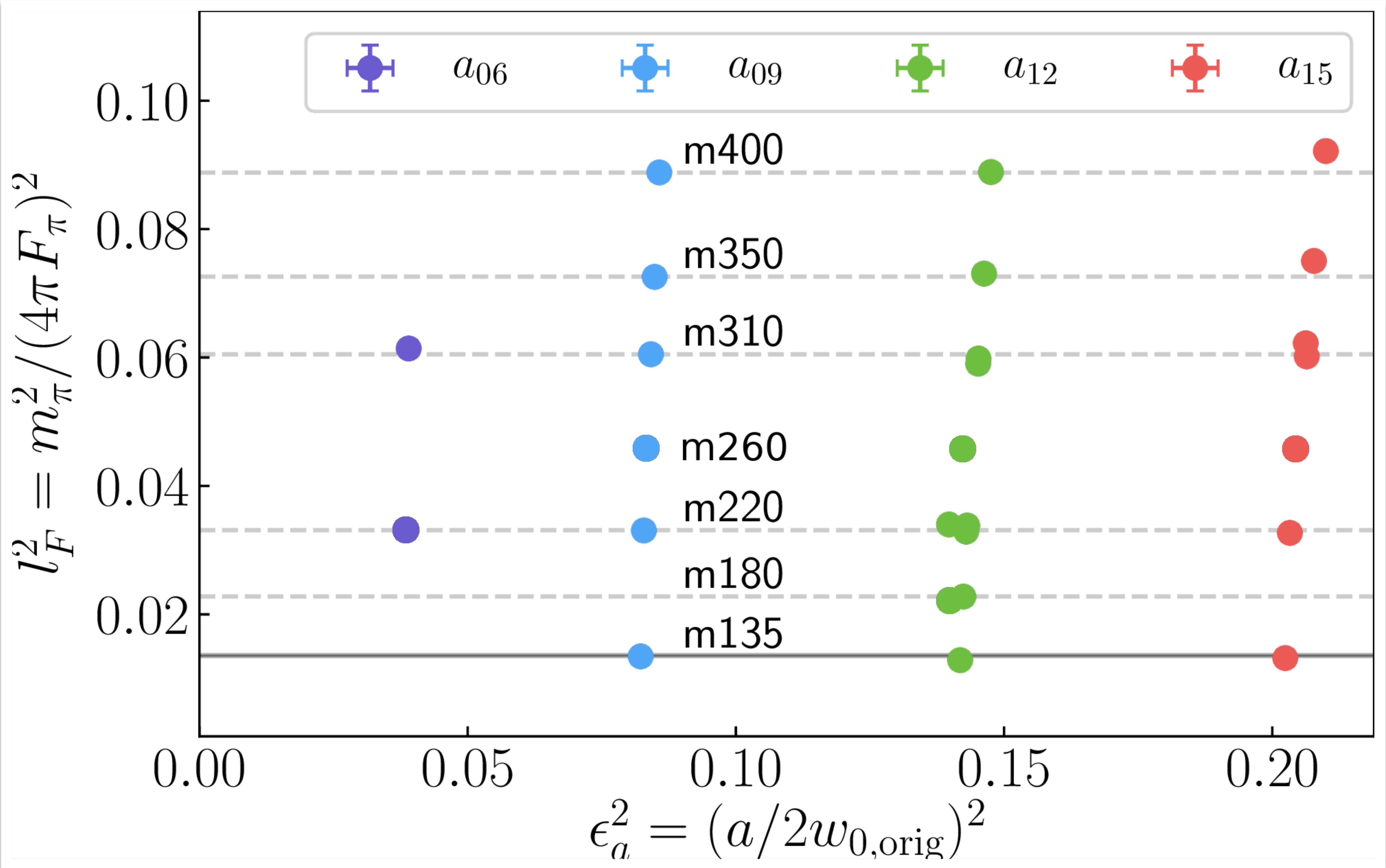
Fit Strategy



Determine F_K, $F_\pi \to m_\pi$, $m_K \to m_q^l$, m_q^s

- Bayesian fits
  - 18 ensembles used for preliminary analysis
  - Models:
    - $F^2 = \{F_\pi^2, F_\pi F_K, F_K^2\}$ in defining $\epsilon_P = m_P/4\pi F_P$ and μ_0
      - Changing the scale induces N^{2}LO corrections

