Additional proposal for the treatment of EFT truncation, validity and related uncertainties

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Unitarity bounds on effective field theories at the LHC

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Abstract: Effective Field Theory (EFT) extensions of the Standard Model are tools to compute observables (e.g. cross sections with partonic center-of-mass energy $\sqrt{\hat{s}}$) as a systematically improvable expansion suppressed by a new physics scale M. If one is interested in EFT predictions in the parameter space where $M < \sqrt{\hat{s}}$, concerns of self-consistency emerge, which can manifest as a violation of perturbative partial-wave unitarity. However, when we search for the effects of an EFT at a hadron collider with center-of-mass energy $\sqrt{s}$ using an inclusive strategy, we typically do not have access to the event-by-event value of $\sqrt{\hat{s}}$. This motivates the need for a formalism that incorporates parton distribution functions into the perturbative partial-wave unitarity analysis. Developing such a framework and initiating an exploration of its implications is the goal of this work. Our approach opens up a potentially valid region of the EFT parameter space where $M \ll \sqrt{s}$. We provide evidence that there exist valid EFTs in this parameter space. The perturbative unitarity bounds are sensitive to the details of a given search, an effect we investigate by varying kinematic cuts.

Keywords: Beyond Standard Model, Effective Field Theories

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Proposal based on this paper

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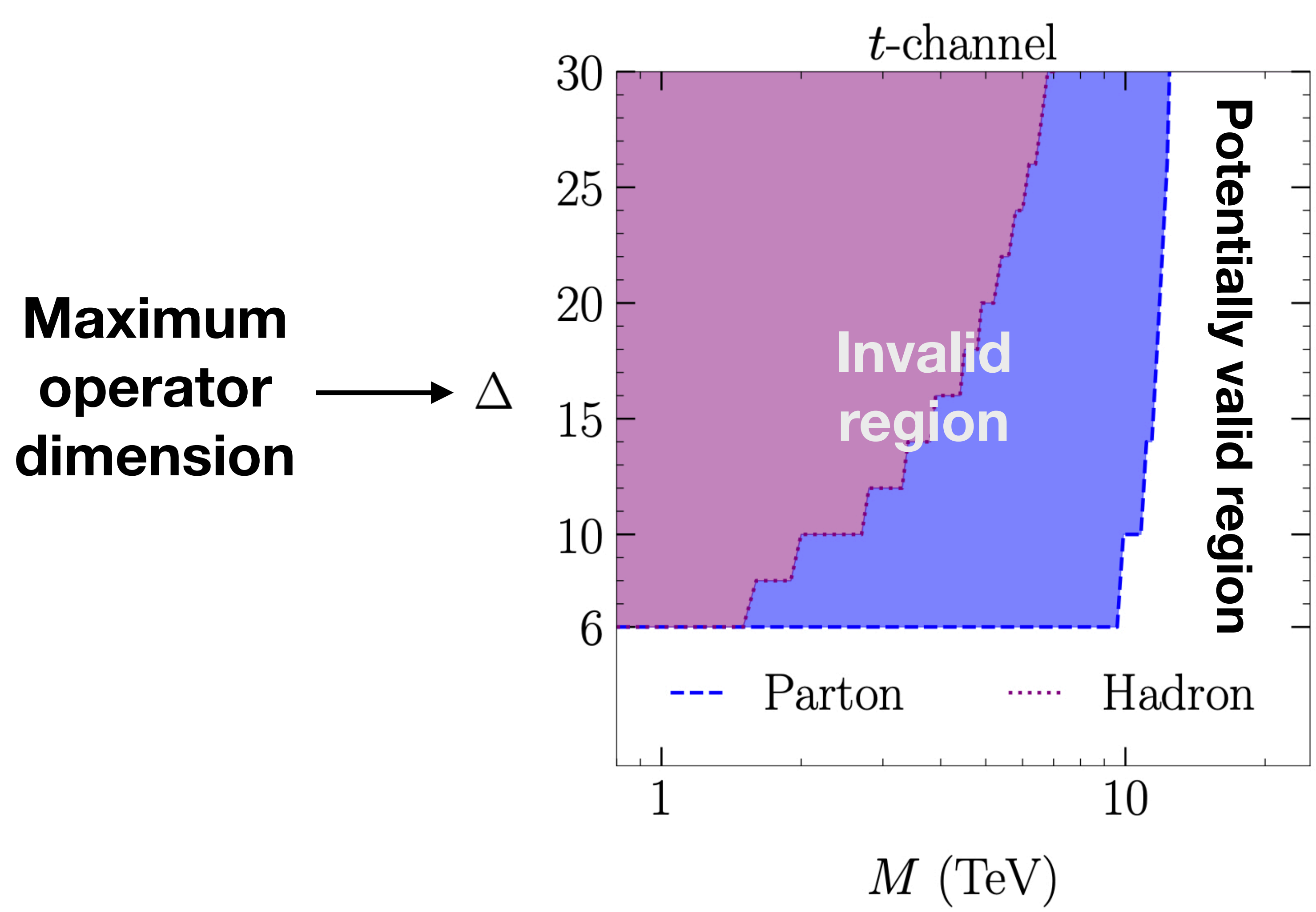
Work in progress with Spencer Chang, Joel Doss, Xiaochuan Lu, and Aria Radick

