Quark mass dependence on hadron resonances

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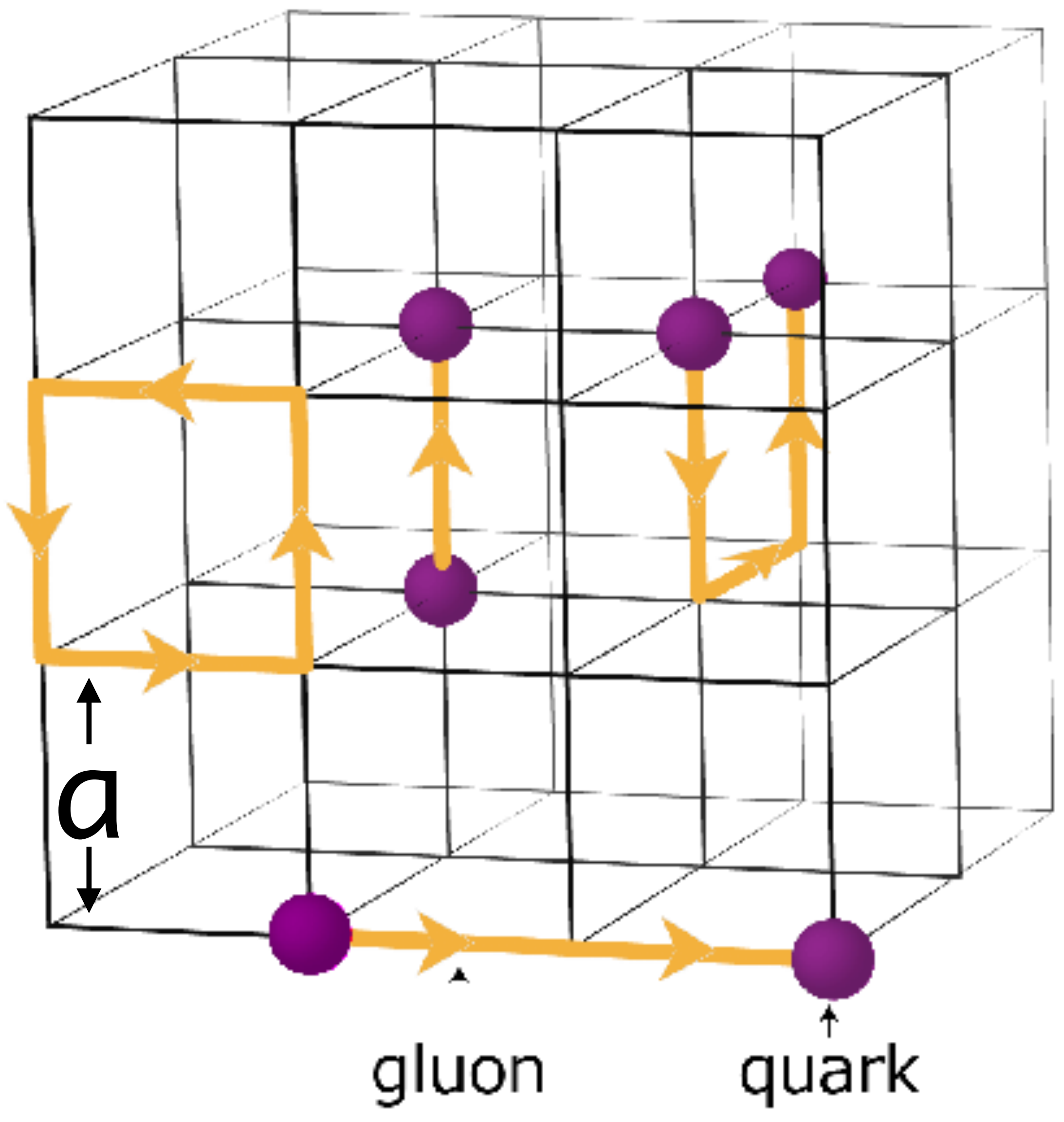
Lattice QCD

a numerical method to solve QCD equation

- Finite and discrete space-time of size a
- Computationally intensive calculations
- Unphysical masses in lattice spacing units



An extrapolation to the continuum is needed in order to extract results

What do we want to do?

as an important question to answer

- We want to:
  - Analyze the quark mass dependence on D_{s0} (2317) and D_{s1} (2460) resonances
- Why we want to do that?
  - Quark model predicts them above their thresholds but they lie bellow them
  - There is debate about whether they are quark states or if they are molecular states

What do we need to do?

as an important question to answer

- We need to:
  - Compute the $DK \to DK$ and $D^*K \to D^*K$ scattering amplitudes with I=0, S=1, C=1
  - Calculate the poles of the amplitude, the resonances
  - Obtain D meson masses as functions of pion mass
  - Plot the curves of the resonances as functions of quark masses

D and D_s meson mass functions

fitting

- Meson mass equations from HQET at one loop order

$$\frac{1}{4}(D+3D^*) = m_H + \alpha_a - \sum_{X=\pi,K,\eta} \beta_a^{(X)} \frac{M_X^3}{16\pi f^2} + \sum_{X=\pi,K,\eta} \left(\gamma_a^{(X)} - \lambda_a^{(X)}\alpha_a\right) \frac{M_X^2}{16\pi^2 f^2} \log\left(M_X^2/\mu^2\right) + c_a$$

$$(D^* - D) = \Delta + \sum_{X=\pi,K,\eta} \left(\gamma_a^{(X)} - \lambda_a^{(X)}\Delta\right) \frac{M_X^2}{16\pi^2 f^2} \log\left(M_X^2/\mu^2\right) + \delta c_a$$

$$\left.\begin{array}{l} \frac{1}{4}(D+3D^*) = m_H + f(\sigma, a, b, c, d) \\ (D^* - D) = \Delta + g(\Delta^{(\sigma)}, \Delta^{(a)}) \end{array}\right\}$$

