Analysis of Meson-Photon Interactions using Lattice QCD

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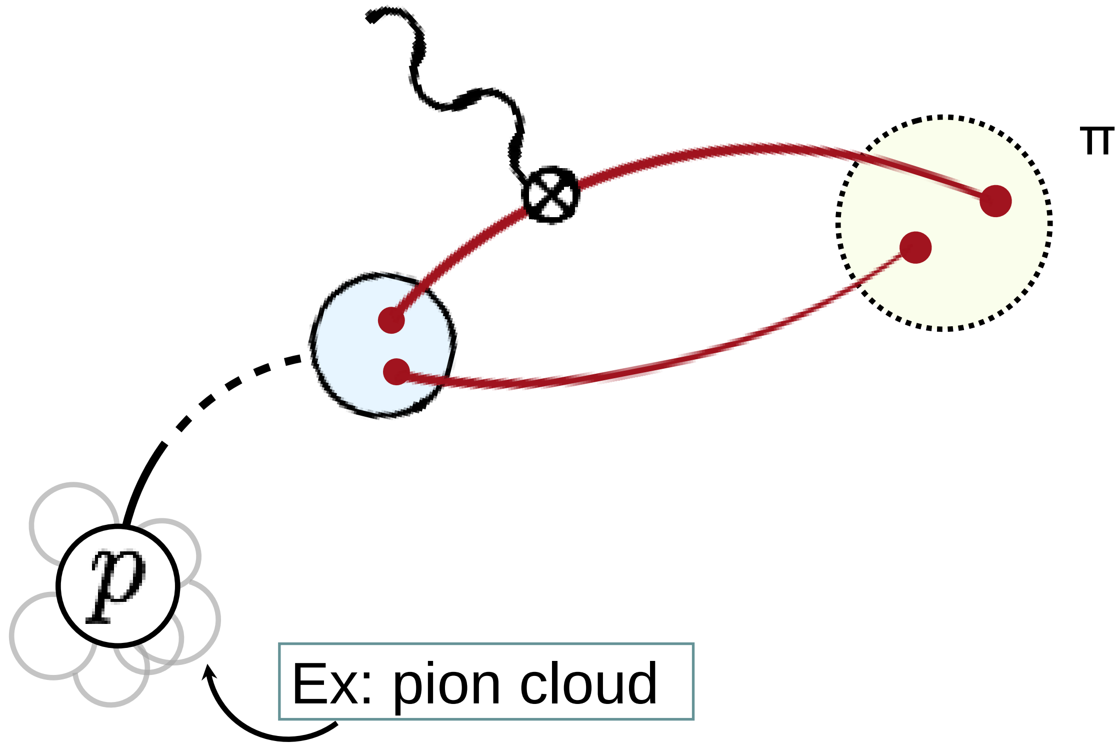
Motivation

- Electromagnetic currents are commonly used for experiments to investigate states of QCD
- Lattice QCD- Only rigorous theoretical model to describe such states

What do I mean by "state of QCD?"



- Most QCD states are **composite states**, which are:
  - unstable under QCD (resonances)
  - *accidentally* stable (bound states)
  - depending on the QCD parameters, a state can *transition*

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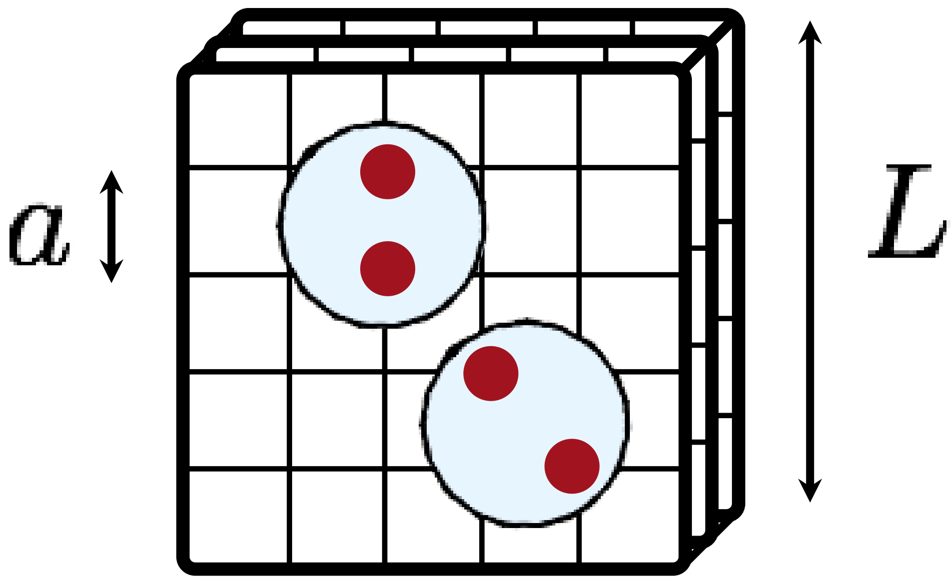
Lattice QCD overview

- Wick rotation [Euclidean spacetime]: $t_M \to -it_E$
- Quark masses: $m_q \to m_q^{\text{phys.}}$
- Lattice spacing: $a \sim 0.03 - 0.15\ \text{fm}$
- Finite volume



