Weak Physics using the FMS Mechanism

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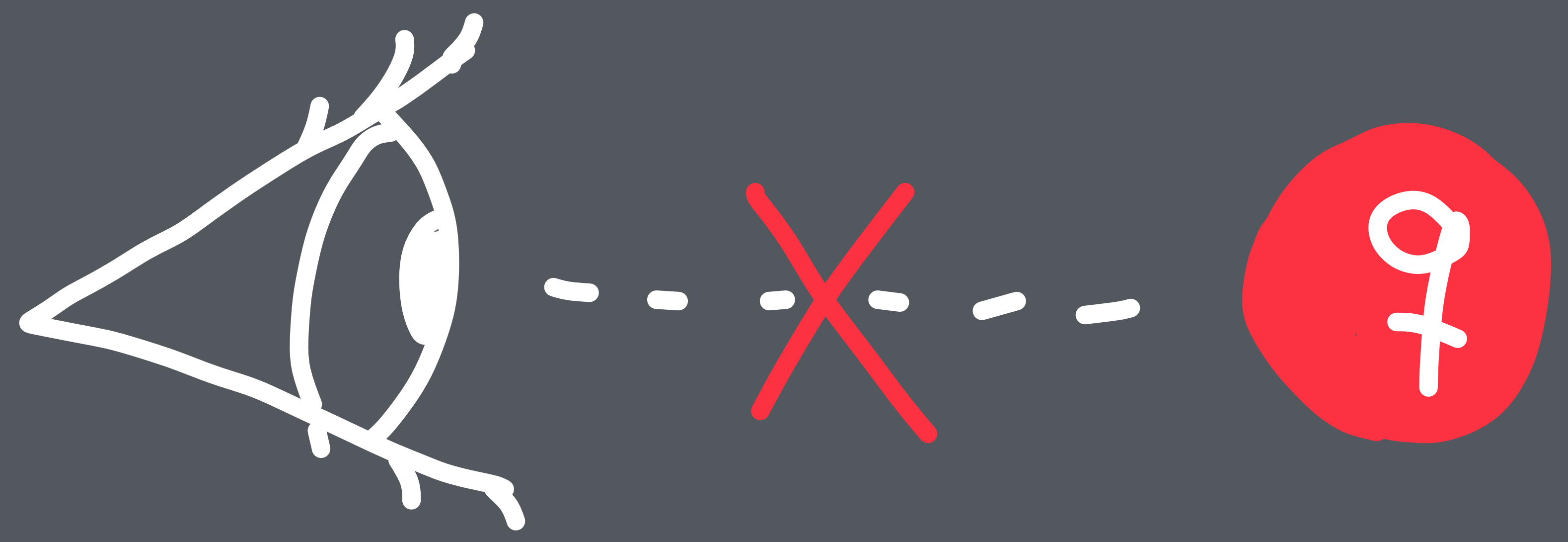
17th February 2026
University of Graz

Introduction

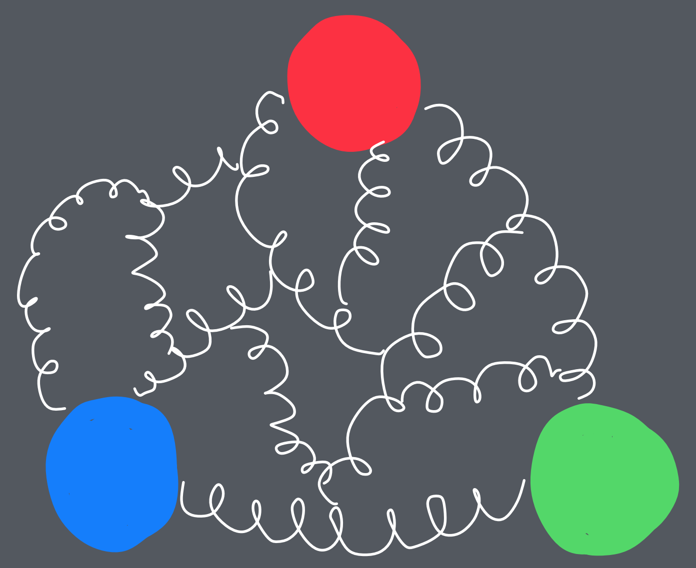
Confinement in QCD (SU(3))

1. Observers are color blind



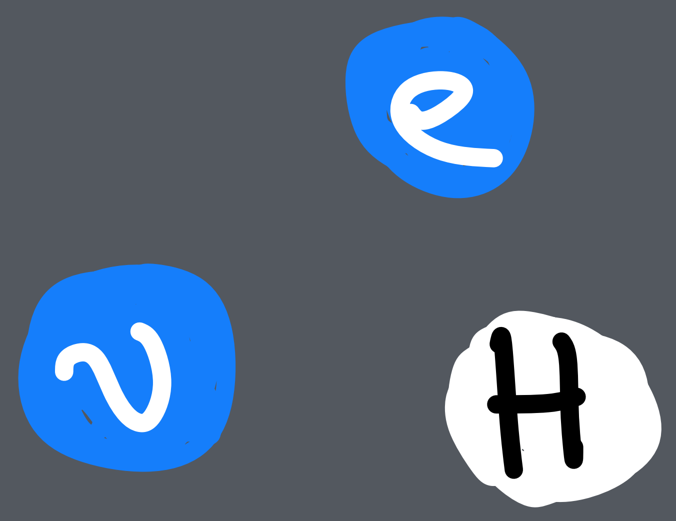
2. Physical objects are color singlets

3. Predictions require non-perturbative techniques



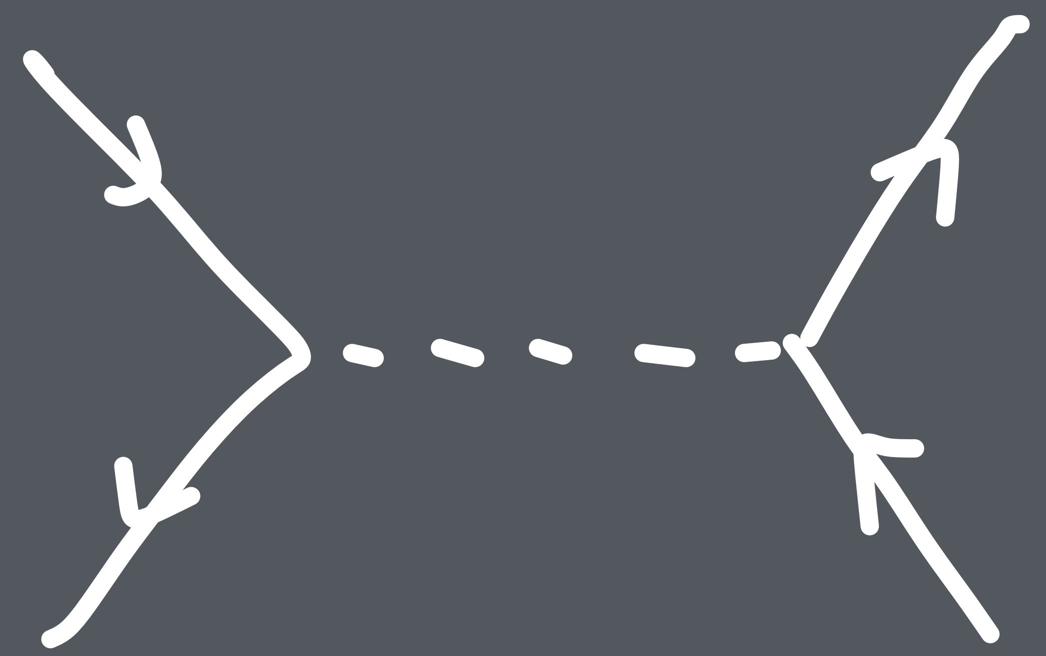
Some claims about the weak interaction

1. Observers are **not** weak isospin blind



2. Leptons and neutrinos are individually observable

3. Perturbative treatment possible using the BRST construction



Elitzur's theorem: Gauge symmetries cannot be spontaneously broken!