10 parameters
+
7 parameters

→

17 parameters

72 points

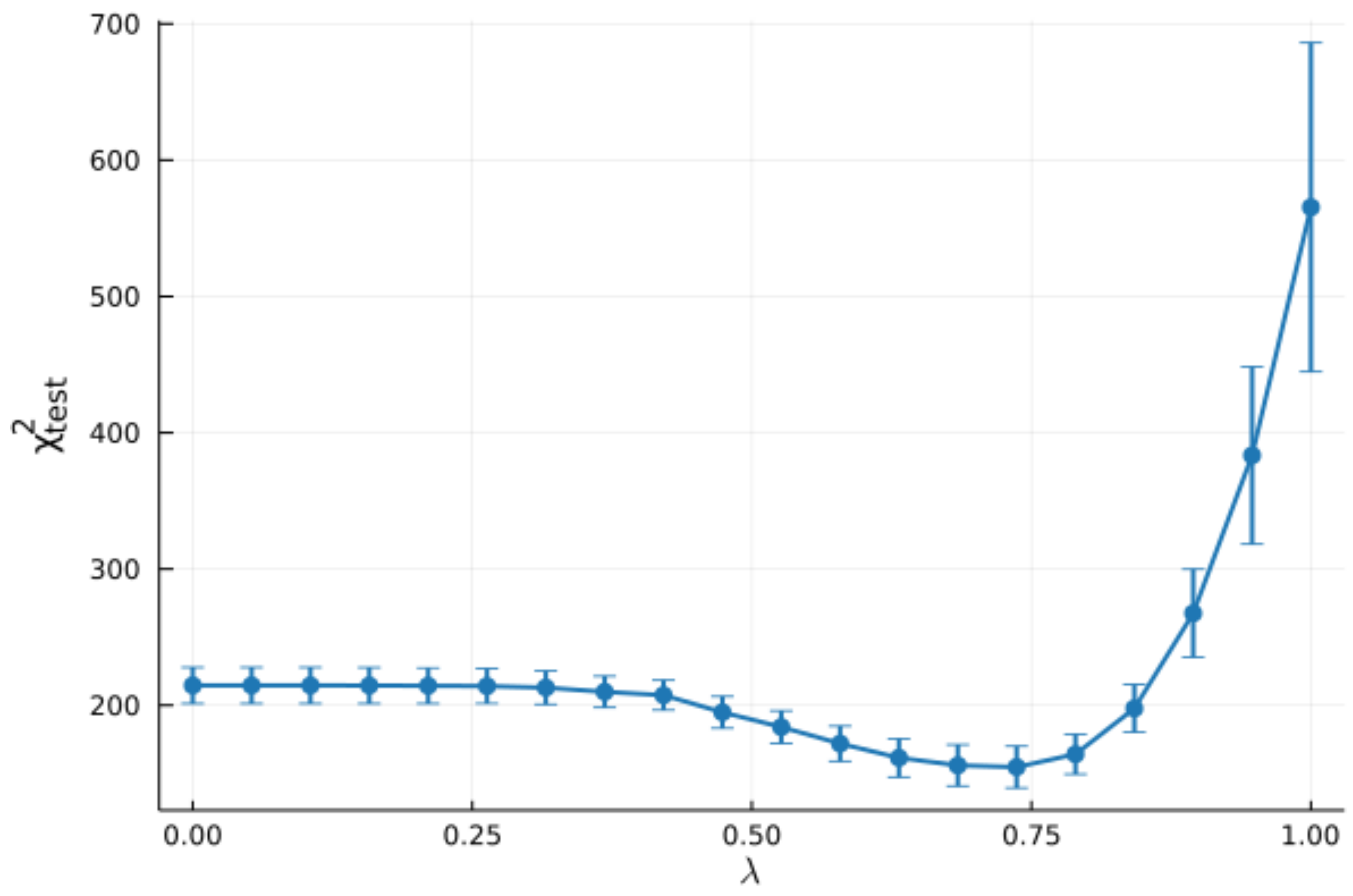
LASSO

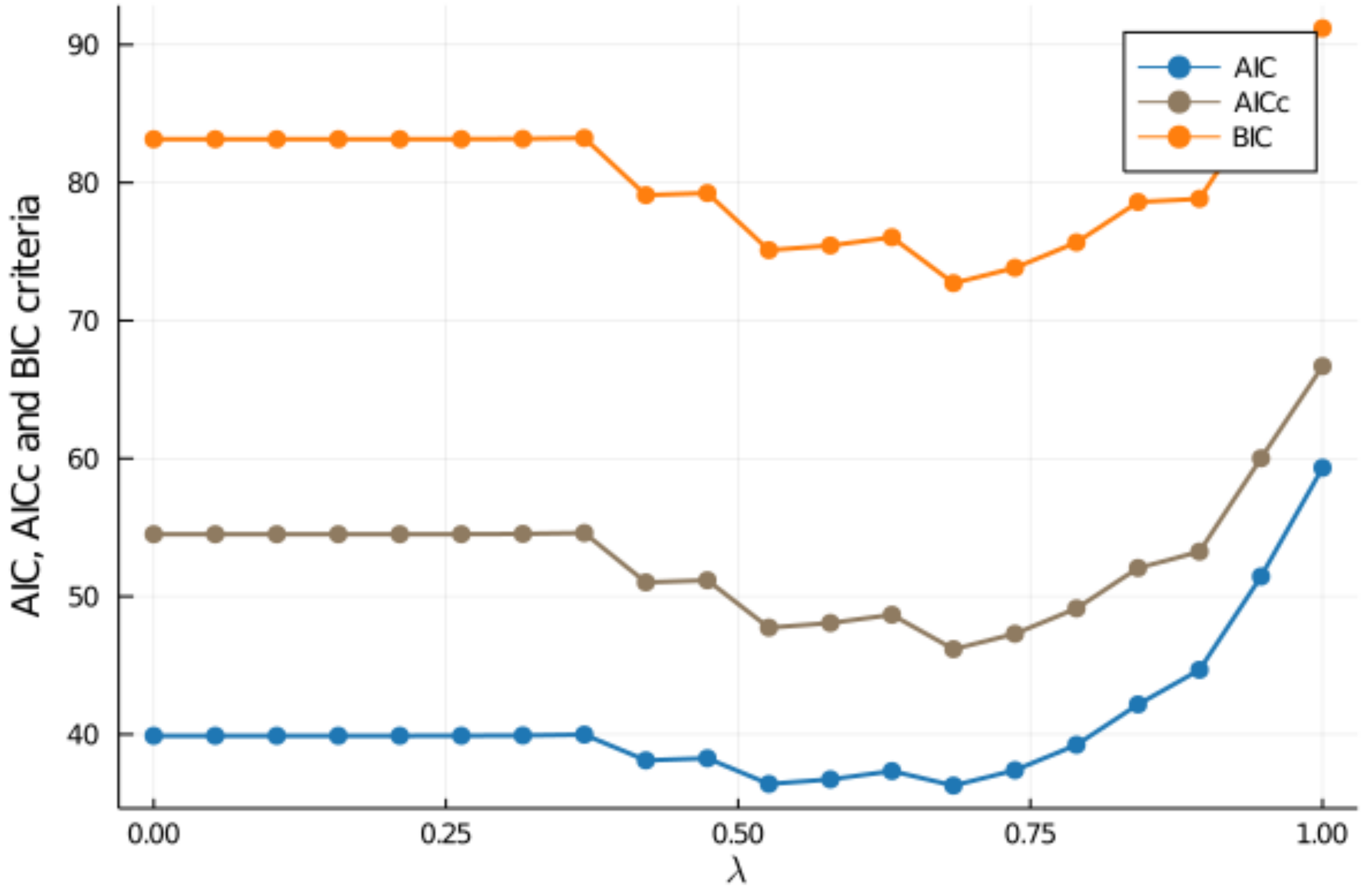