Finite Volume Physics

1 Dimensional Scattering

Natural units: $\hbar = c = 1$

Wavefunction as a plane wave: $\phi_p(x) = e^{ipx}$

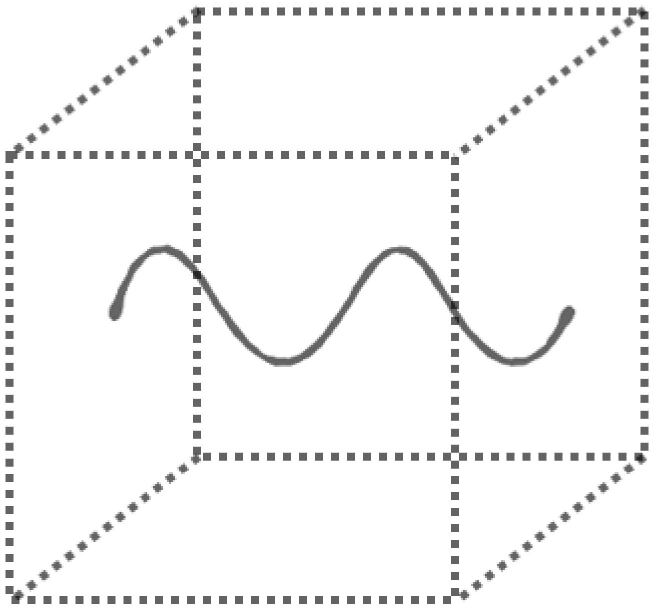
Consider system in a finite, periodic volume

Periodicity Condition: $\phi_p(x) = \phi_p(x+L)$

$$\phi_p(x) = e^{ipx} = \mathrm{e}^{\mathrm{ip(x+L)}} = \phi_p(x+L)$$

Momentum spectrum: $p = \hbar k = \frac{2\pi n}{L}$ for integer n

The takeaway: Finite volume conditions quantizes the system to a discrete spectrum of states.



Kinematics

Dynamics

Examining Kinematics

Flexible Python script analyzing kinematics of such interactions

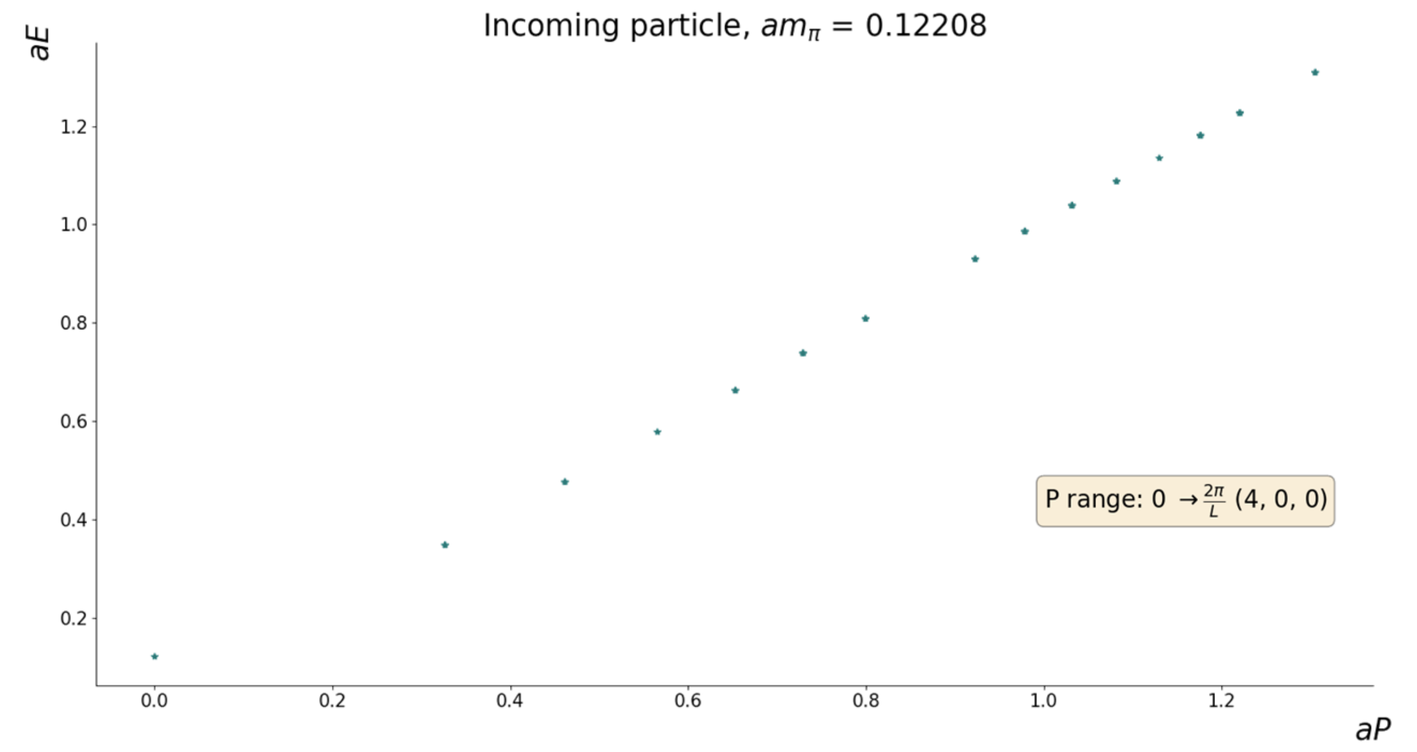
Lattice parameters:

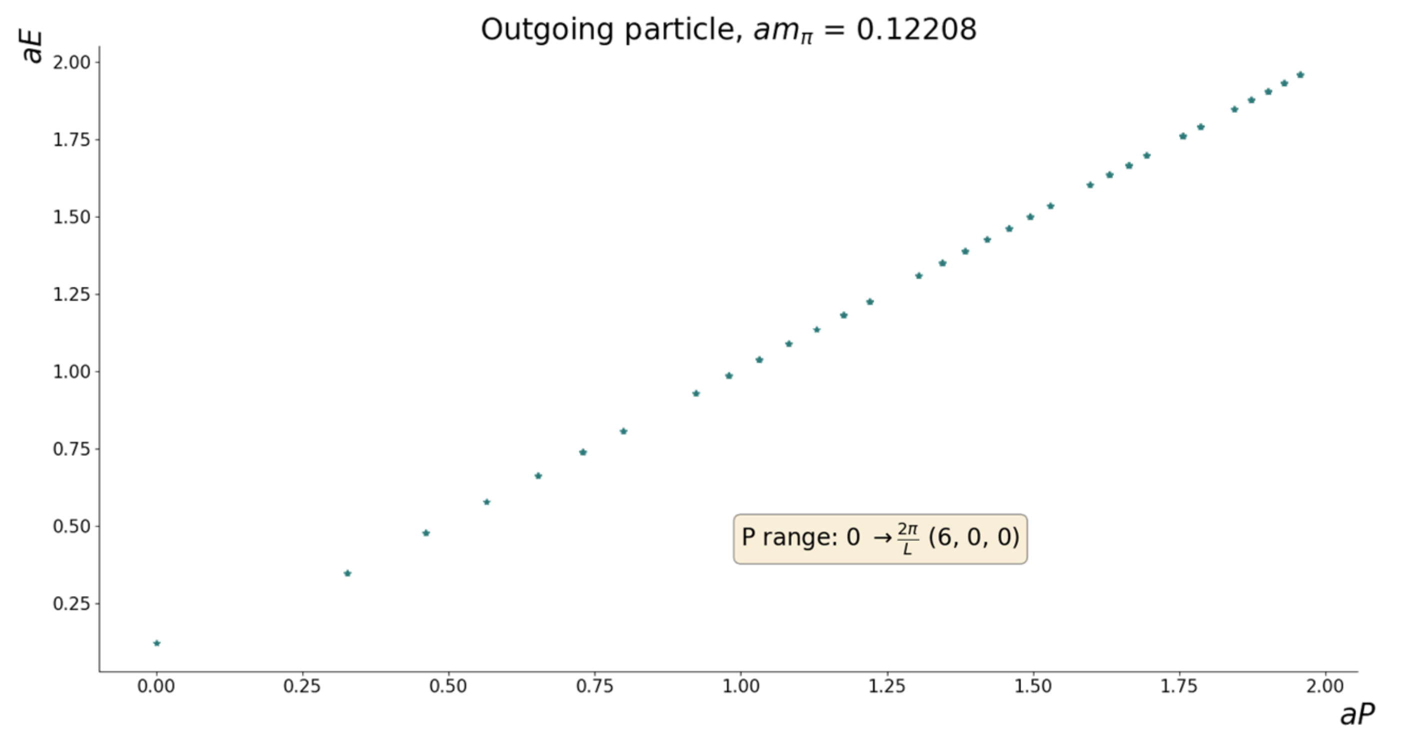
- L – length of lattice volume, varied 3.8 – 5.6 fm
- a – spacing of lattice, fixed to ~0.035 fm

Instance of particle class for each particle before and after interaction

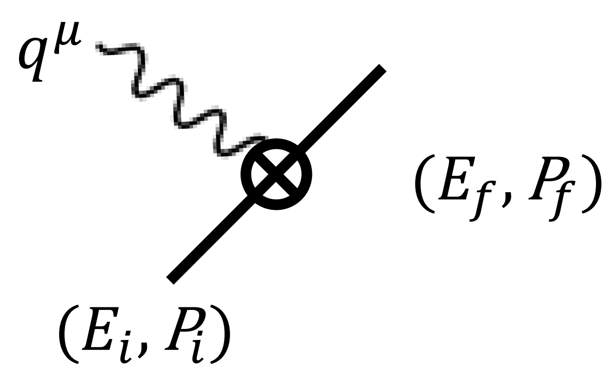
- m – particle mass, fixed to m_π= 700 MeV
- n range – range of allowed values of n for momentum vectors, or single fixed value.