Fit Strategy



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    - χPT- NLO
    - At N^{2}LO- full χPT or just ct
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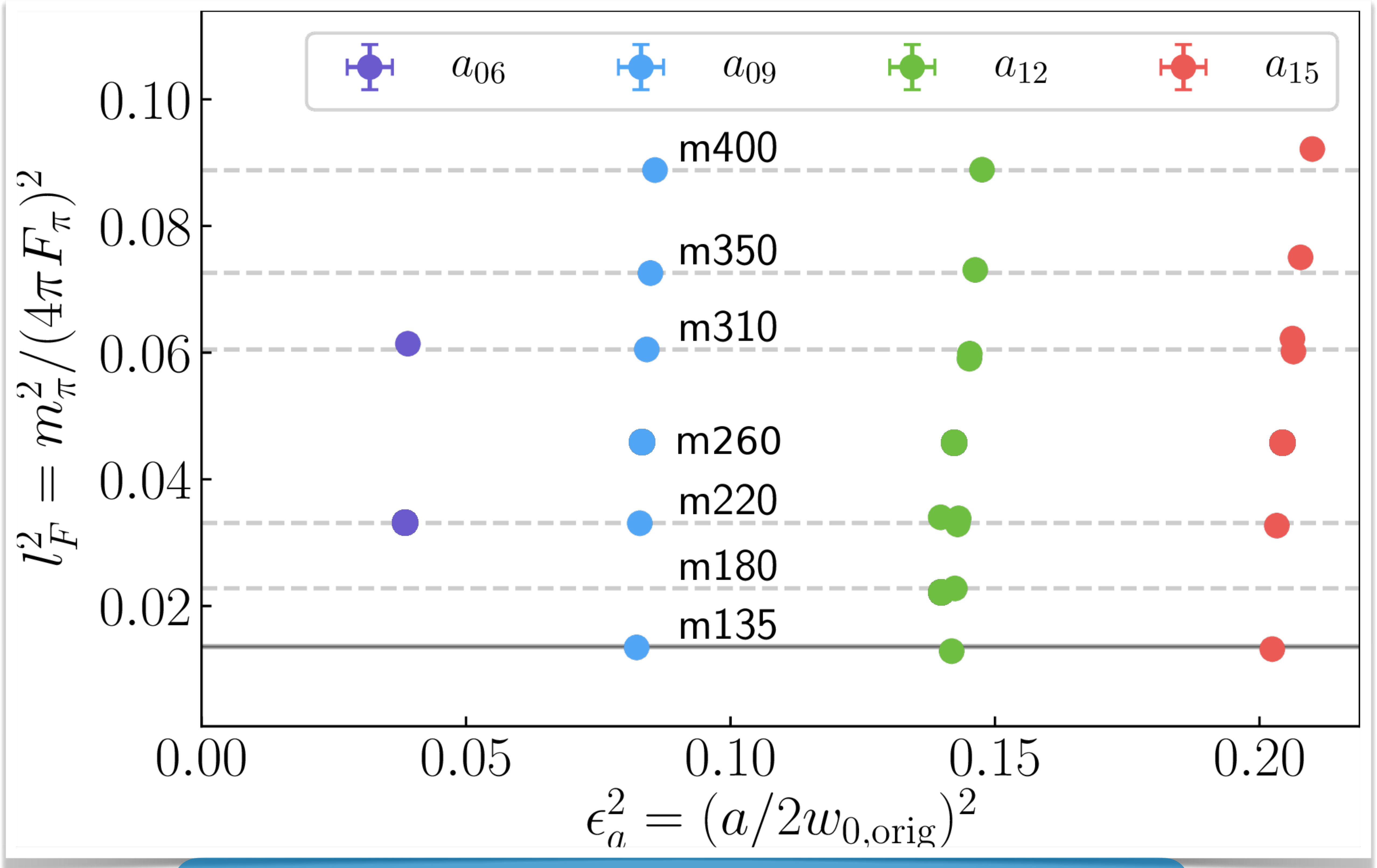
Fit Strategy



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  - Include N^{3}LO ct or not
- Each assigned a weight based on the Gaussian Bayes Factor of each fit.
  - NLO - had a weight of zero, excluded from the analysis.
- 12 models considered.