regression method

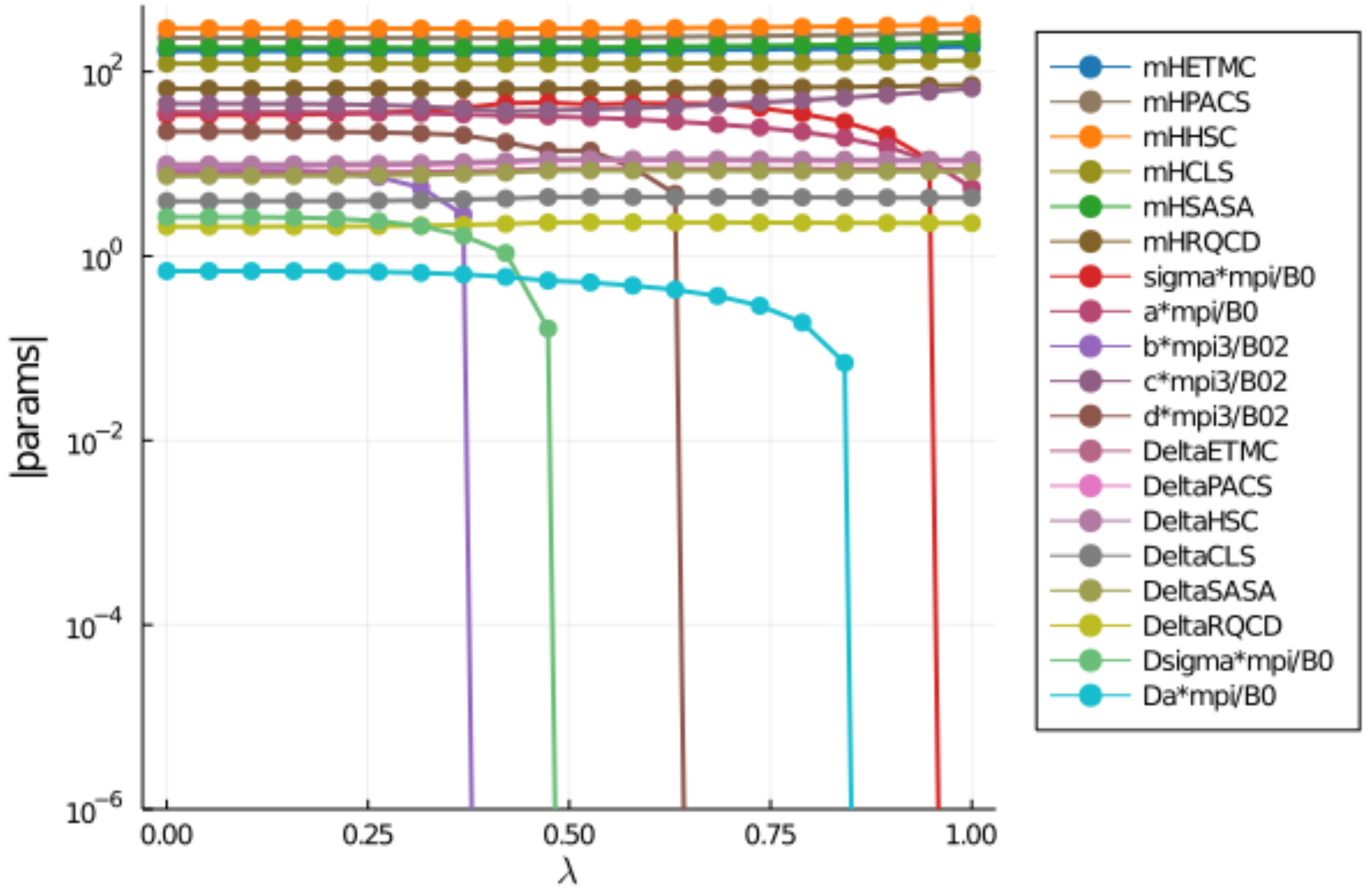
$$\chi^2_P(p,d) = \chi^2(p,d) + \lambda^4 \sum_i^n |p_i| \rightarrow$$