Executive Summary

Our proposal is based on first principles.

The essential idea is to incorporate the parton distribution functions into the computation of the partial wave unitarity bound on EFT validity.



Derivation

Generalize partial wave unitarity bound to allow for mixed initial state

$$|\langle f|T|i\rangle|^2 \leq 1 \qquad \Longleftrightarrow \qquad \mathrm{tr}\left(\rho_i\, T^\dagger\, |f\rangle\langle f|\, T\right) \leq 1$$

with

$$\rho_p = \sum_i p_i\, |i\rangle\langle i| = \sum_i p_i\, \rho_i$$

The bound becomes

$$\mathrm{tr}\left(\rho_p\, T^\dagger\, |f\rangle\langle f|\, T\right) = \sum_i p_i\, \mathrm{tr}\left(\rho_i\, T^\dagger\, |f\rangle\langle f|\, T\right) \leq \sum_i p_i$$

Derivation

Defining the parton level matrix element:

$$\hat{\Omega}_{i\to f} \equiv |\mathcal{M}_{i\to f}|^2 = |\langle f|T|i\rangle|^2$$

The validity condition becomes

$$\Omega_{pp\to\phi\phi^\dagger}(s) \equiv \frac{\sum_{\{q,\bar{q}\}\in p} \int_{\tau_\phi}^1 \mathrm{d}\tau\, L_{q\bar{q}}(\tau)\, \hat{\Omega}_{\phi_q\phi_q^\dagger\to\phi\phi^\dagger}(\hat{s}=\tau s)}{\sum_{\{q,\bar{q}\}\in p} \int_{\tau_\phi}^1 \mathrm{d}\tau\, L_{q\bar{q}}(\tau)} \leq 1$$

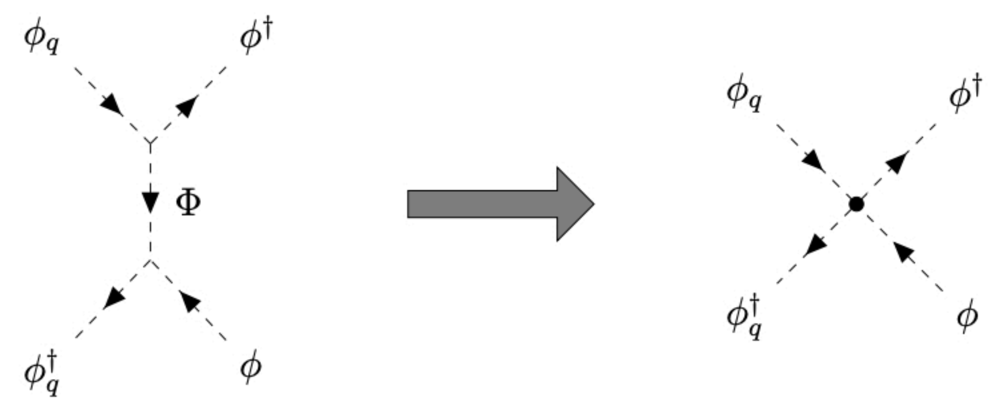
Where we have introduce the parton luminosity function:

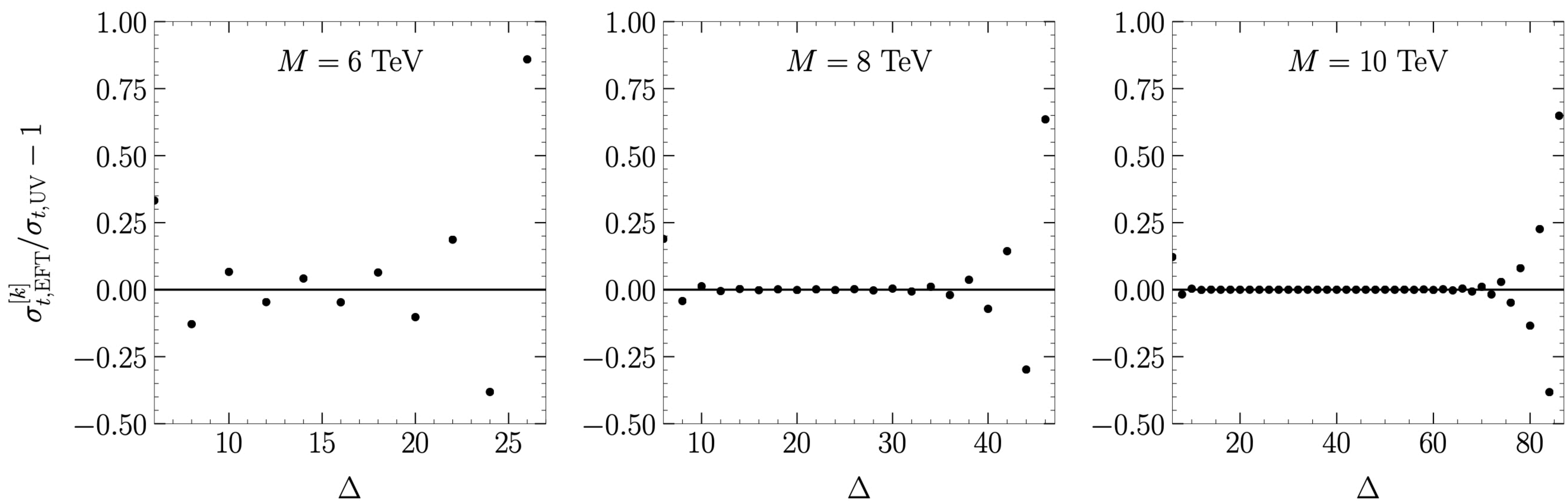
$$L_{q\bar{q}}(\tau) \equiv \int_0^1 \mathrm{d}x_1 \mathrm{d}x_2 \left[f_q(x_1) f_{\bar{q}}(x_2) + f_{\bar{q}}(x_1) f_q(x_2)\right] \delta(\tau - x_1 x_2)$$