Analyze spectrum of energies and range of accessible Q^2

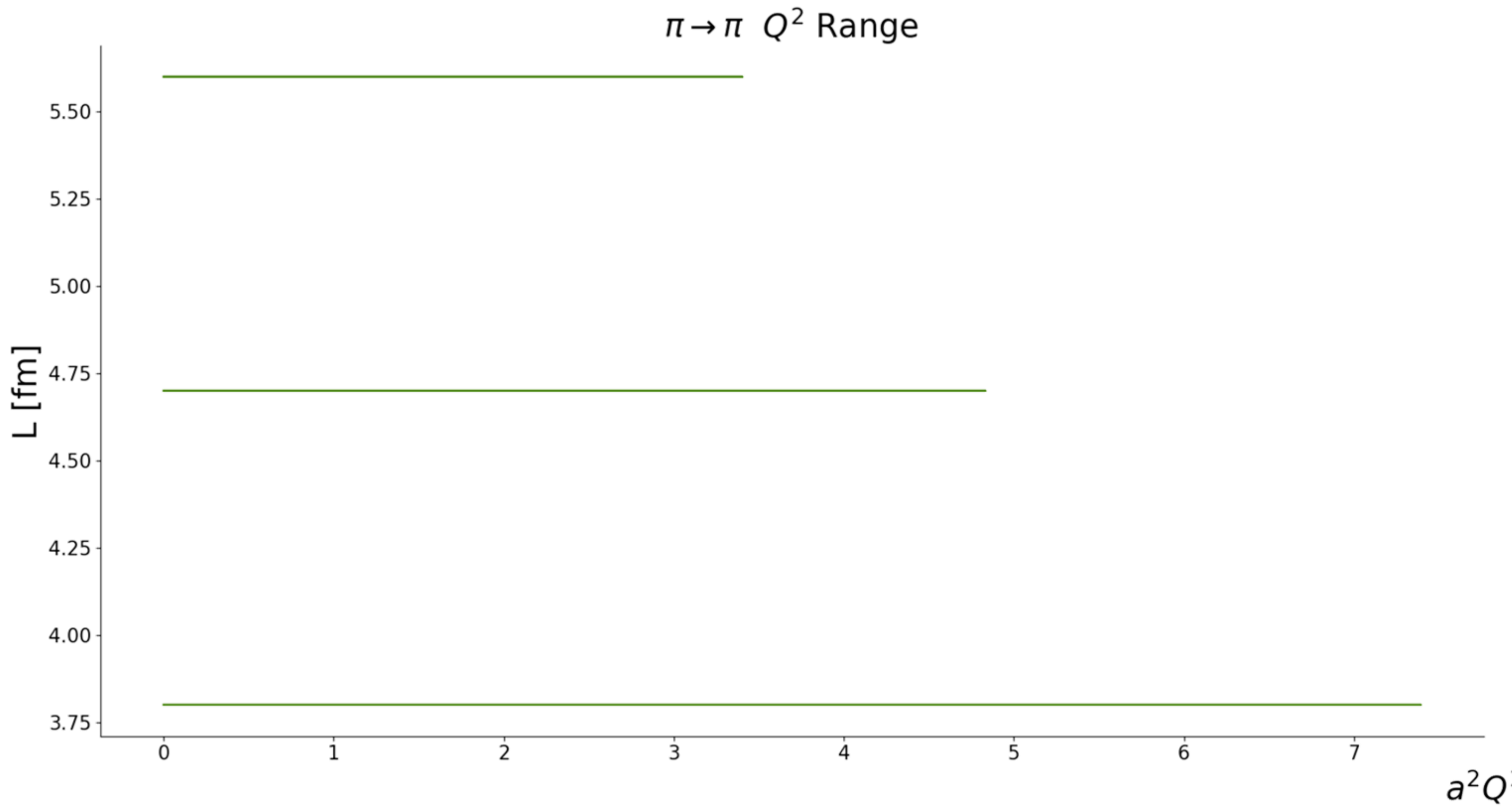


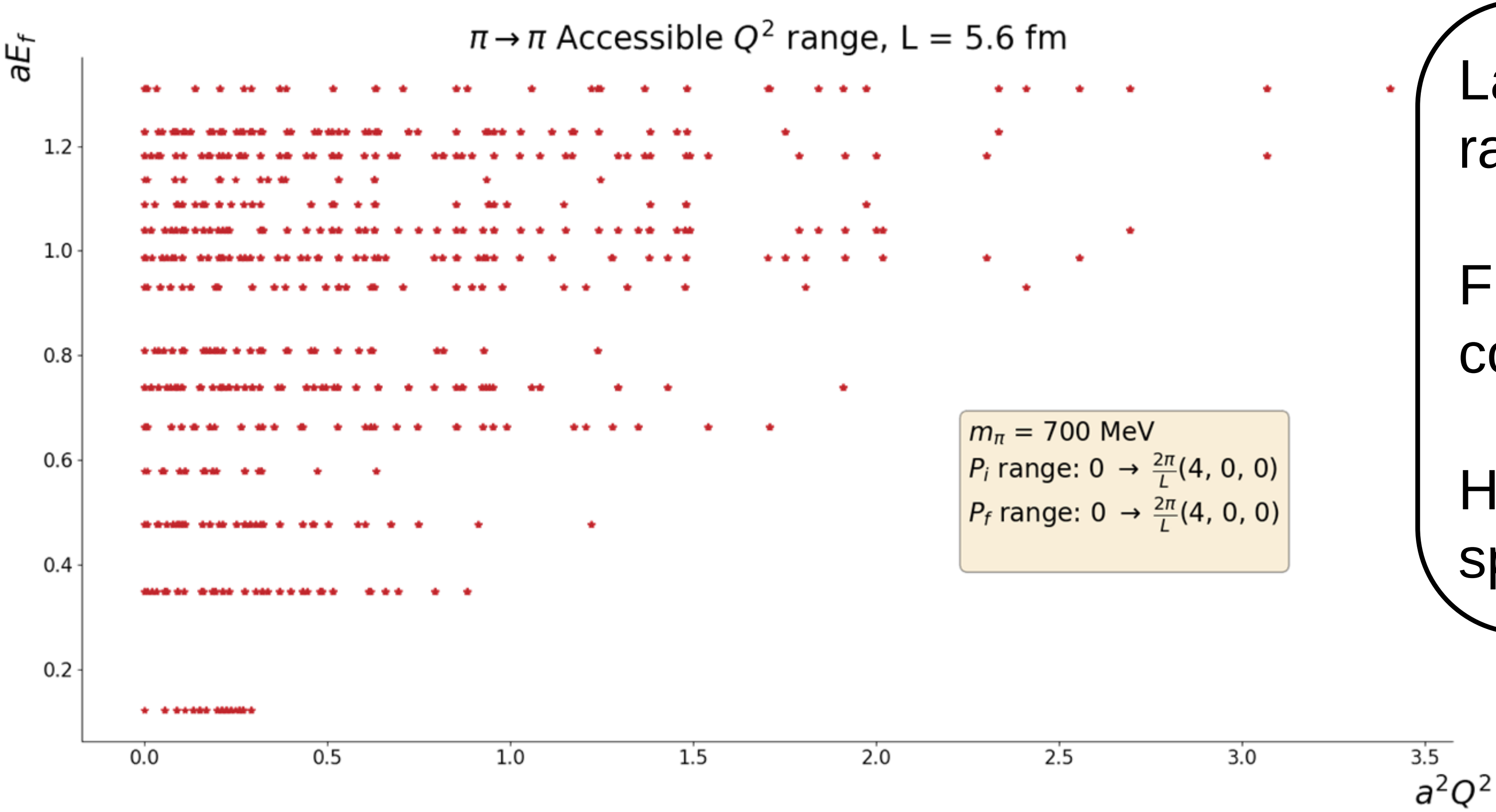


$\pi \to \pi$ transitions