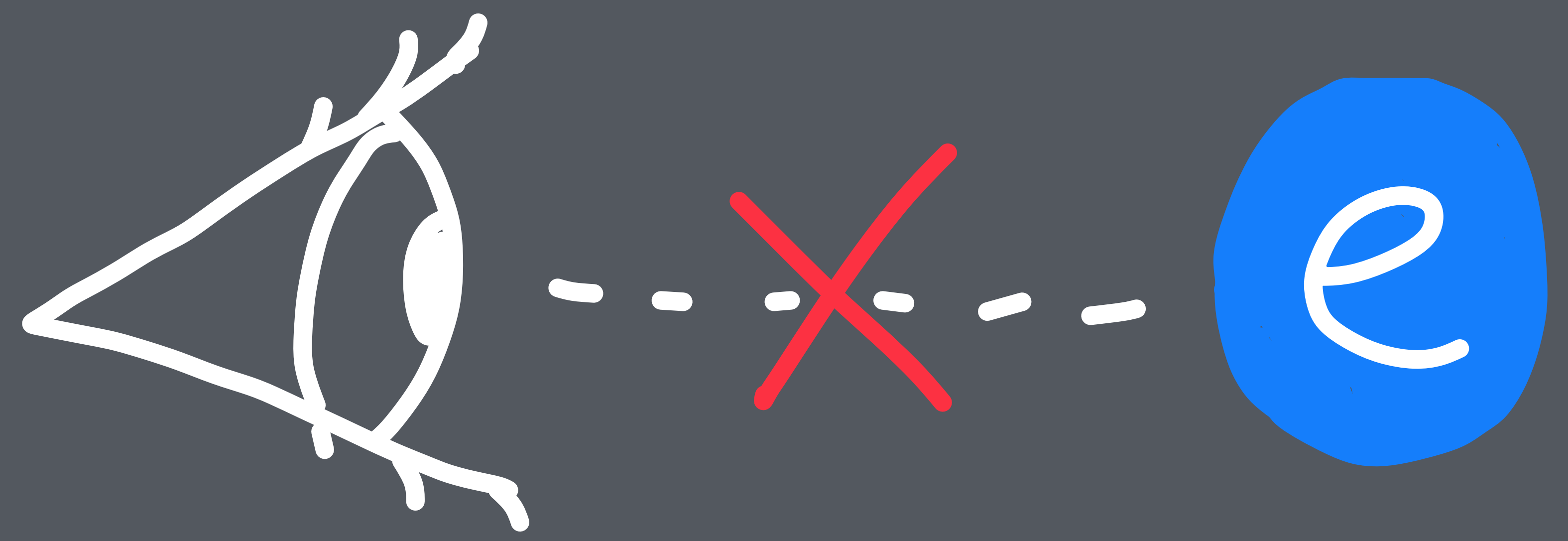
Elitzurs Theorem

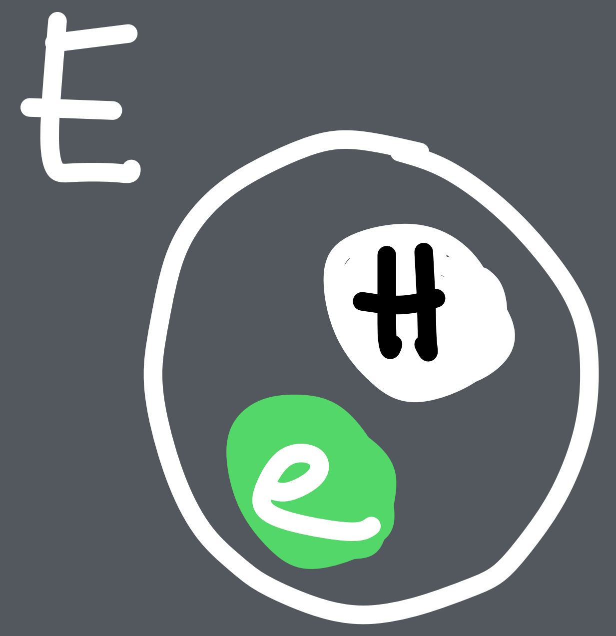
$$\langle O \rangle = \int D\mu \, O \, e^{iS} = \int D\mu^{g^{-1}} \, O \, e^{iS}$$

$$= \int D\mu \, O^{g} \, e^{iS} = \langle O^{g} \rangle$$

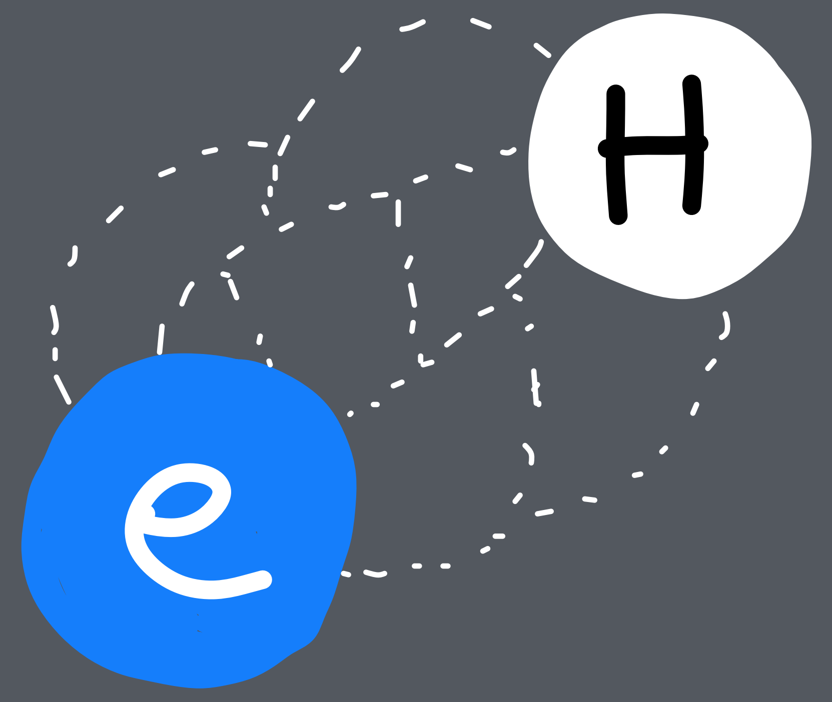
What would make more sense

1. Observers are weak-isospin blind





2. Physical fermions are composite



3. Predictions require non-perturbative techniques

For example …

Fundamental left-handed fermion doublet and Higgs doublet reorganized in matrix X

$$\psi = \begin{pmatrix} \nu_e \\ e \end{pmatrix} \qquad X = \begin{pmatrix} \phi_2^* & \phi_1 \\ -\phi_1^* & \phi_2 \end{pmatrix}$$