Fit Strategy

model	chi2/dof	Q	logGBF	weight	F_π
xpt_nnlo_ct_FV_PP	1.041	0.408	-67.736	0.269	92.9(1.0)
xpt_nnnlo_ct_FV_PP	1.039	0.411	-67.880	0.233	92.9(1.1)
xpt_nnlo_ct_FV_PK	1.250	0.211	-68.222	0.165	92.29(95)
xpt_nnnlo_ct_FV_PK	1.242	0.217	-68.222	0.165	92.38(99)
xpt_nnnlo_ct_FV_KK	1.585	0.054	-69.667	0.039	92.00(98)
xpt_nnlo_FV_PP	1.303	0.173	-69.976	0.029	93.0(1.0)
xpt_nnlo_ct_FV_KK	1.620	0.046	-69.982	0.028	91.79(95)
xpt_nnnlo_FV_PP	1.299	0.176	-70.060	0.026	93.0(1.1)
xpt_nnnlo_FV_PK	1.461	0.093	-70.354	0.020	92.5(1.0)
xpt_nnlo_FV_PK	1.473	0.088	-70.420	0.018	92.36(95)
xpt_nnnlo_FV_KK	1.799	0.020	-71.904	0.004	92.1(1.0)
xpt_nnlo_FV_KK	1.834	0.017	-72.221	0.003	91.84(97)
Bayes Model Avg:					92.6(1.0)

$$F_\pi = F\left\{1 + \delta(F_\pi)^{\text{NLO}}_{\chi\text{-logs}} + \delta(F_\pi)^{\text{NLO}}_{\text{CT}} + \delta(F_\pi)^{\text{NLO}}_{a^2} + \delta(F_\pi)^{\text{N}^2\text{LO}}_{\text{ct}}\right\}$$

$$\ell_P^{\mu_\pi,\text{FV}} = \ell_P^{\mu_\pi} + 4\epsilon_P^2 \sum_{|\mathbf{n}|\neq 0} \frac{c_n}{m_P L|\mathbf{n}|} K_1(m_P L|\mathbf{n}|)$$