$$Q^2 = -(E_f - E_i)^2 + (P_f - P_i)^2$$



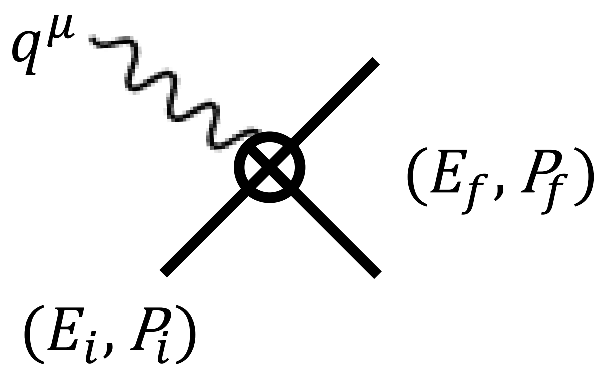


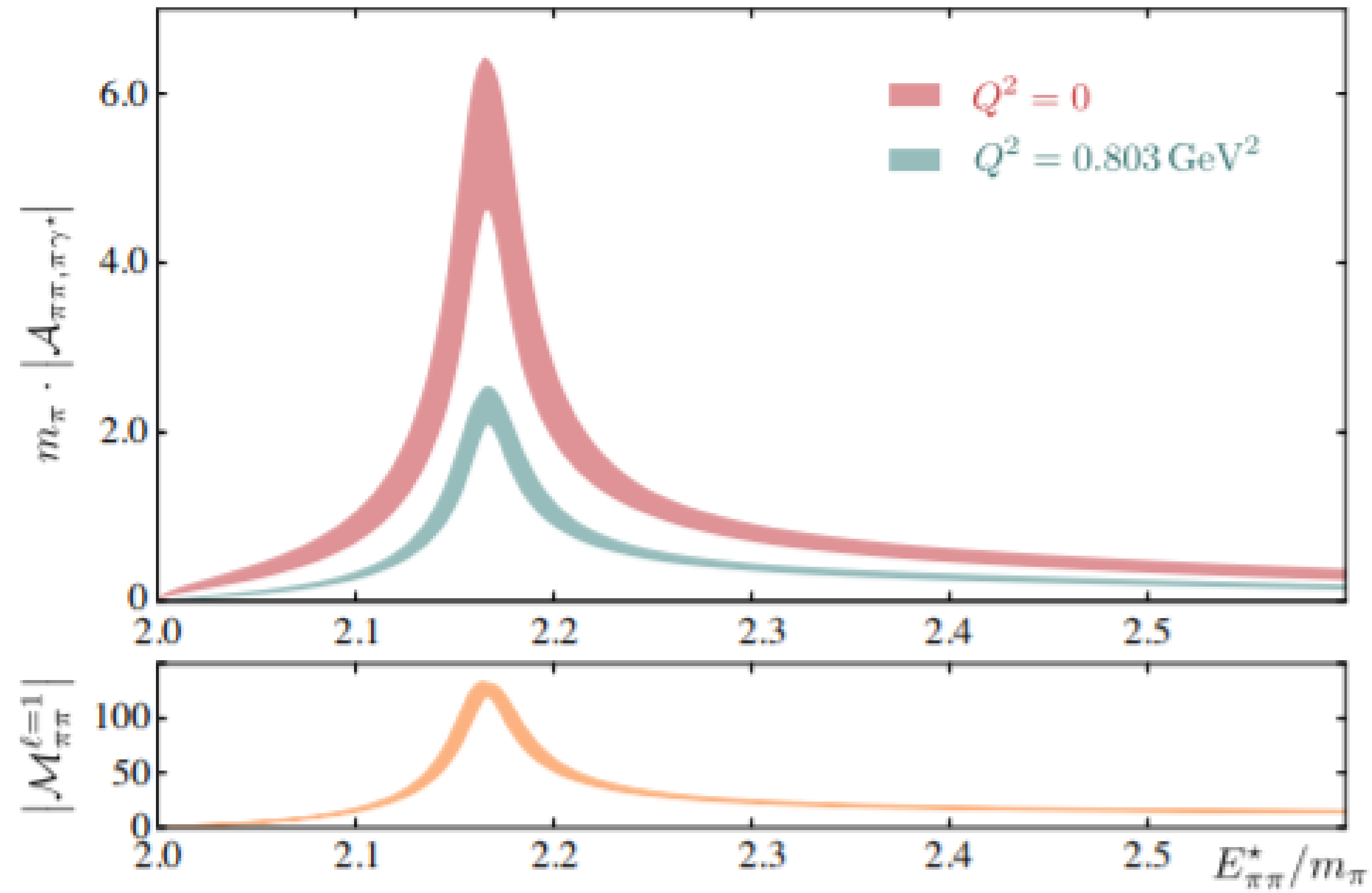
Larger lattice sizes reduce the range of the spectrum of Q^2