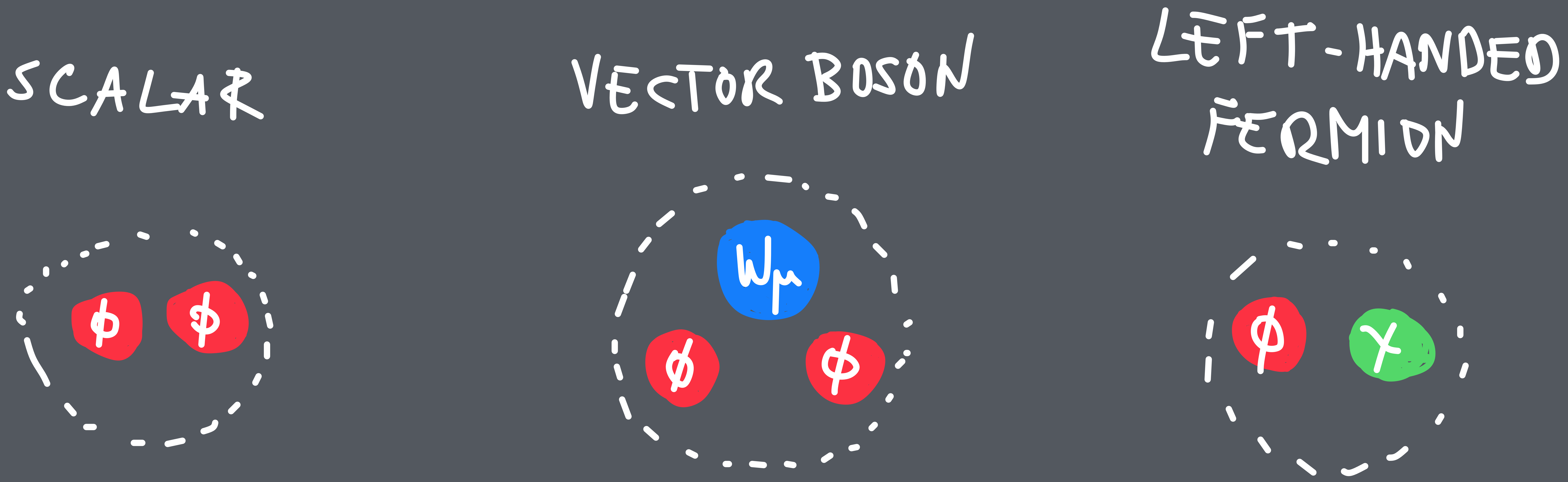
Combine to physical & observable fermion

E

$$= \begin{pmatrix} N \\ E \end{pmatrix}_2 = (X^\dagger \psi)_2$$

[A. Maas, Prog. Part. Nucl. Phys., 2019, 1712.04721] and references therein

More operators



[A. Maas, Prog. Part. Nucl. Phys., 2019, 1712.04721] and references therein

Lattice Approach

Target theory

GAUGE SCALAR

$$\mathcal{L} = -\frac{1}{4} W^a_{\mu\nu} W^{a\mu\nu} + \frac{1}{2} \mathrm{tr}\left[(D_\mu X^\dagger)(D^\mu X) \right] - \lambda \left(\frac{1}{2} \mathrm{tr}(X^\dagger X) - f^2 \right)$$

+ LEFT-HANDED & RIGHT-HANDED FERMIONS

+ YUKAWA - COUPLINGS

LATTICE

PDFs:

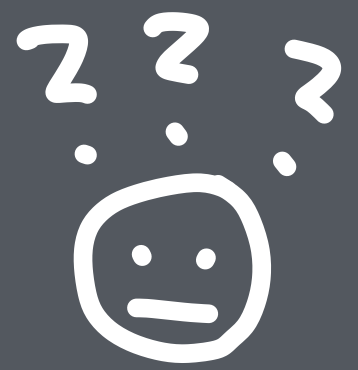
GAUGE + SCALAR

SPECTROSCOPY:

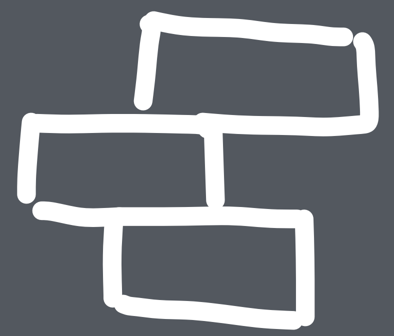
GAUGE + SCALAR + LEFT-HANDED FERMIONS

[A. Maas, Prog. Part. Nucl. Phys., 2019, 1712.04721] and references therein

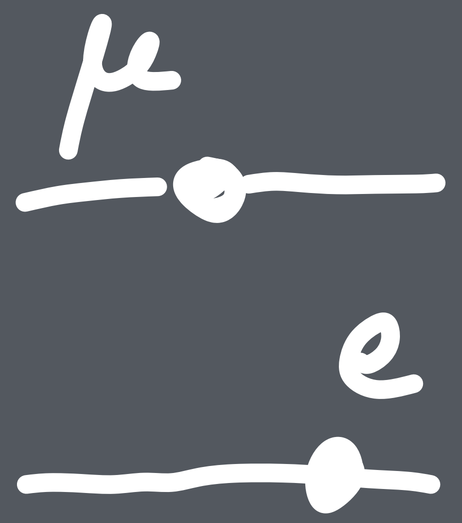
Why you should care



To not confuse a BSM with NP SM effects



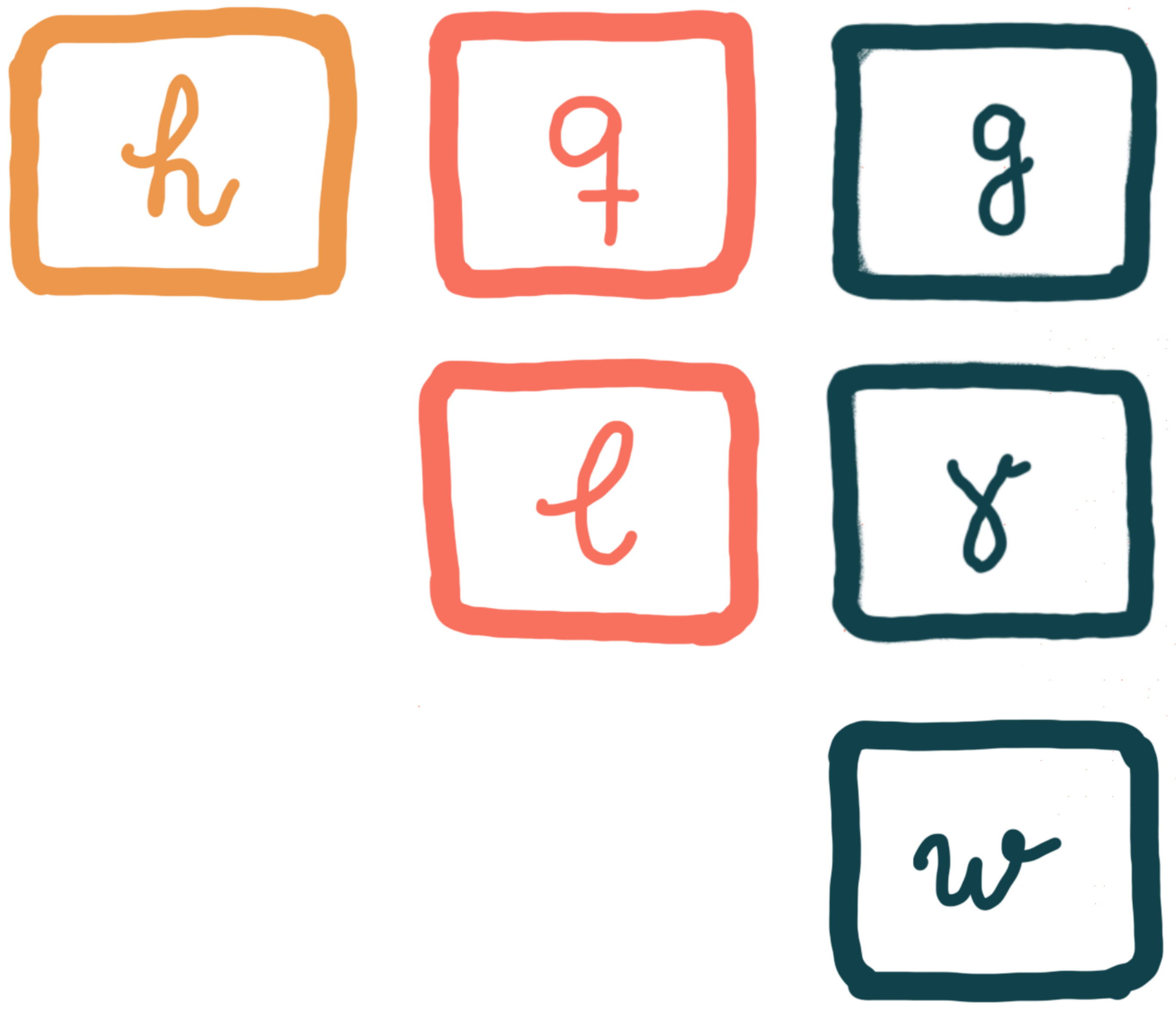
To correctly build extensions of the SM on top of the weak sector

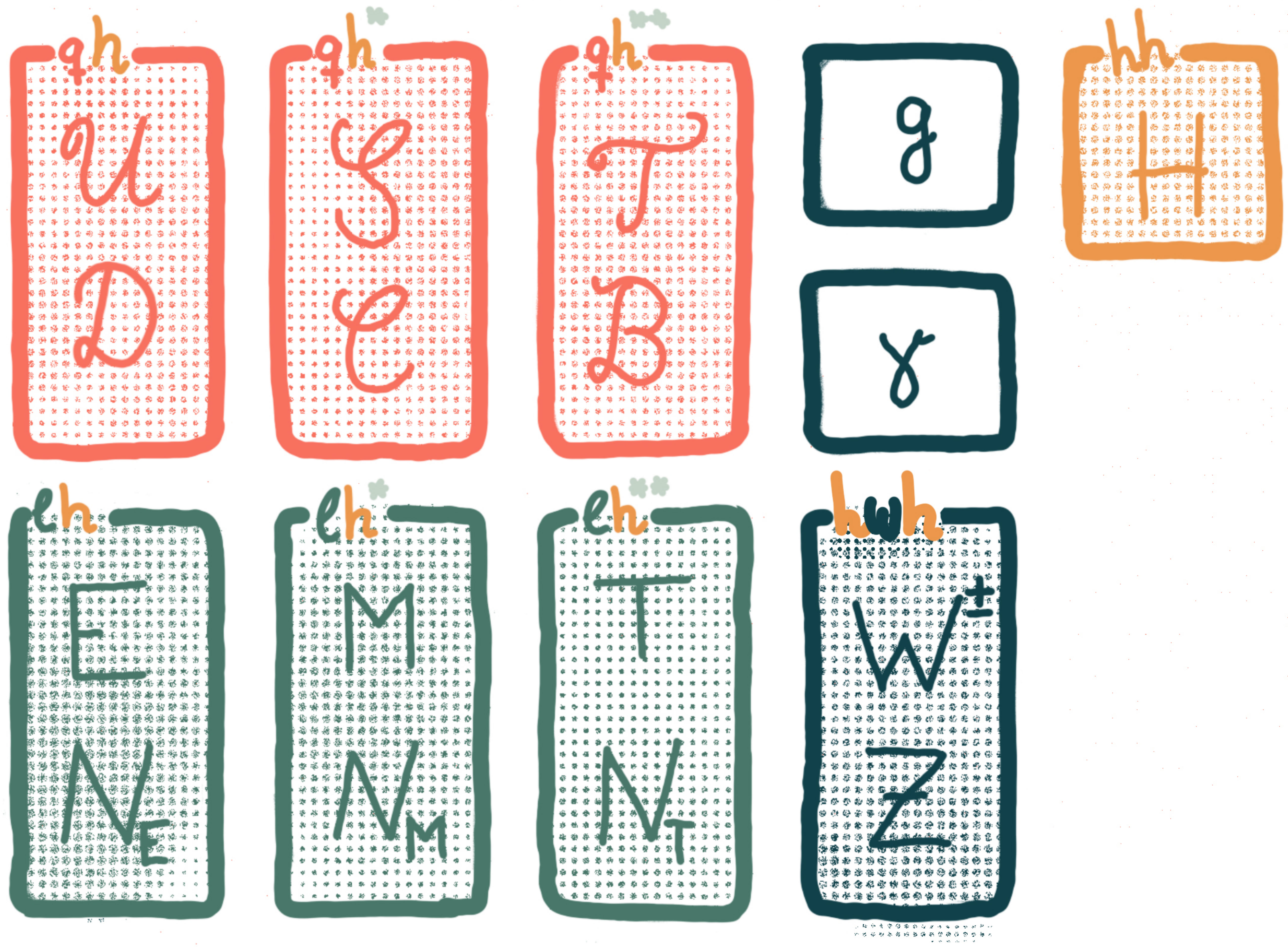


It is consistent with the PDG that lepton & quark generations are levels of excited states -> compute CKM/ PMNS matrix elements from the lattice

[Egger et. al., Mod.Phys.Lett. A, 2017, 1701.02881]

The standard model but simpler





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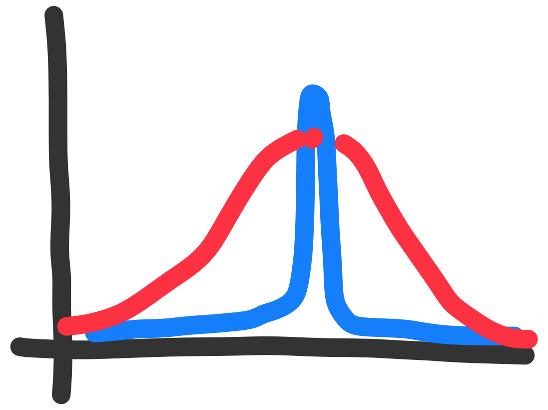
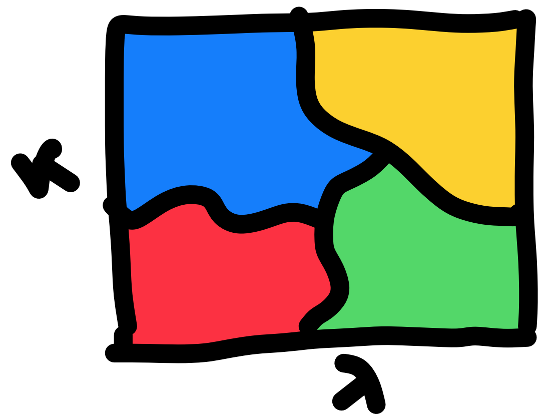
Outline