70% of data $\chi^2_P(p, d_{train})$

30% of data $\chi^2_P(p, d_{test})$







D and D_s meson mass functions

fitting (after LASSO)

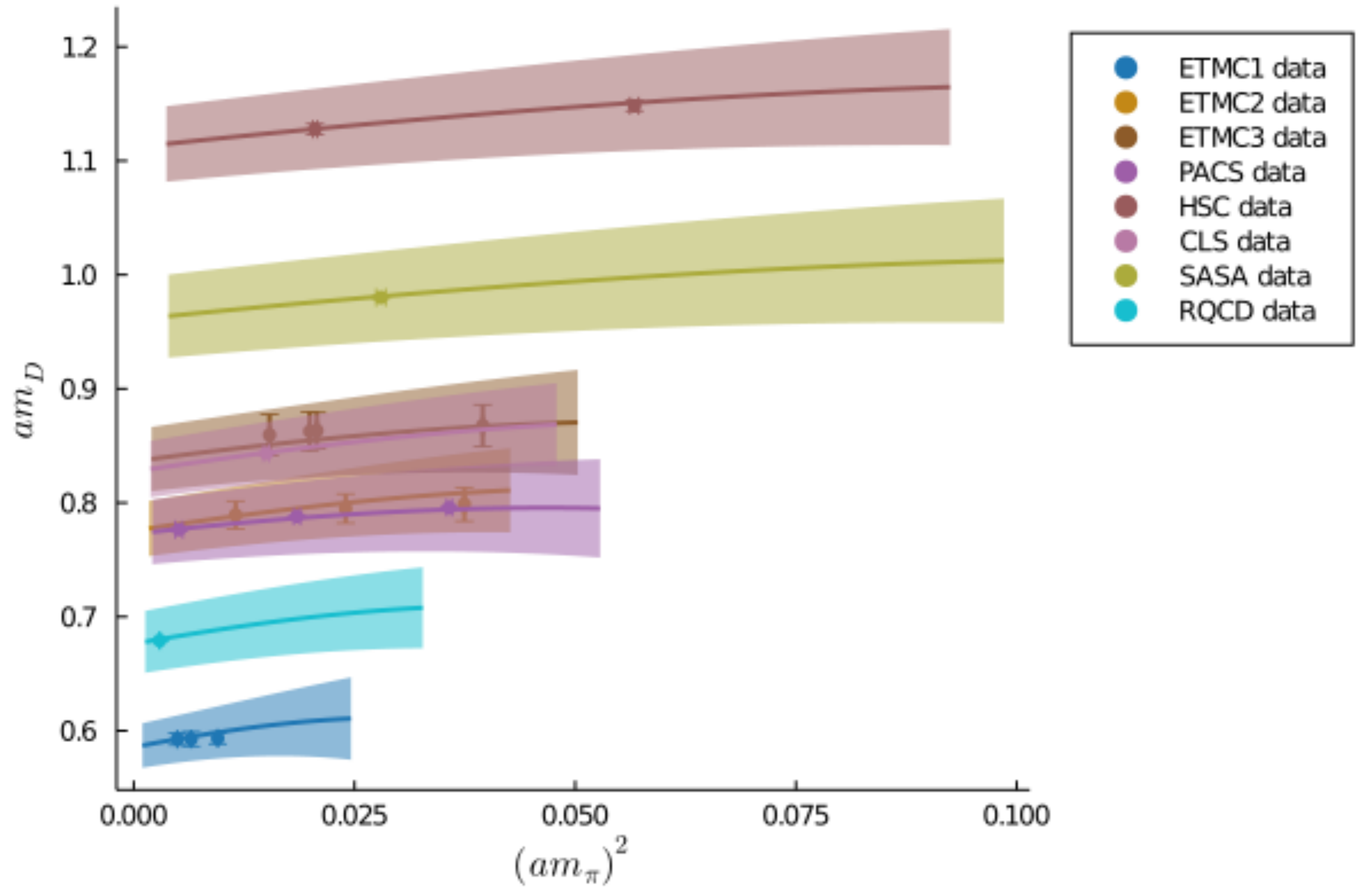
$$\frac{1}{4}(D + 3D^*) = m_H + f(\sigma, a, \cancel{b}, c, \cancel{d})$$