Bayesian fits

- Models:
  - $F^2 = \{F_\pi^2, F_\pi F_K, F_K^2\}$ in defining $\epsilon_P = m_P/4\pi F_P$
  - χPT- NLO
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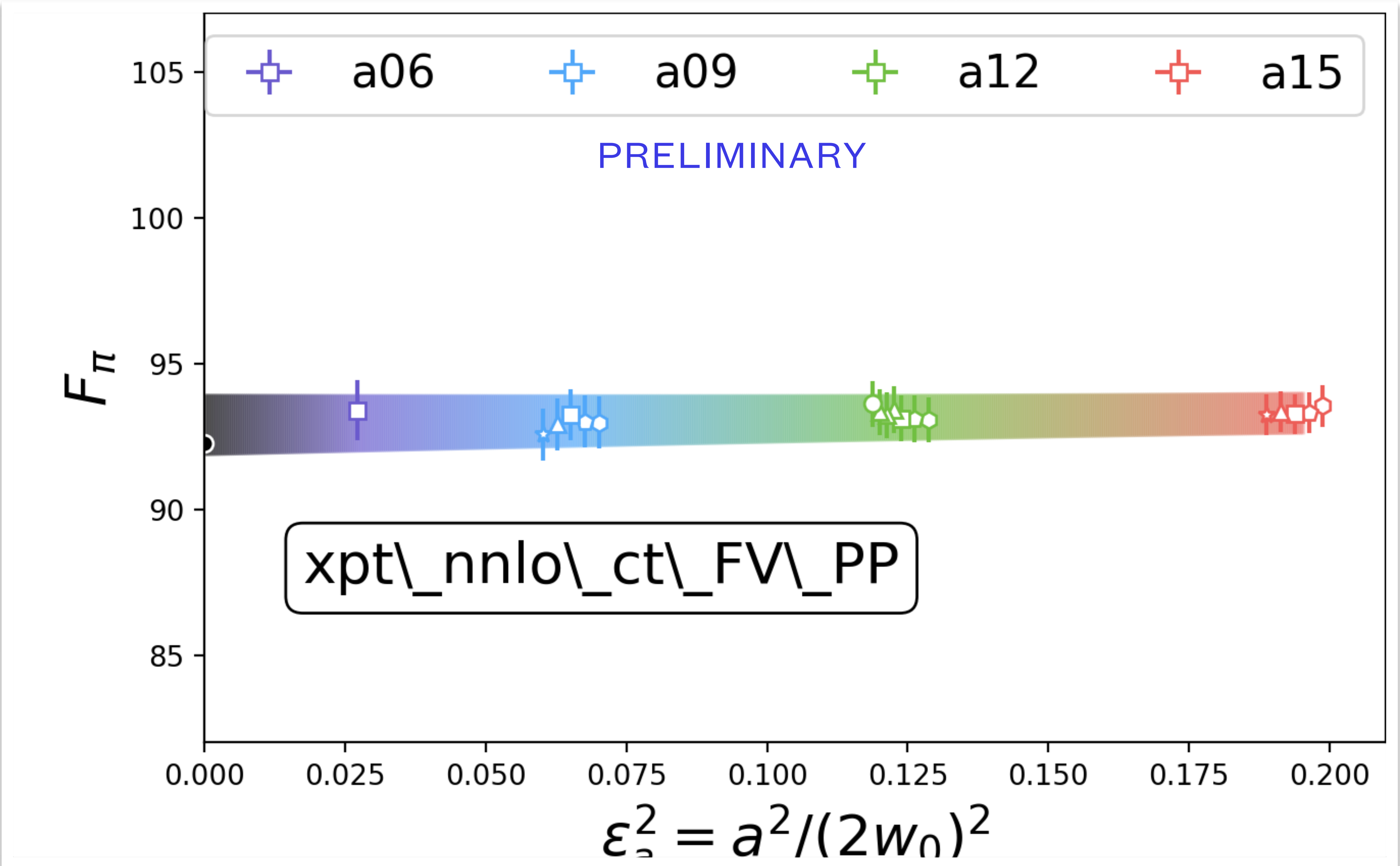
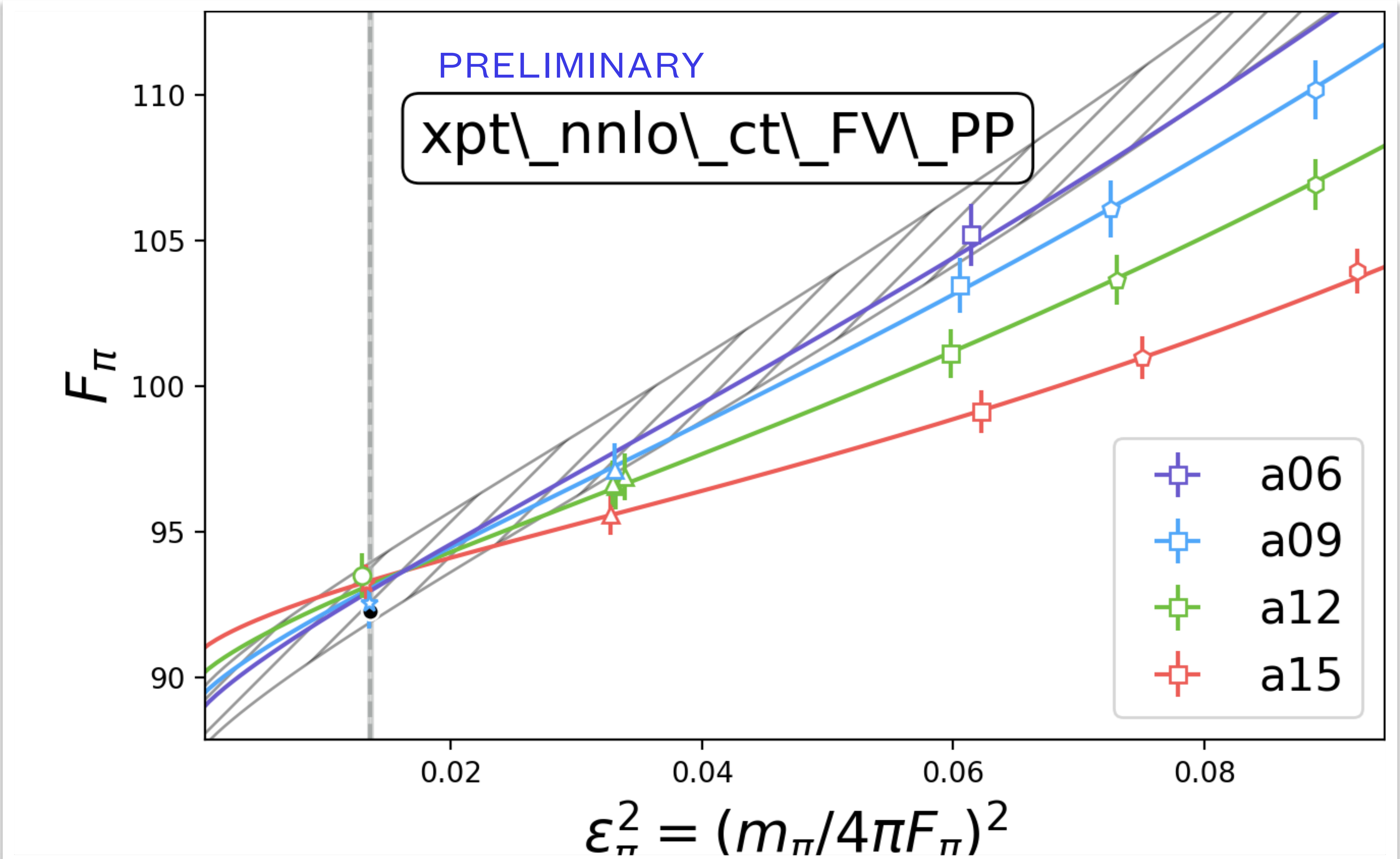
F_π at the Physical Point