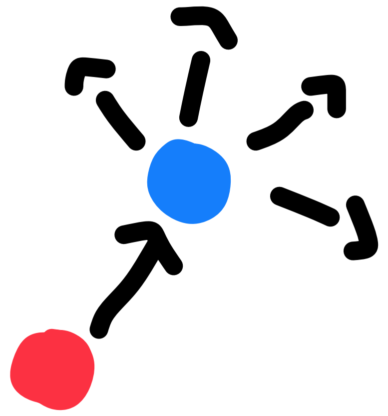
1. Quasi-PDFs

   How much internal structure do we see theoretically?



2. Physical Phases and Mass Hierarchies in the system

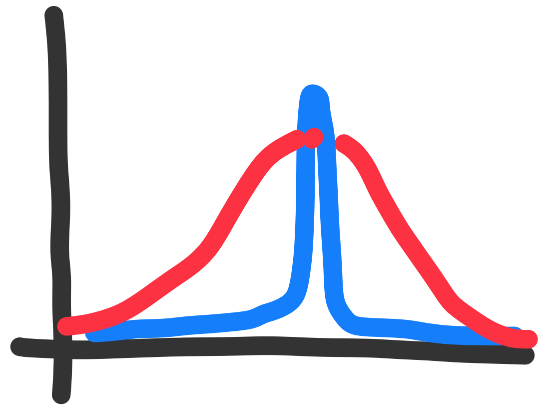
   How does the theory behave?



3. Cross-sections obtained from spectral densities

   Identify deviations from perturbation theory

Outline



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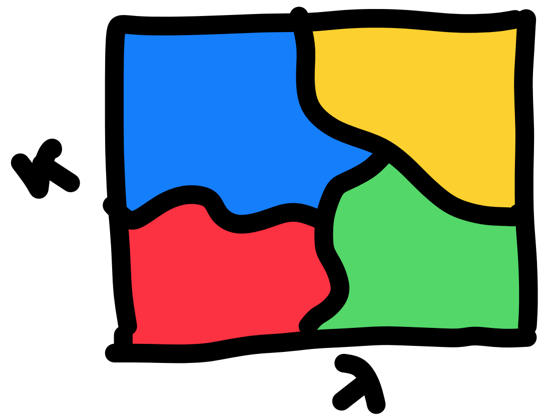

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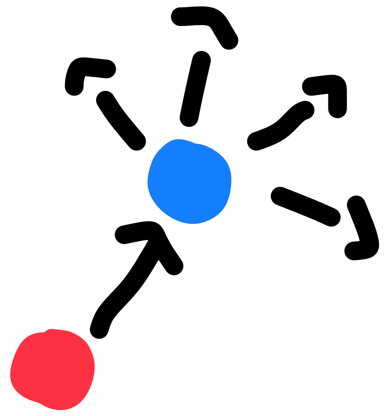


3. Cross-sections obtained from spectral densities

   Identify deviations from perturbation theory

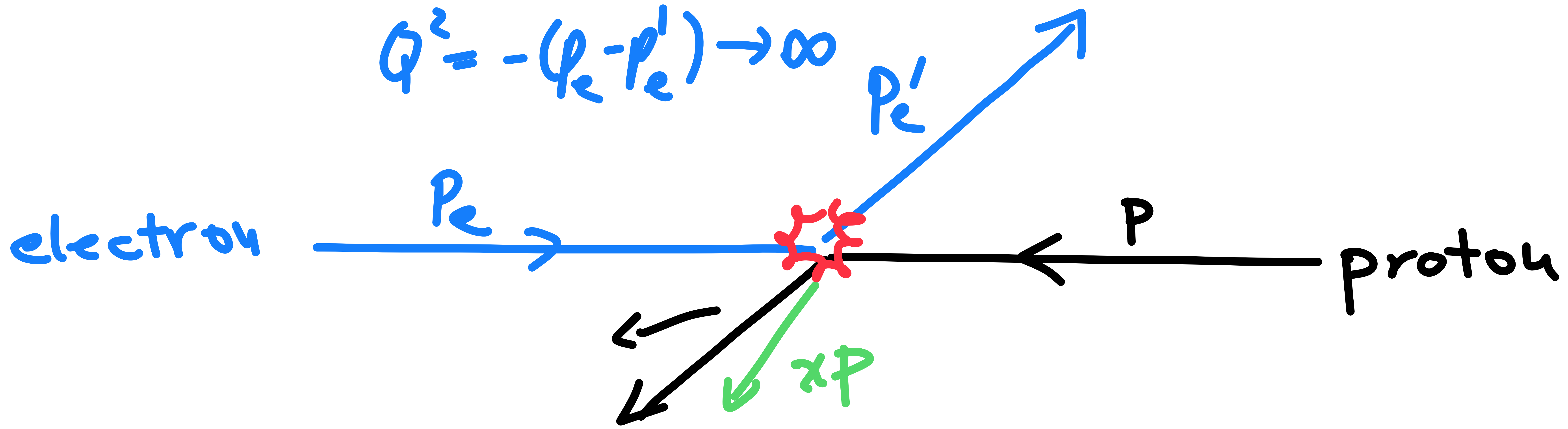
See excited states!

Parton Distribution Functions for electroweak physics

Parton Distribution Functions

Example: Deep-inelastic scattering of the proton

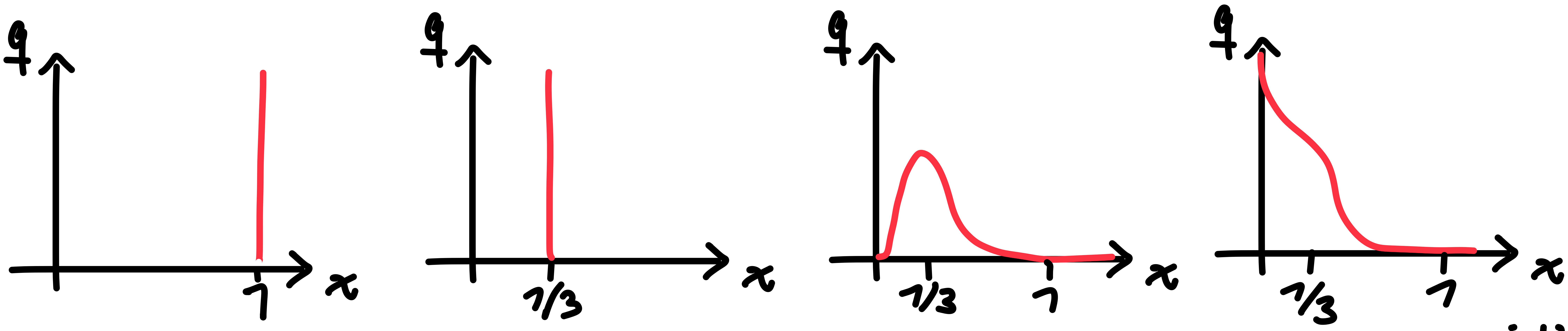
- Shows the distribution of a **single constituent momentum** relative to the total momentum
- Is computed in the Bjorken Limit: Infinite momentum transfer