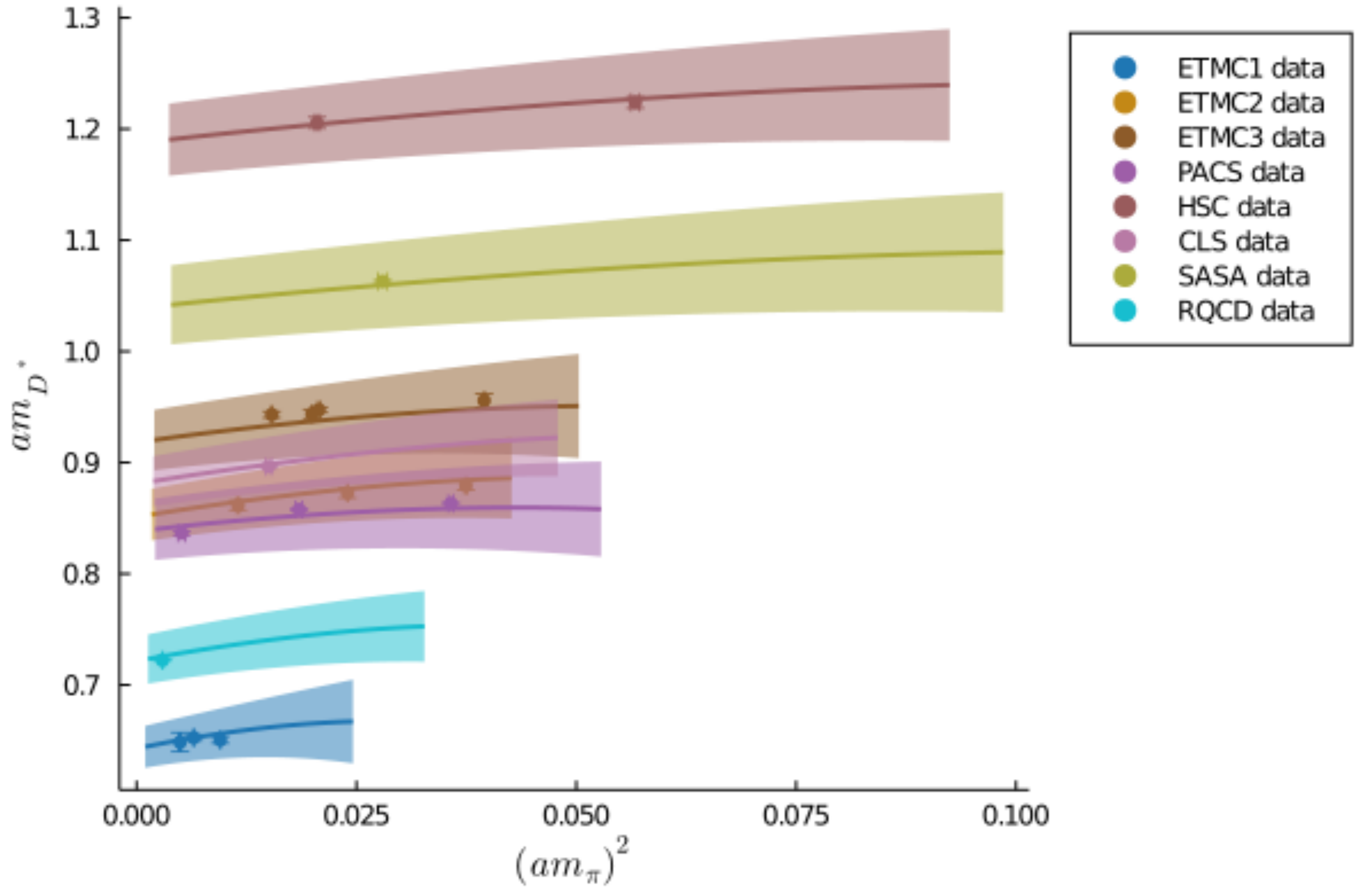
$$(D^* - D) = \Delta + g(\cancel{\Delta^{(\sigma)}}, \Delta^{(a)})$$