$$= 2\int_\tau^1 \mathrm{d}x\, \frac{1}{x}\, f_q(x)\, f_{\bar{q}}(\tau/x)\,.$$

It makes sense

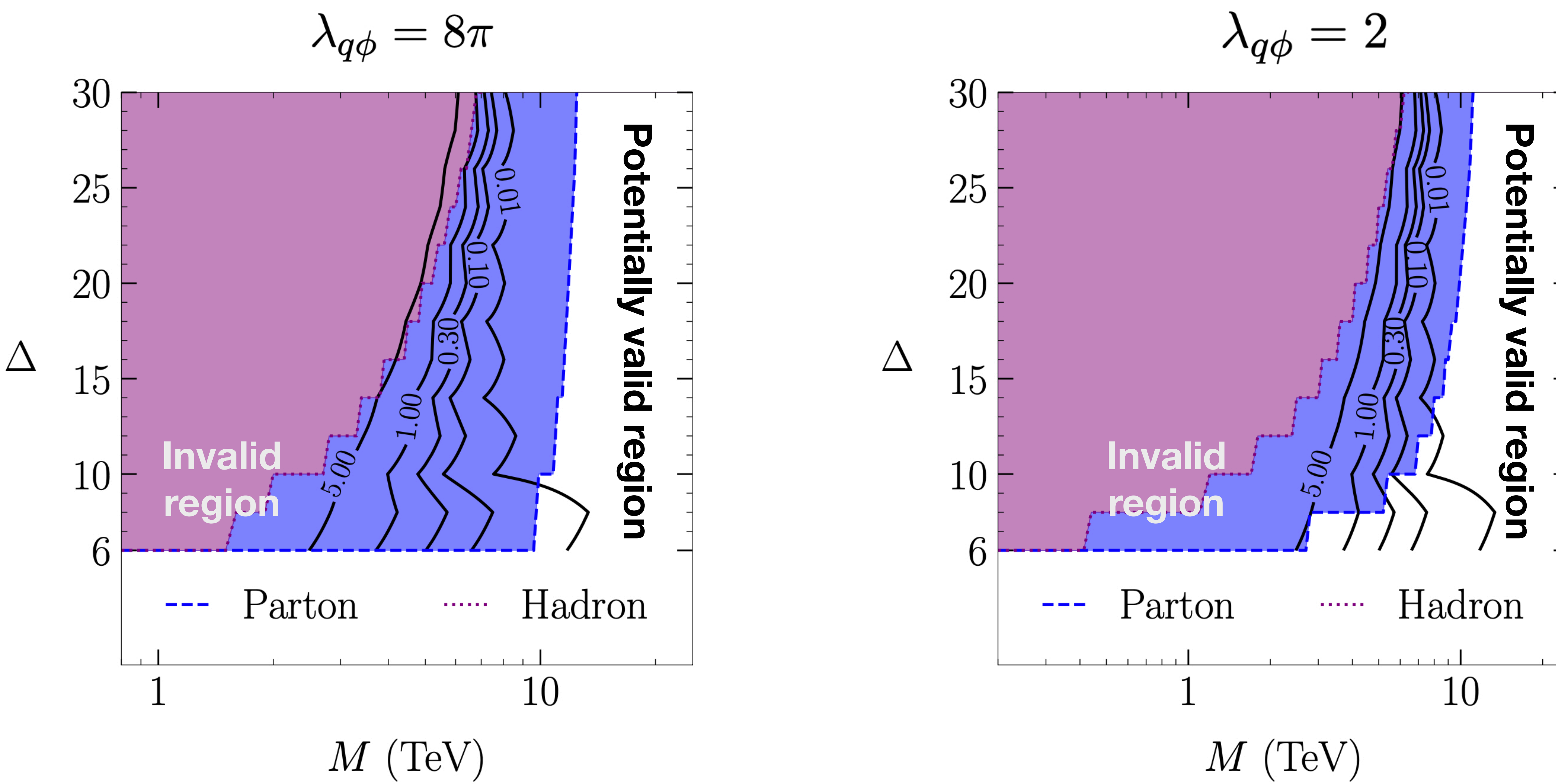
Toy example





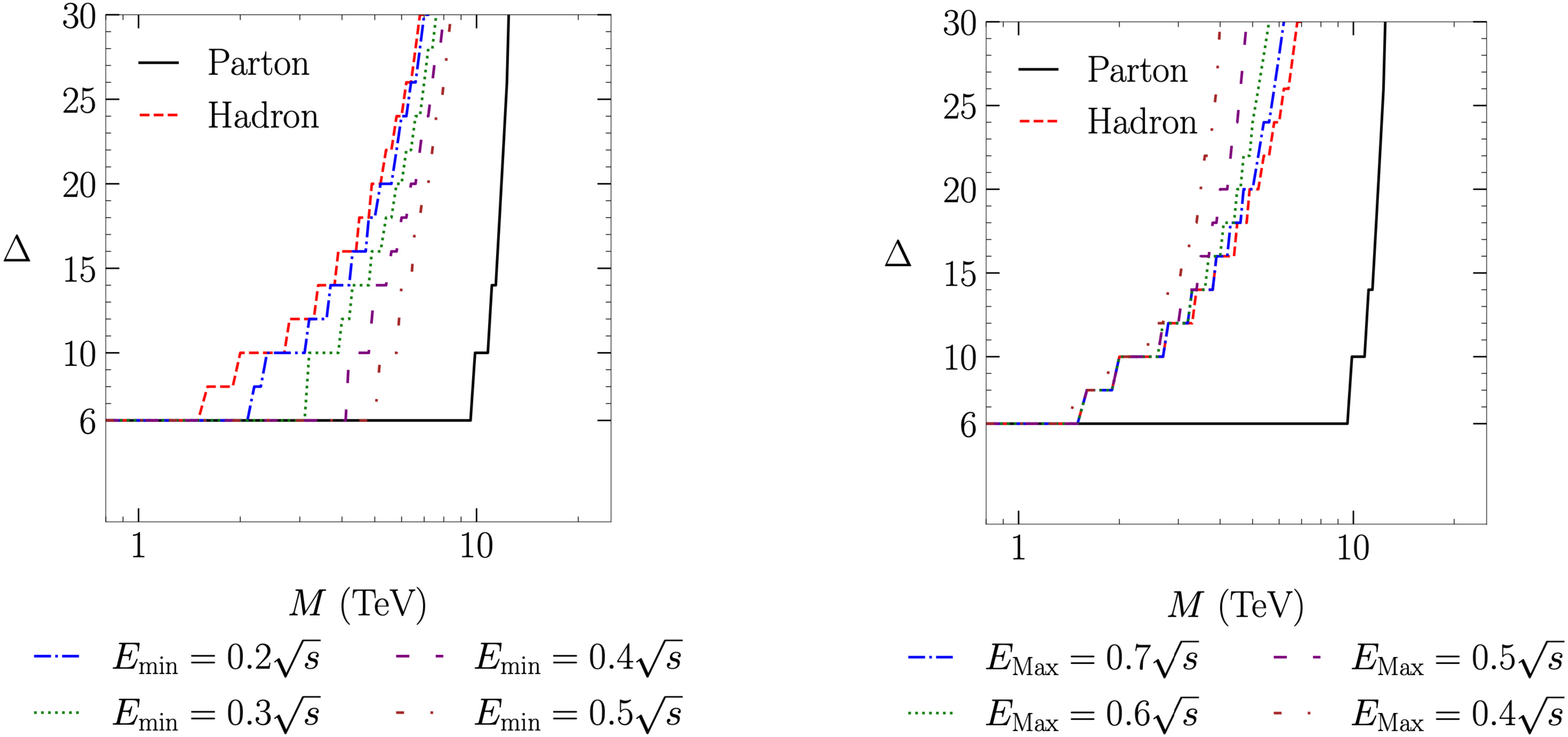
EFT power counting fails in invalid region

Using t-channel toy model



Contours are power counting uncertainty

Bounds depend on cuts



Outlook

More needs to be done:

In first paper, we used scalar toy models

Incorporating spin is not a problem

Working to generalize formalism to include angular cuts

Long term vision:

Unitarity bound can be incorporated into priors for EFT fits

Interplay of unitarity bound and signal region cuts can be used to inform search strategies