Parton Distribution Functions

Example: Deep-inelastic scattering of the proton

- Contains information about the **internal structure** of the proton



A fundamental proton

A proton consisting of 3 free quarks

A proton consisting of 3 bound quarks

A proton consisting of
* 3 bound quarks
* sea quarks
* self-interacting gluons

Lattice PDFs: Quasi-PDFs

- We cannot achieve the Bjorken limit: Infinite momentum
- Instead we use large but **finite momenta**

PDF: $q(x)$ from structure functions in Bjorken limit

Quasi-PDF: $\tilde{q}(x, P_3) = \int_{-\infty}^{\infty} \frac{dz}{4\pi} e^{-izxP_3} \langle p | \mathcal{O}(z,0) | p \rangle$

Without proof: $q(x) = \tilde{q}(x, P_3) + \mathcal{O}\left(\frac{\alpha}{2\pi}\right)$

Lattice PDFs: Quasi-PDFs

- We cannot achieve the Bjorken limit: Infinite momentum
- Instead we use large but **finite momenta**

$$q(x) = \tilde{q}(x, P_3) + \mathcal{O}\left(\frac{\alpha}{2\pi}\right)$$

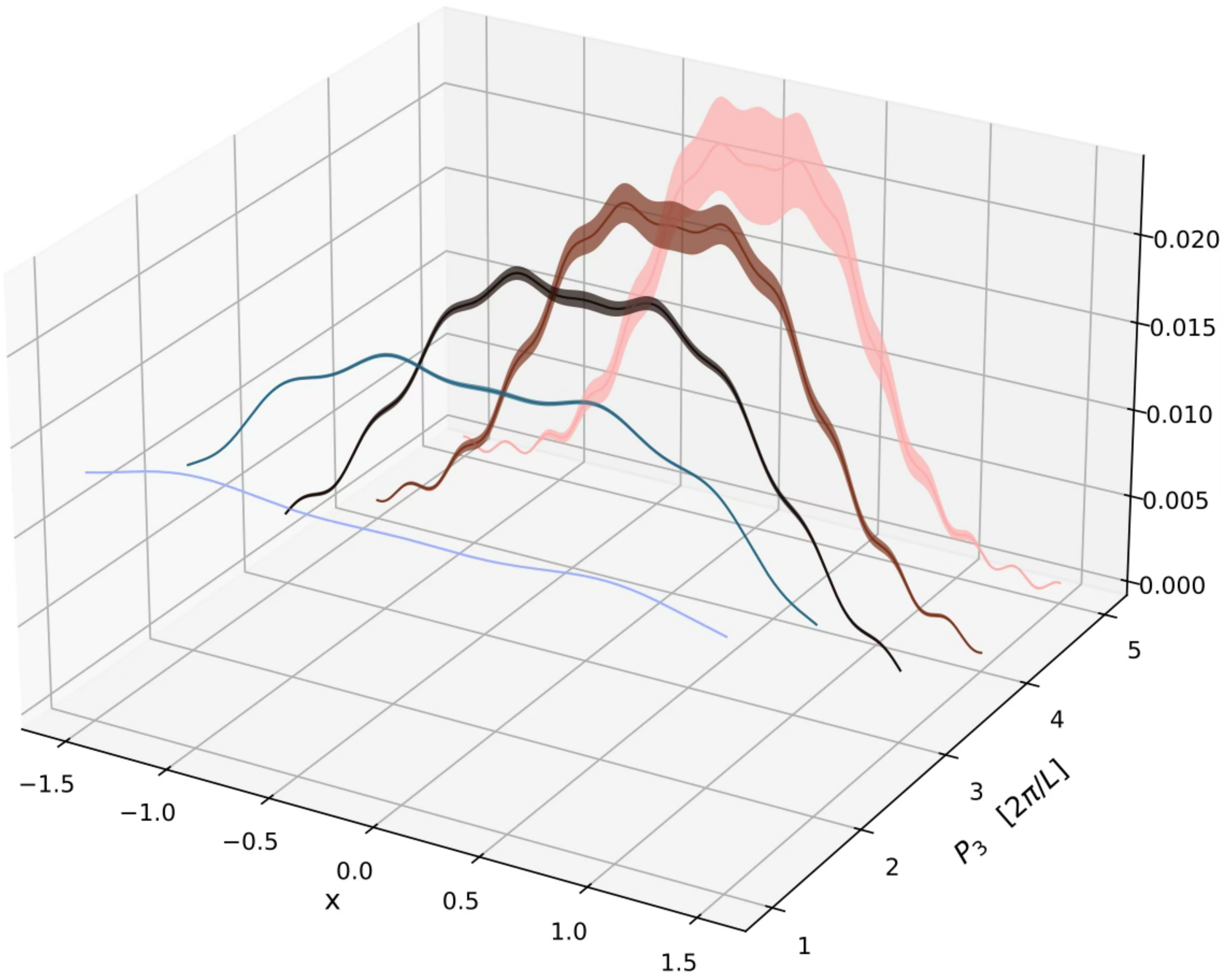
Strong interaction = strong effect

Weak interaction = better control!