10 parameters

+

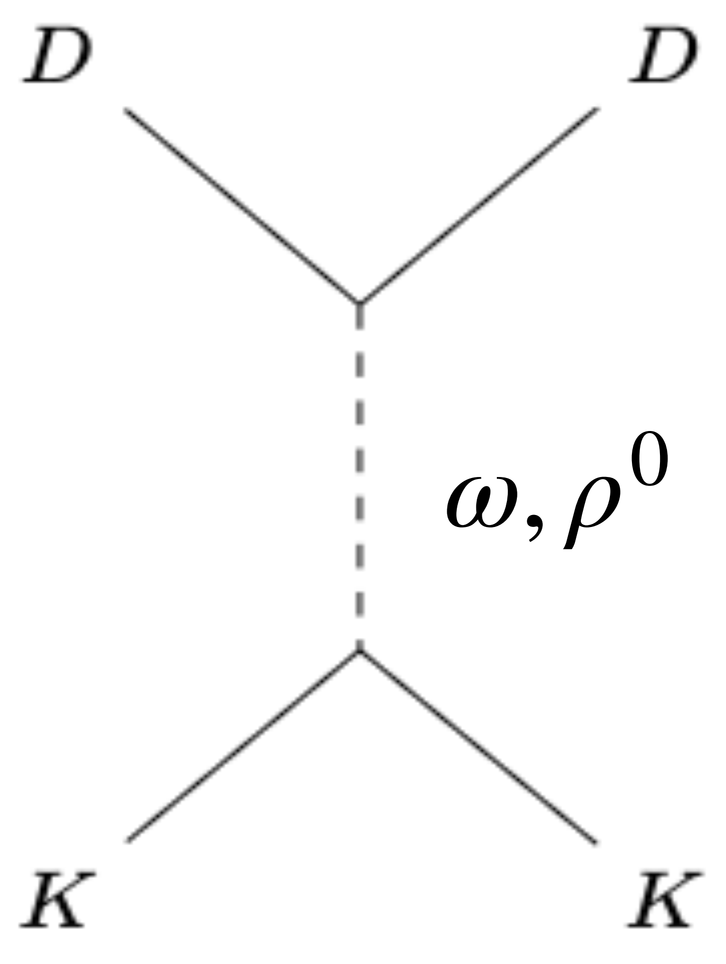
5 parameters

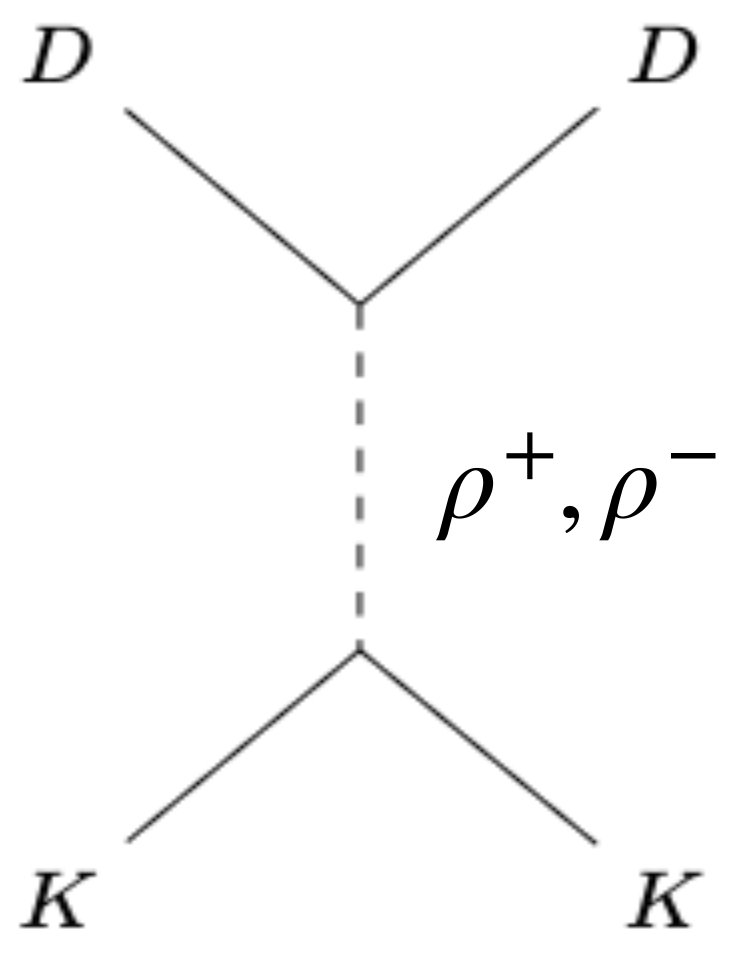


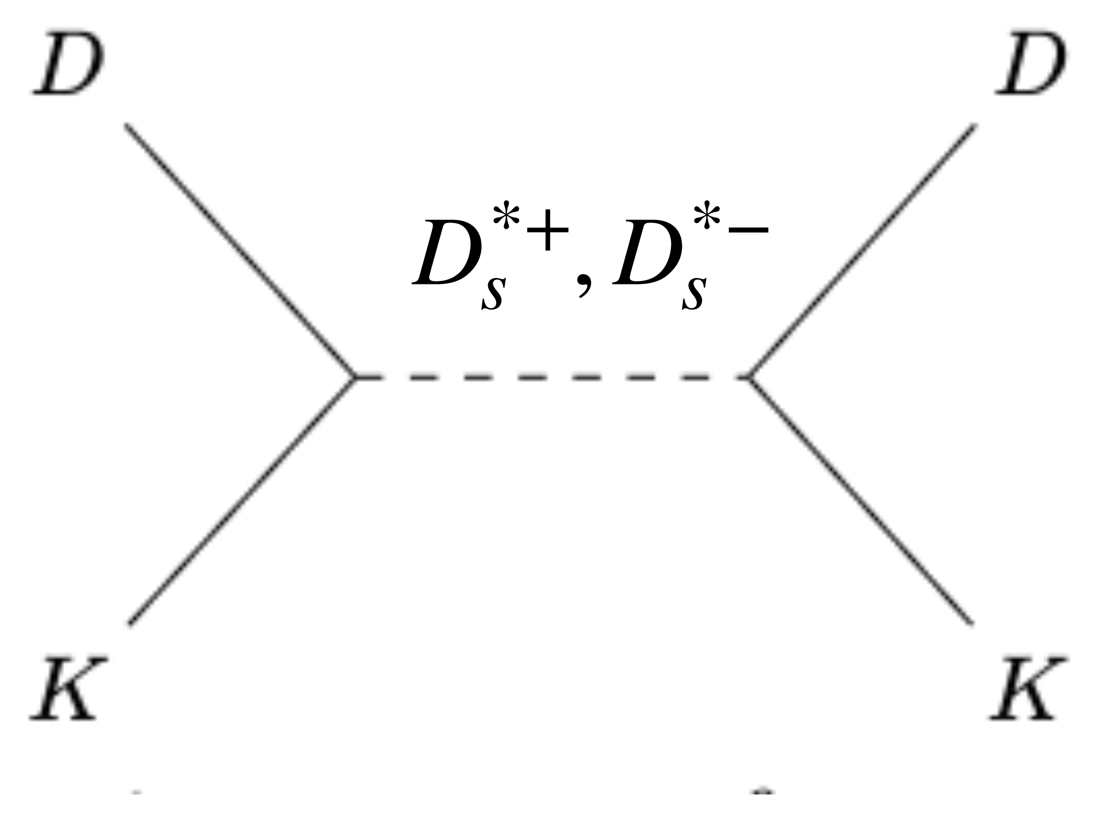


Scattering amplitudes

- Lagrangian from Hidden gauge symmetry formalism
  - $\mathscr{L}_{VPP} = ig < [\partial_\mu \Phi, \Phi] V^\mu >$, $\mathscr{L}_{VVV} = ig < (\partial_\mu V_\nu - \partial_\nu V_\mu) V^\mu V^\nu >$
- The total amplitude from
  - Bethe-Salpeter equation $\rightarrow T = \dfrac{V}{1 - GV}$