One point at .06, the new data will help to improve the precision of the continuum at mpi - 220





ϵ_a^2: all points are shifted to physical ϵ_π^2 and ϵ_K^2

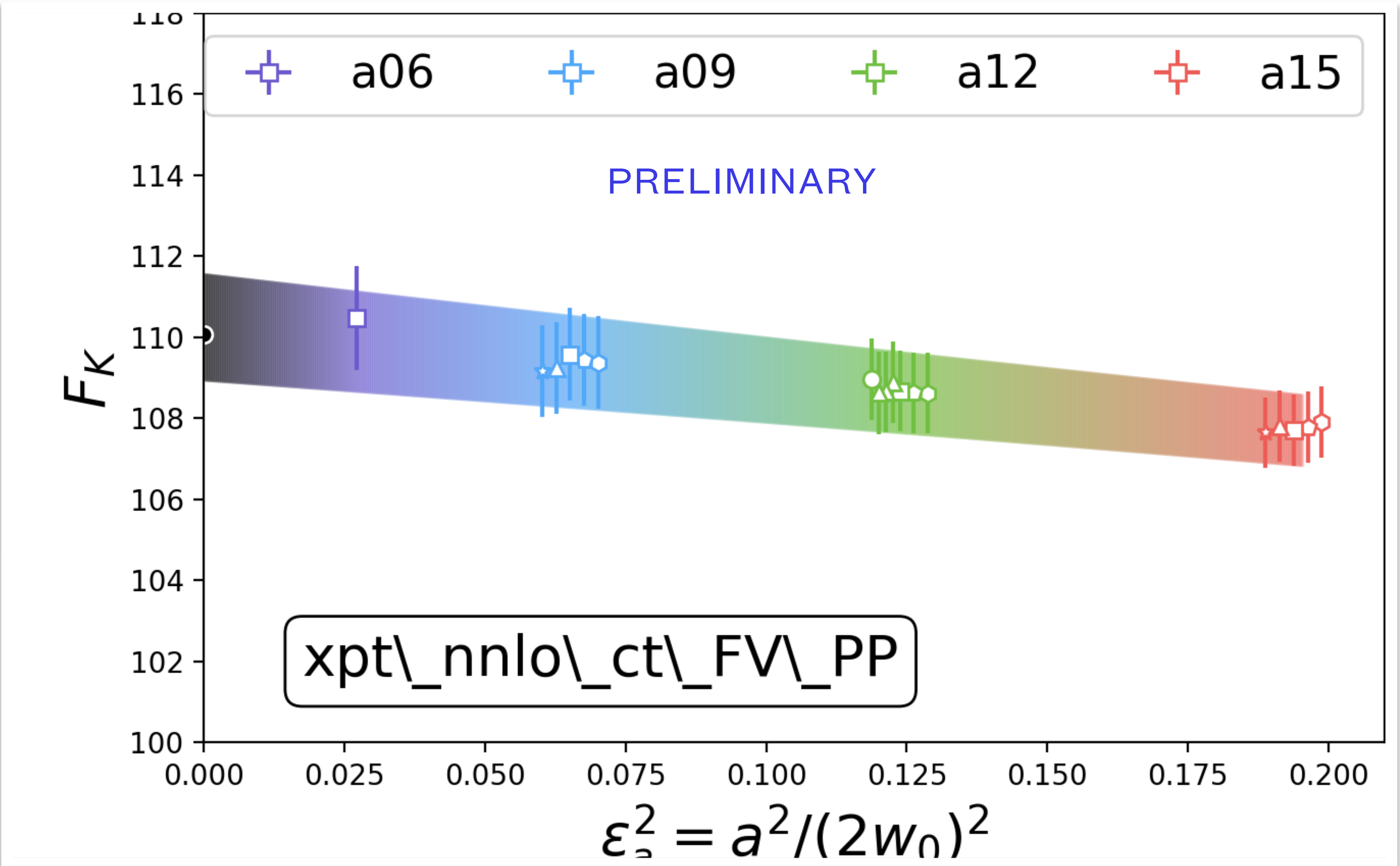
ϵ_π^2: all points are shifted to physical ϵ_K^2