FMS W-boson PDF

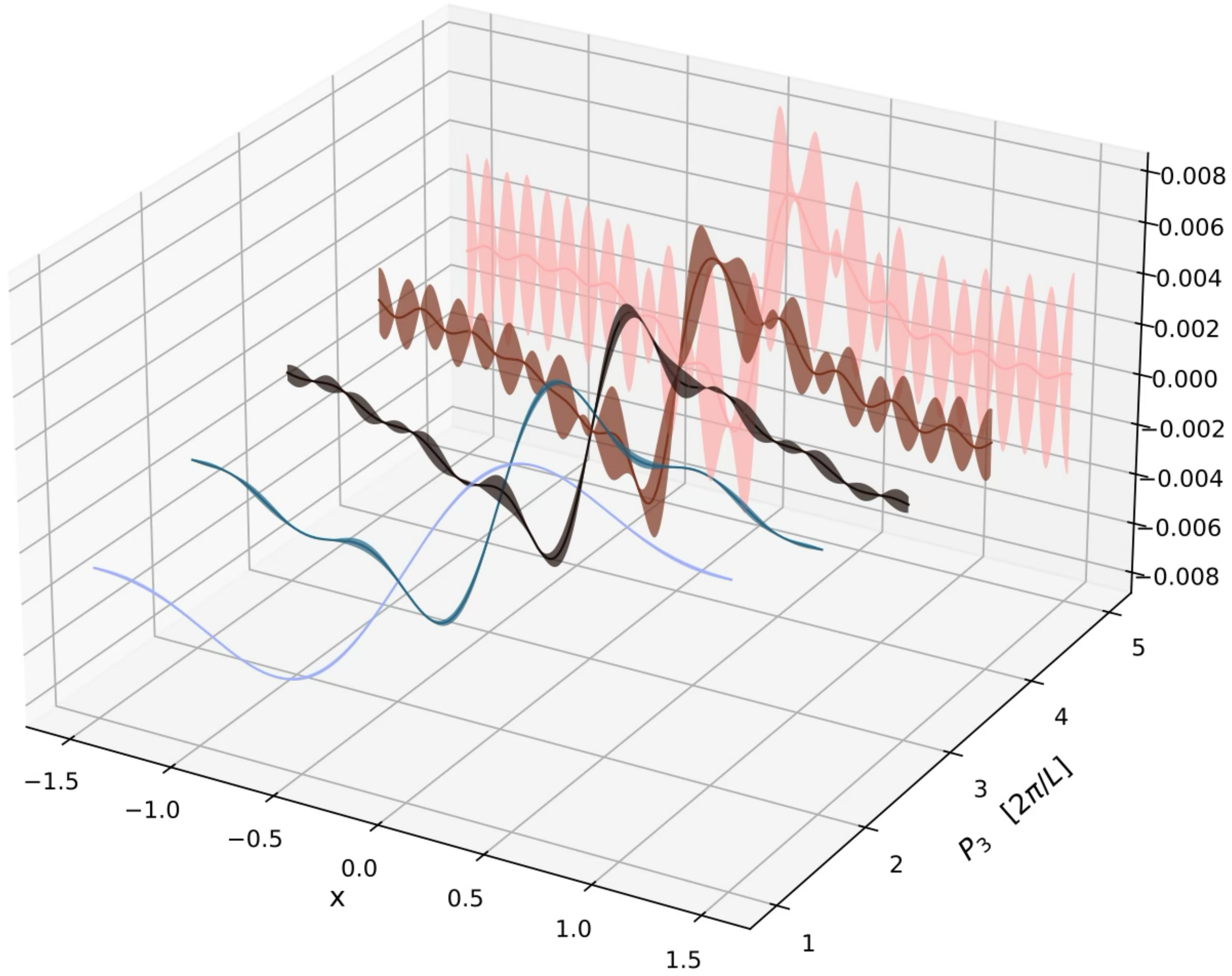
- $x\tilde{w}^{(2)}_{W_{||}}(x; P_3)$ for $L_T = 16$

- Shows the internal structure of physical W under the assumption of FMS



FMS Higgs-boson PDF

- $x\tilde{h}_H^{(1)}(x; P_3)$ for $L_T = 16$
- We may be able to compare this to results from the High-Luminosity LHC



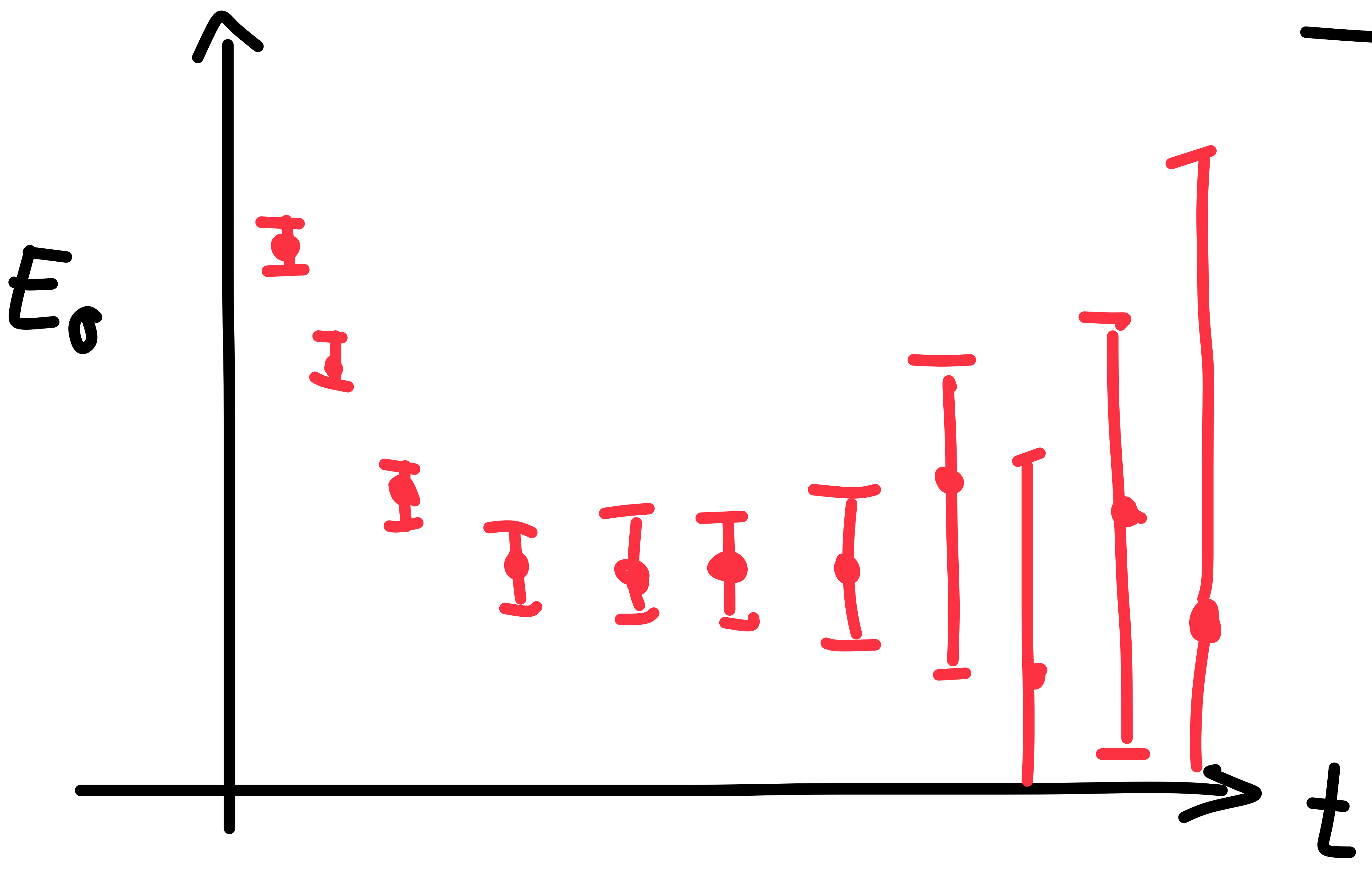
Lattice Spectroscopy

Lattice spectroscopy

$$C(t) = \langle \mathcal{O}(t)\, \mathcal{O}(0) \rangle = \sum_n |\langle 0 | \mathcal{O}(0) | n \rangle|^2 e^{-E_n t}$$