Finite spectrum of E_f from constraint on momenta

Higher E_f provides a wider spectrum of Q^2

$\pi \to \pi\pi$ transitions

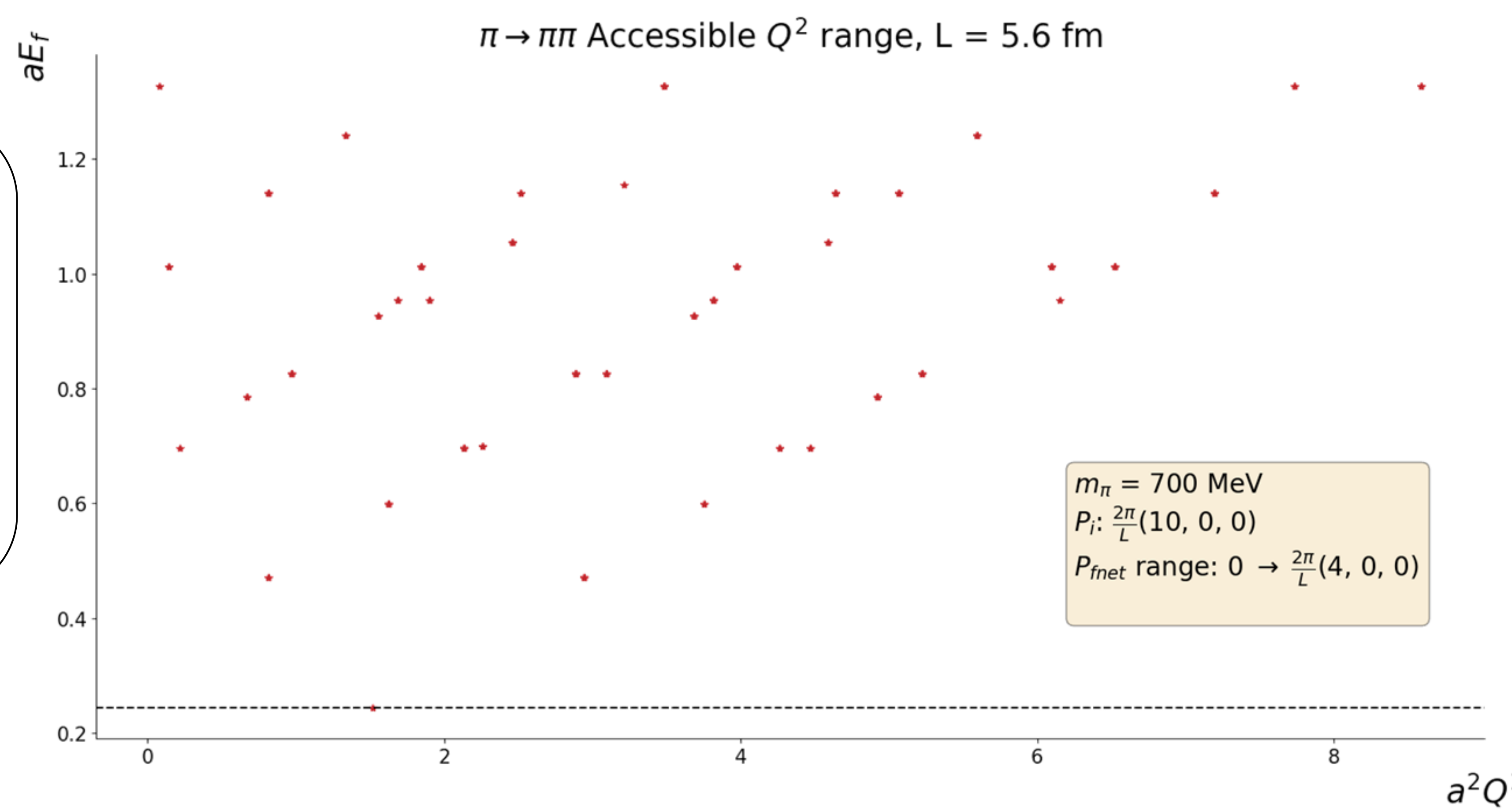




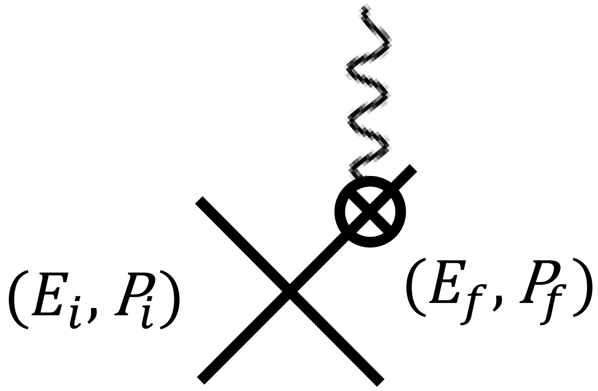
(Briceño, Dudek, Edwards, Shultz, Thomas, & Wilson, 2015)