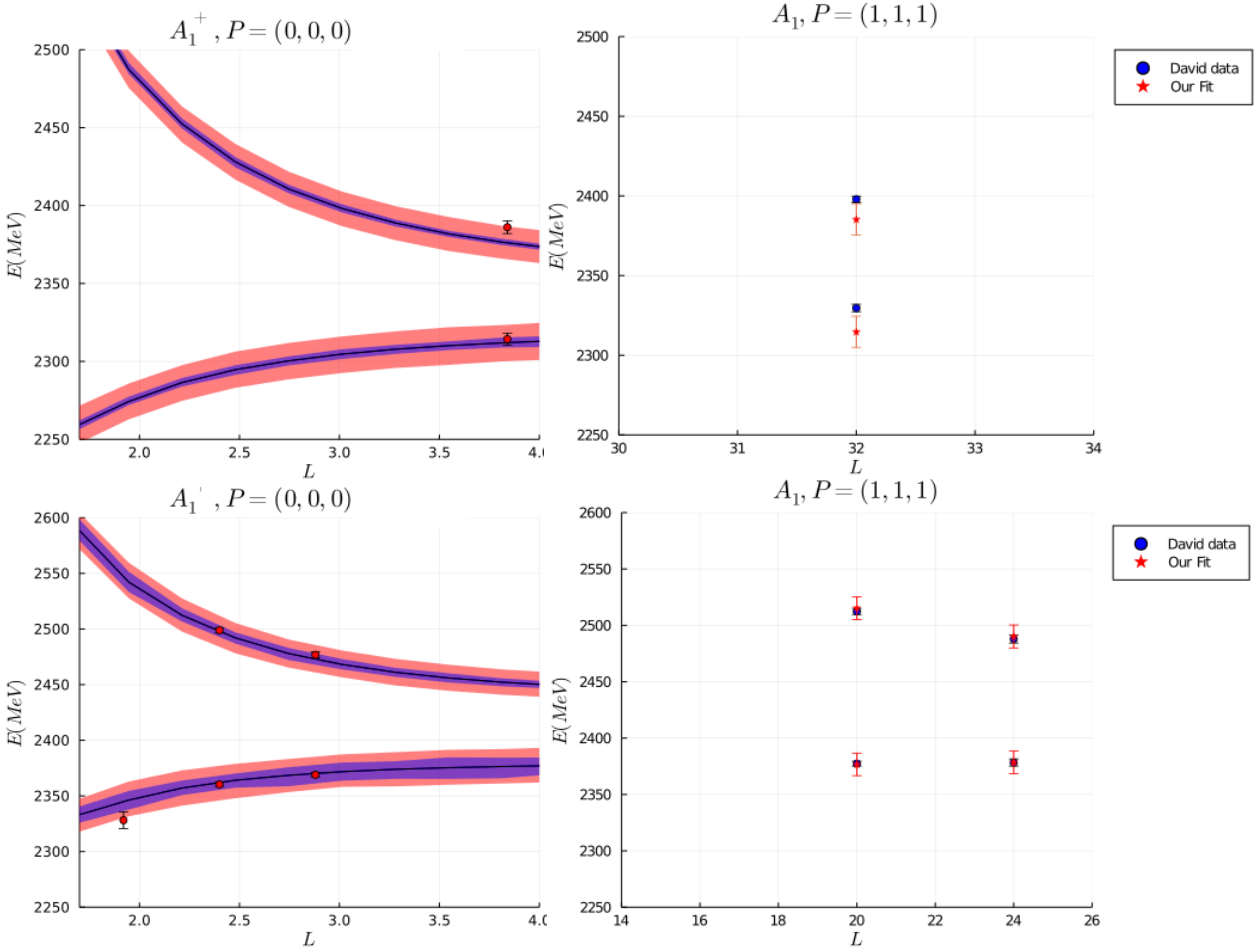




Finite volume energy levels

(one more) fit

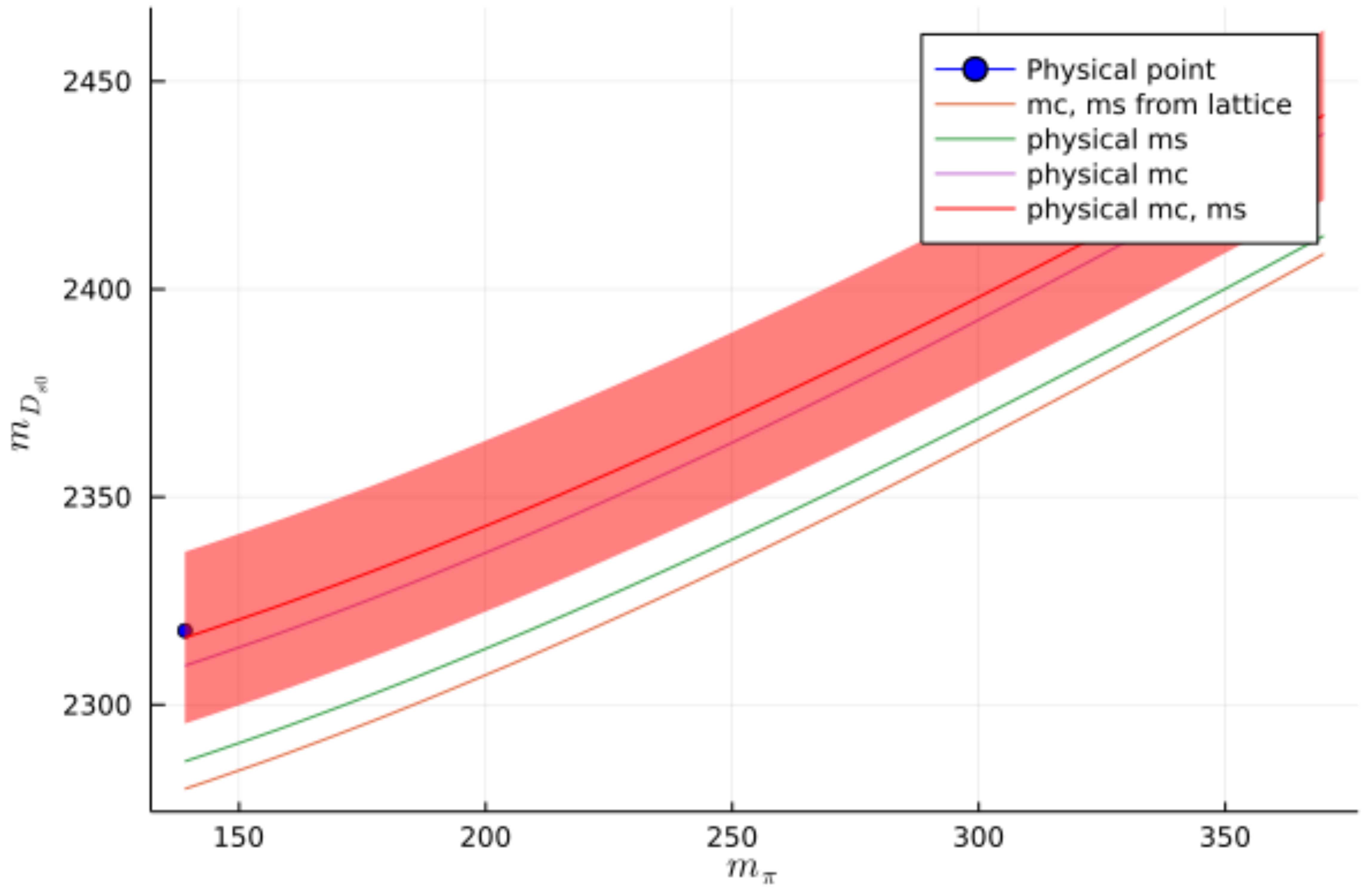
$$T = \frac{V}{1 - GV} \qquad G \rightarrow G_{finite}$$