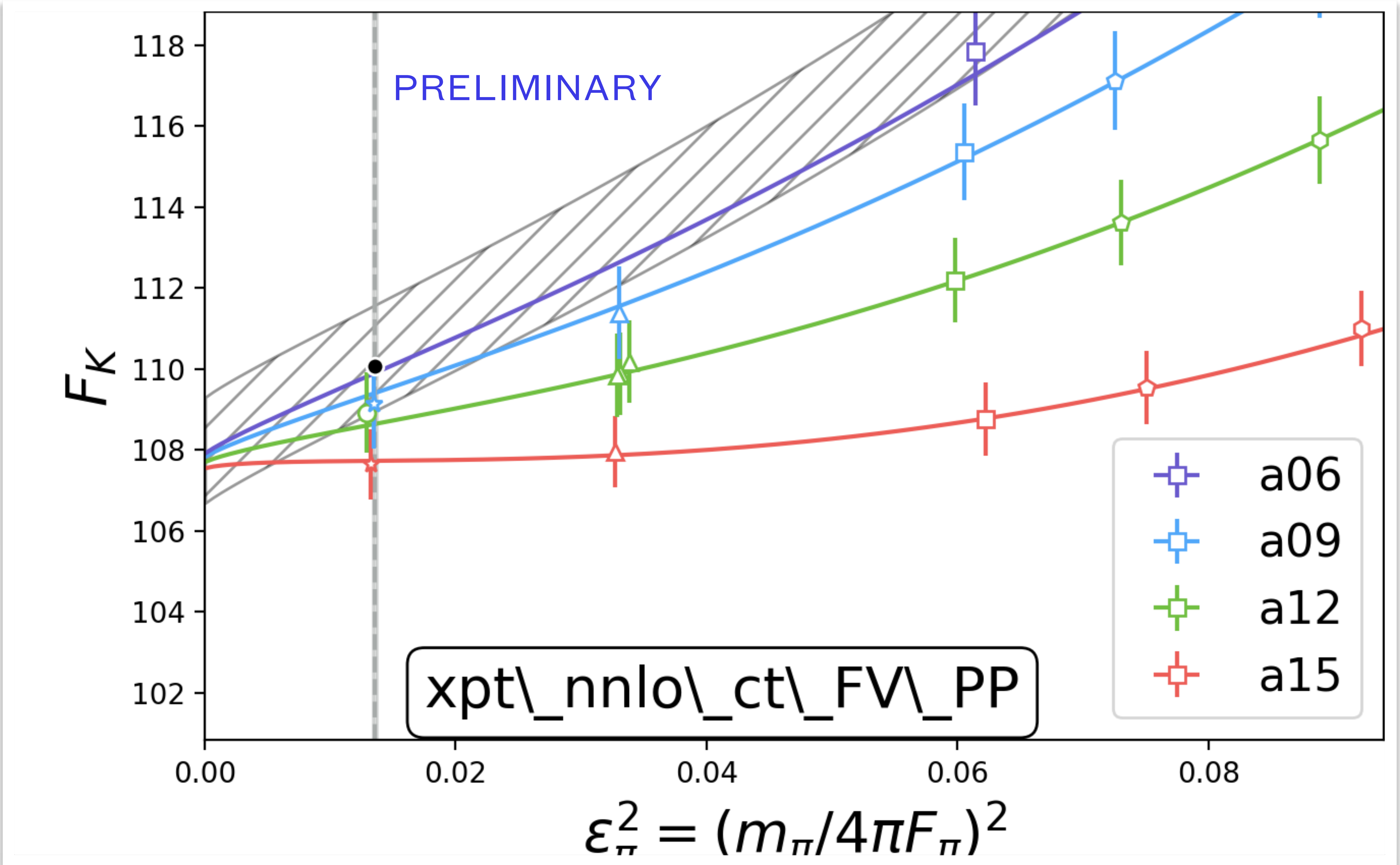
$$F_\pi = 92.6\,(1.0)\text{ MeV}$$

$$F_\pi^{PDG} = 92.277\,(14)\,(21)\,(92)\text{ MeV}$$

F_K at the Physical Point

One point at .06, the new data will help to improve the precision of the continuum at mpi - 220





ϵ_a^2: all points are shifted to physical ϵ_π^2 and ϵ_K^2
ϵ_π^2: all points are shifted to physical ϵ_K^2

$F_K = 110.3\ (1.3)$ MeV

$F_K^{PDG} = 110.08\ (19)(23)(19)$ MeV

Next Steps and Summary

- We have determined preliminary values of the light meson decay constants, $F_\pi = 92.6\,(1.0)$ MeV and $F_K = 110.3\,(1.3)$ MeV.
    - Add additional ensembles to the analysis
    - Incorporate Mixed-Action EFT expressions at NLO
    - Combined global fit with F_K, F_π, and F_K/F_π
    - Challenged by the scale setting uncertainty since it is the largest uncertainty in the data which complicates the analysis.
- Follow the analysis procedure form m_π^2 and m_K^2 which require quark mass renormalization.
- A precise determination of F_K can be used to constrain V_{us} which suffers tension from $K_{\ell 2}$ and $K_{\ell 3}$ decays but needs to be at the 0.2% level to be competitive with the PDG value.