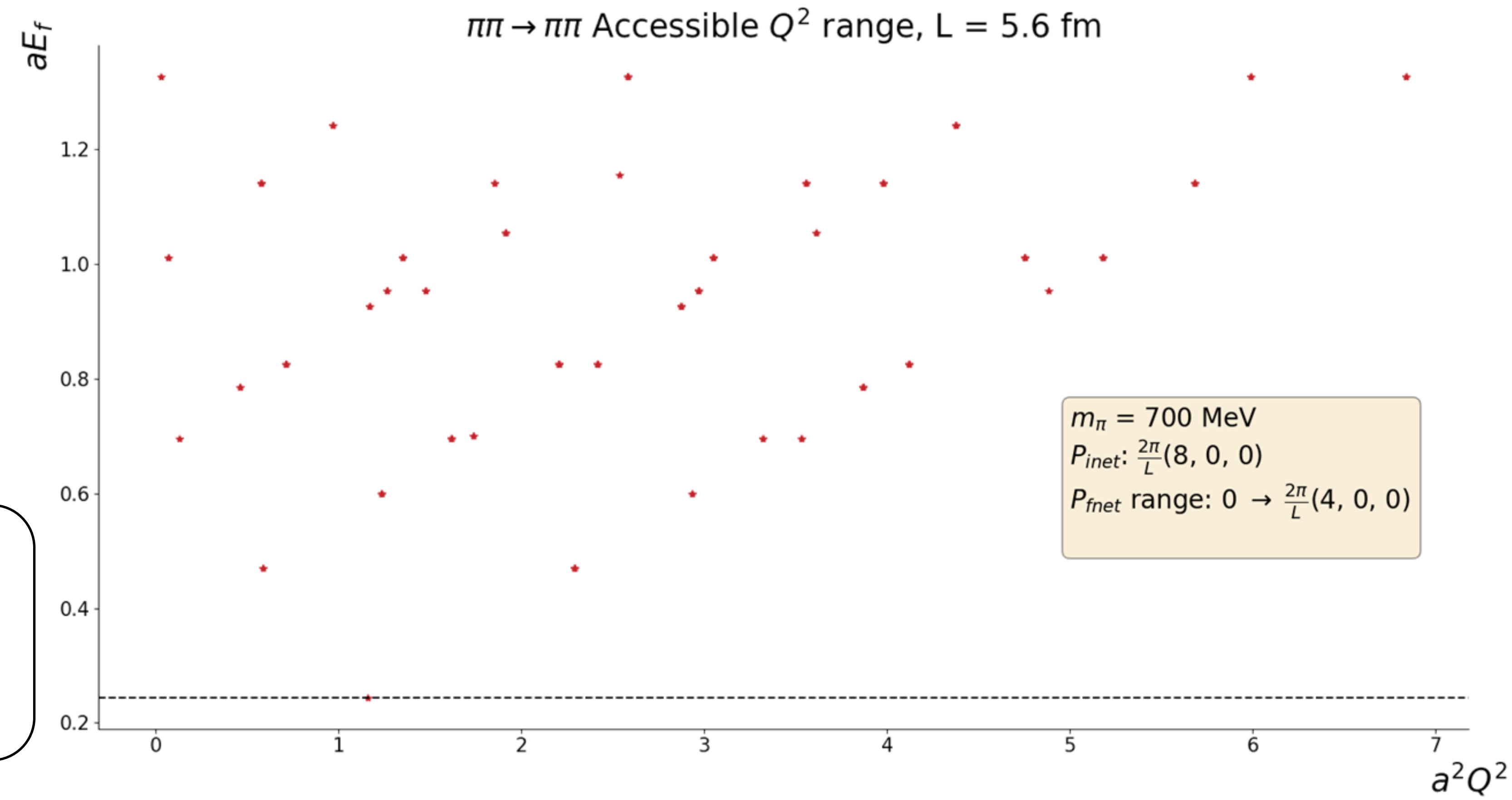
P_i constrained to single value, P_f remains as a discrete spectrum

E_i constrained to ~27*m_π (aE_i = 3.26)