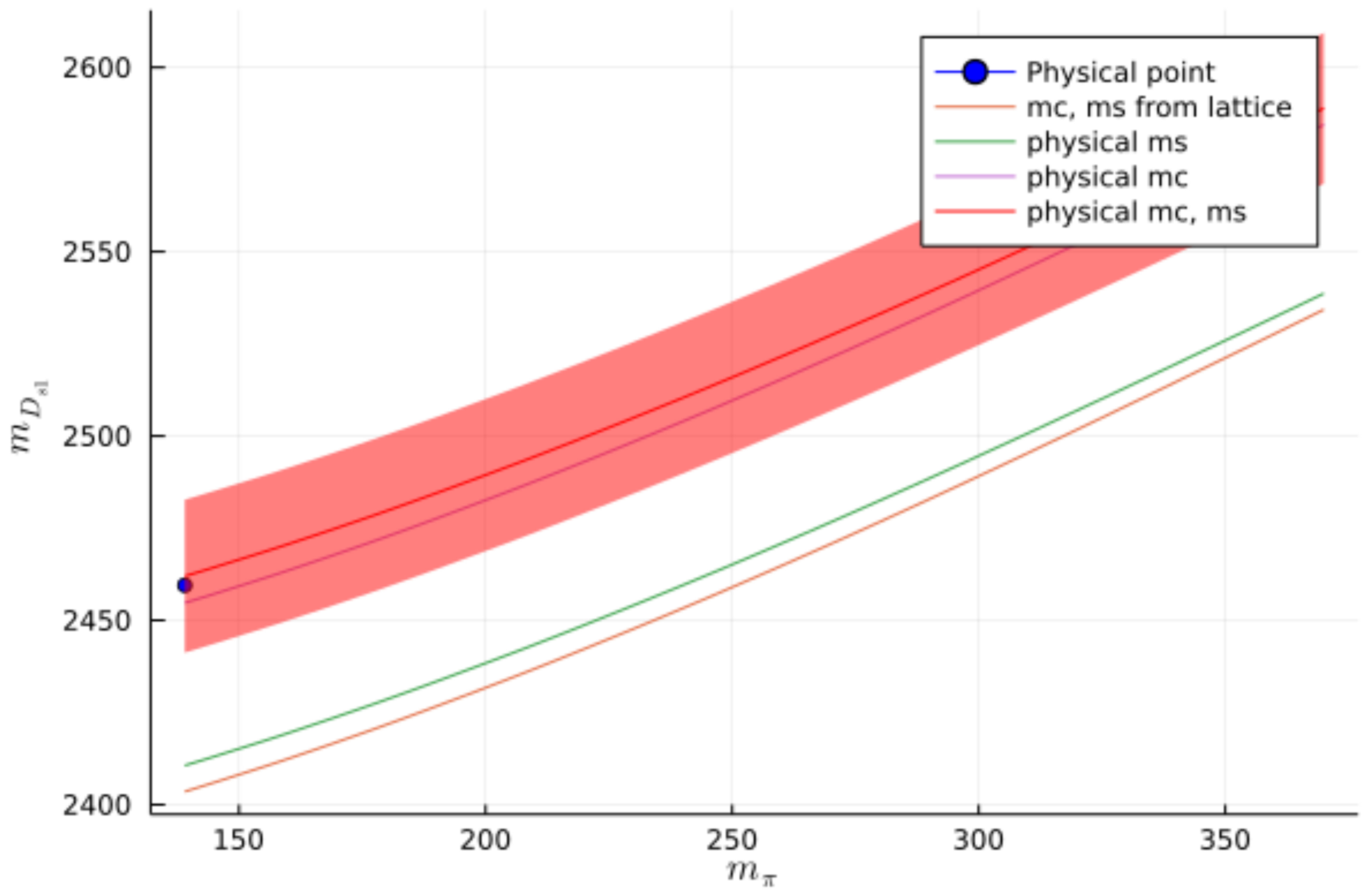
- HSC energy levels
  - $m_\pi = 239$ MeV → 13 points
  - $m_\pi = 391$ MeV → 17 points

D_{s0} and D_{s1} resonances
finally

D_{s0} resonance $(DK \to DK)$



D_{s1} resonance $(D^*K \to D^*K)$



Conclusions

the end

	Prediction	Experimental value
D_{s0} (2317) mass	2318 ± 18 MeV	2318.0 ± 0.7 MeV
D_{s1} (2460) mass	2462 ± 18 MeV	2459.6 ± 0.9 MeV

- D_{s0} and D_{s1} resonances change considerably with the pion mass

$$\downarrow$$

Supports the idea of D_{s0} and D_{s1} as molecular states

Thank you for your attention!