Acknowledgements

QED_M Collaboration

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Amy Nicholson
Andrea Schiller
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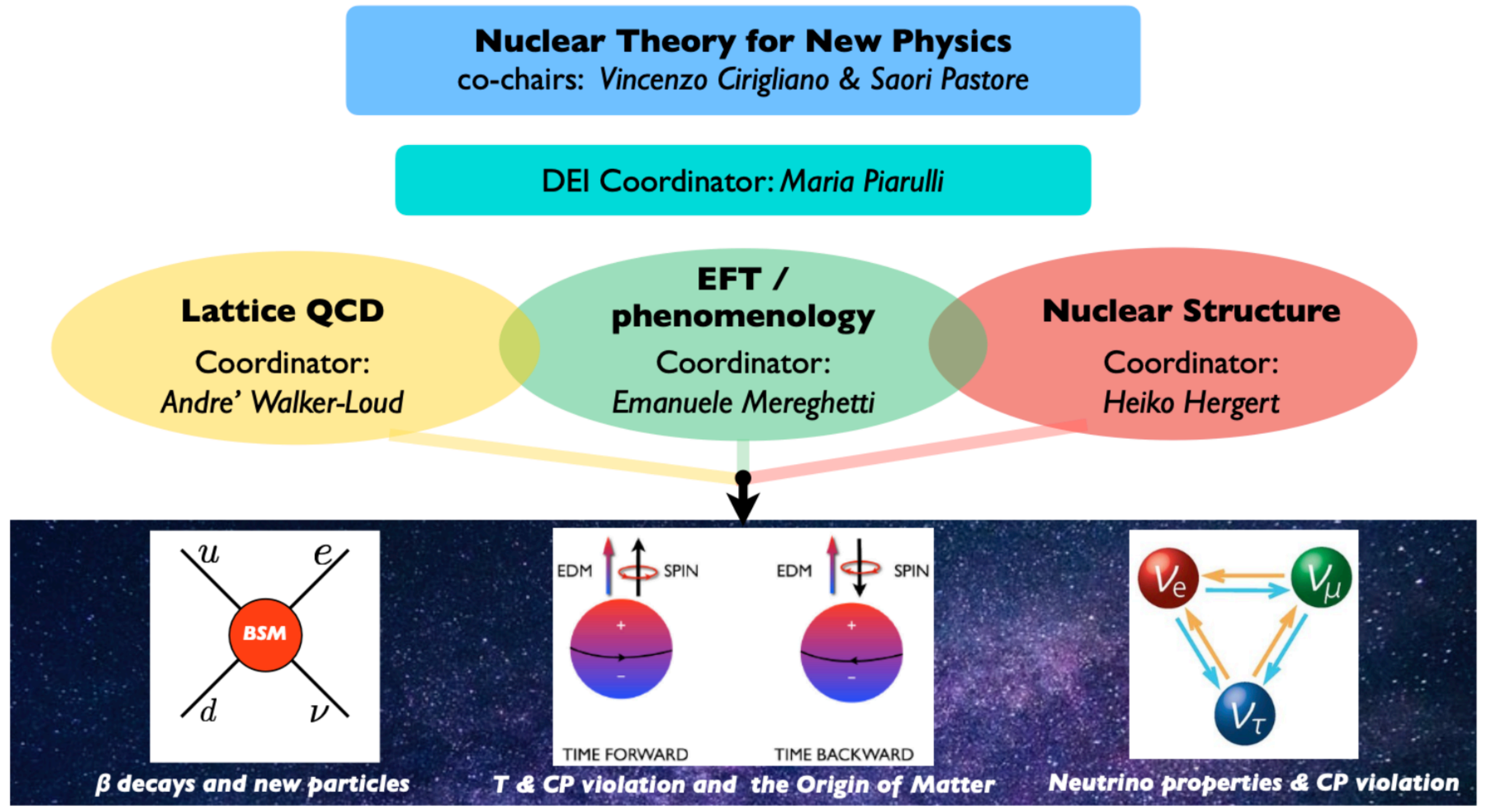
Kate Clark
Henry Monge-Camacho
Zack Hall
Haobo Yan
Ben Hoerz
Dean Howarth
Pavlos Vranas

California Lattice Collaboration



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