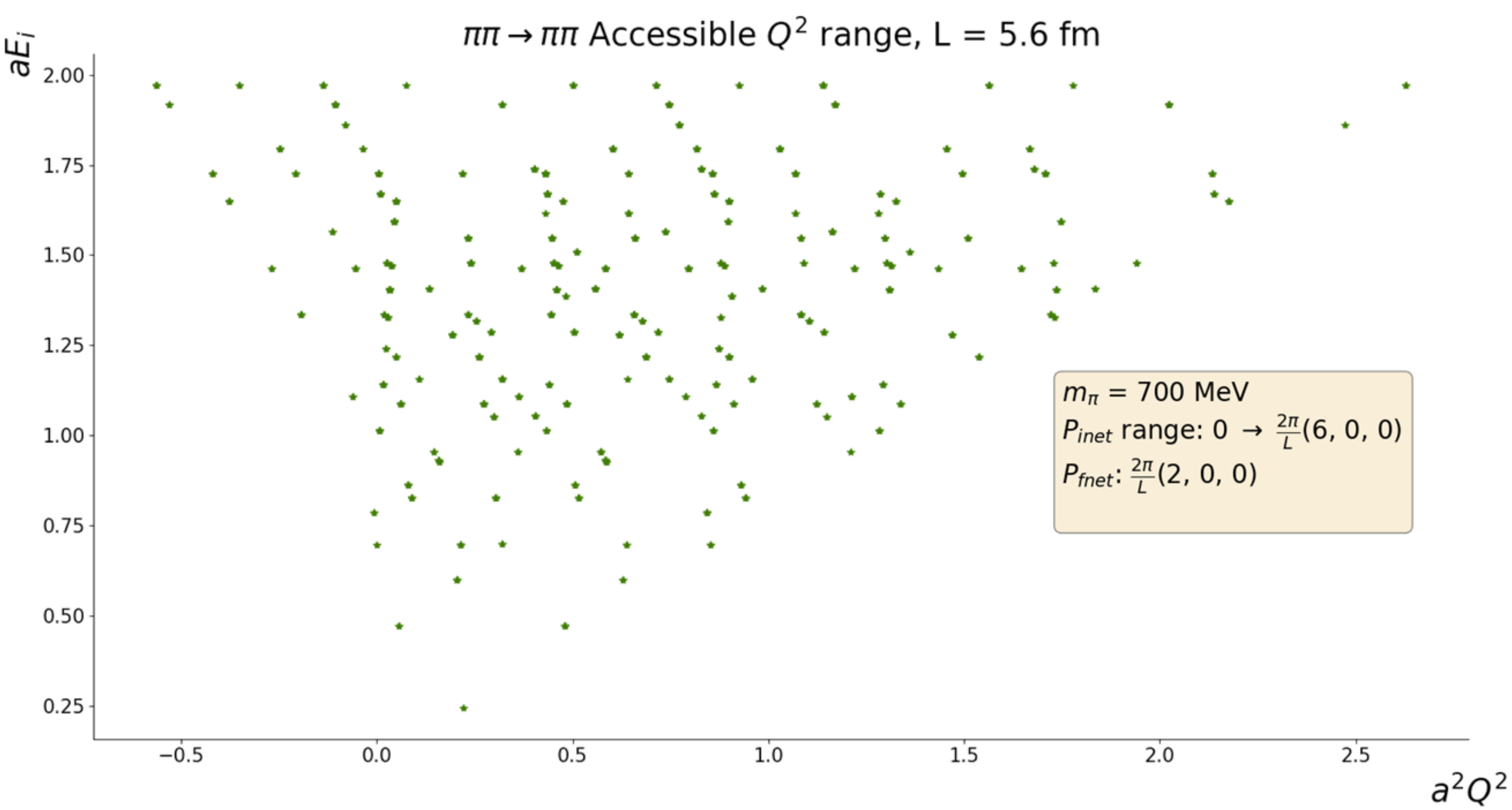


$\pi\pi \to \pi\pi$ transitions



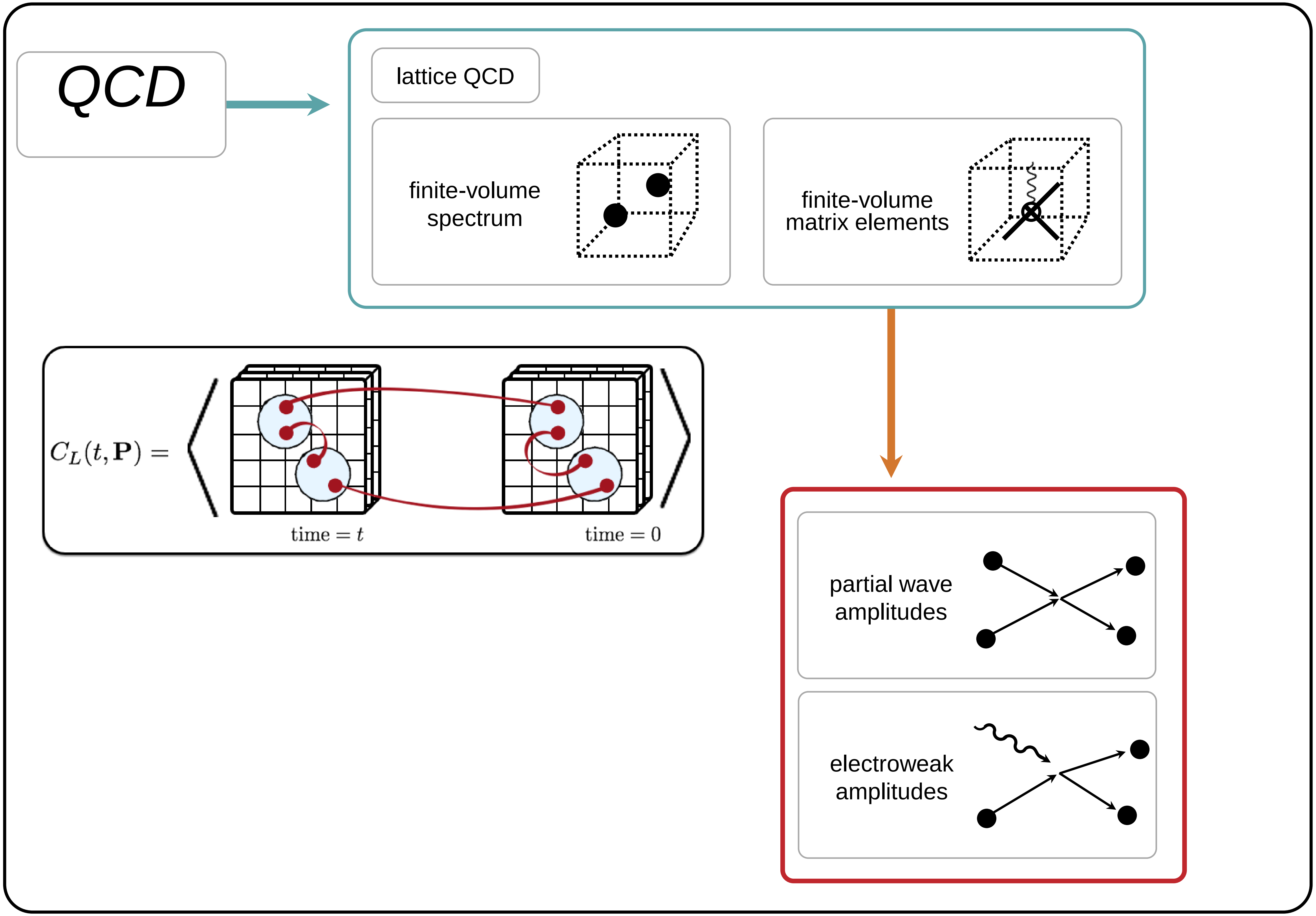


E_i constrained to ~ 21*m_π (aE_i = 2.62)



E_f constrained to ~ 5*m_π (aE_f = 0.696)

Looking ahead to dynamics



Outlook

- Coupled channel scattering amplitudes from hadron-current interactions
- Proof of concept for extracting scattering amplitudes from the lattice
- Next step: Understand relationship between investigated spectrum and scattering amplitudes, first without currents

Quantization condition

$$\det[F^{-1}(E,\boldsymbol{P},L) + \mathcal{M}(E)] = 0$$

- Develop code for F, which encodes kinematics within the finite volume
- Use to predict finite volume spectrum given some model for $\mathcal{M}^0$

$$\mathcal{M}^{-1} = -F$$

Summary

Kinematics

- Analysis of finite volume spectrum of momentum
- Effect of lattice size on kinematic quantities
- Flexible code for modeling kinematics

Dynamics

- Relationship between finite volume spectrum and scattering amplitudes
- Coupled channel scattering amplitudes

More to come…

Acknowledgements/ Questions

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