$$\xrightarrow{t \gg 1} |\langle 0 | \mathcal{O}(0) | 1 \rangle|^2 e^{-E_0 t}$$

EUCLIDEAN



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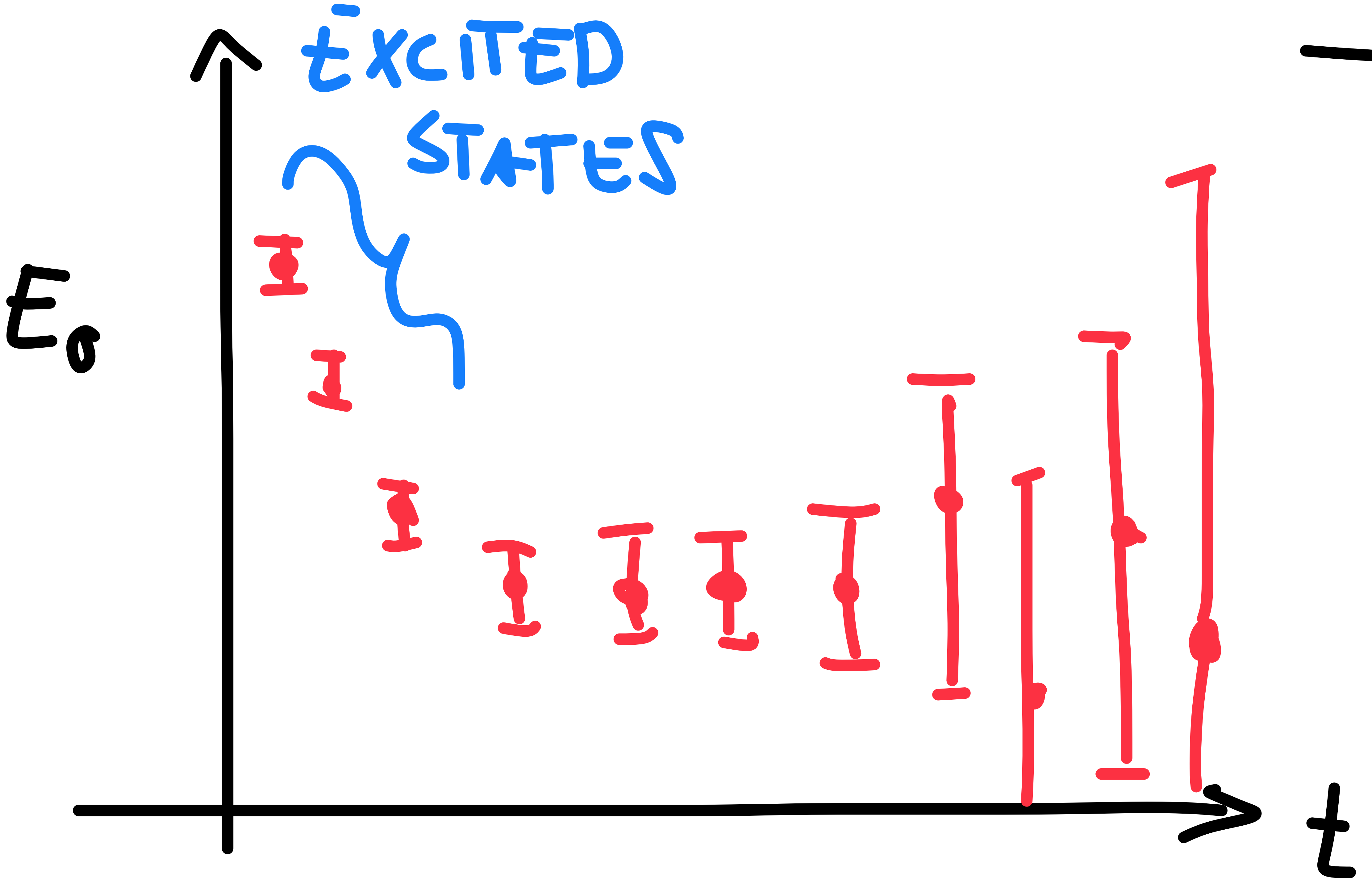

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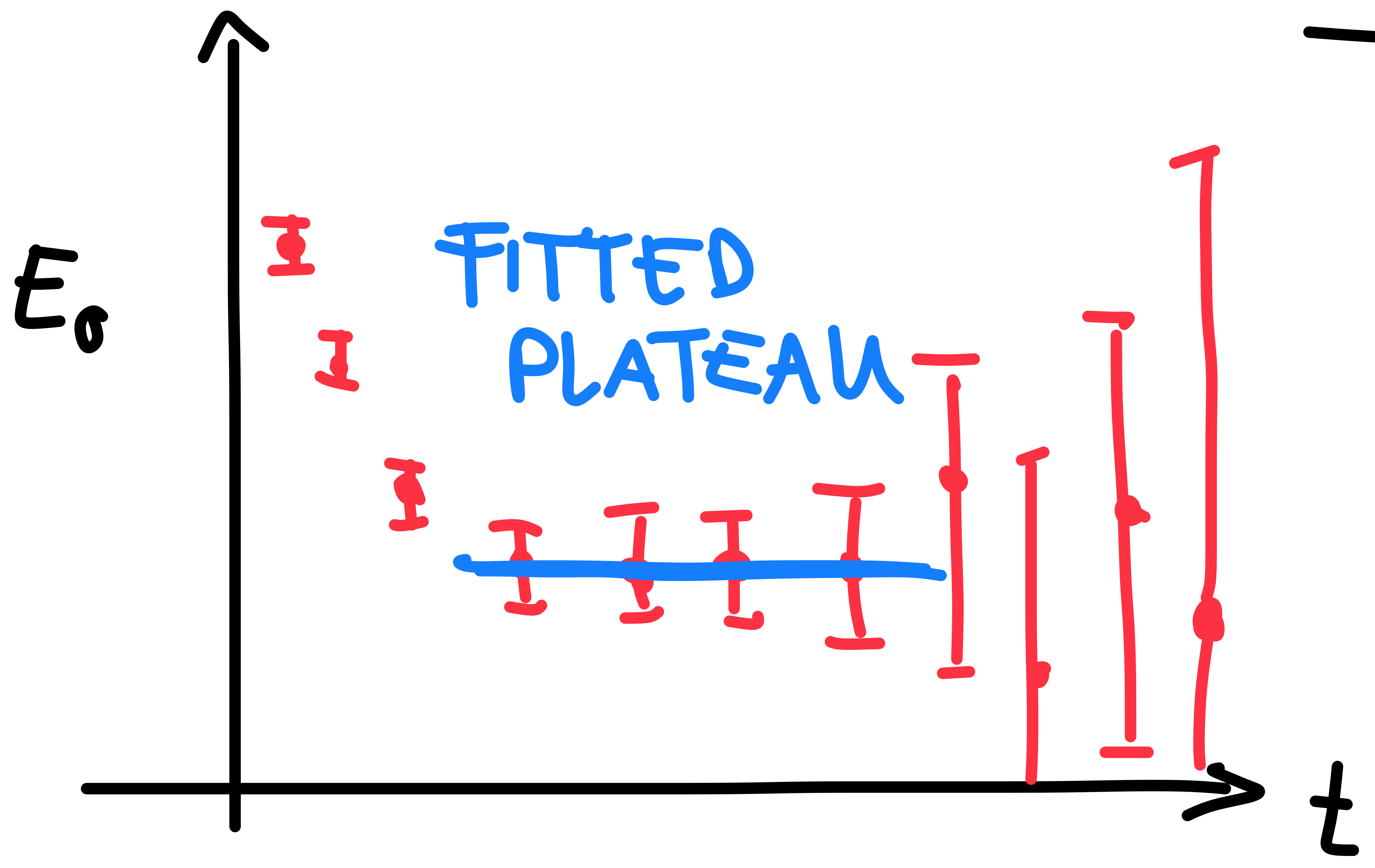

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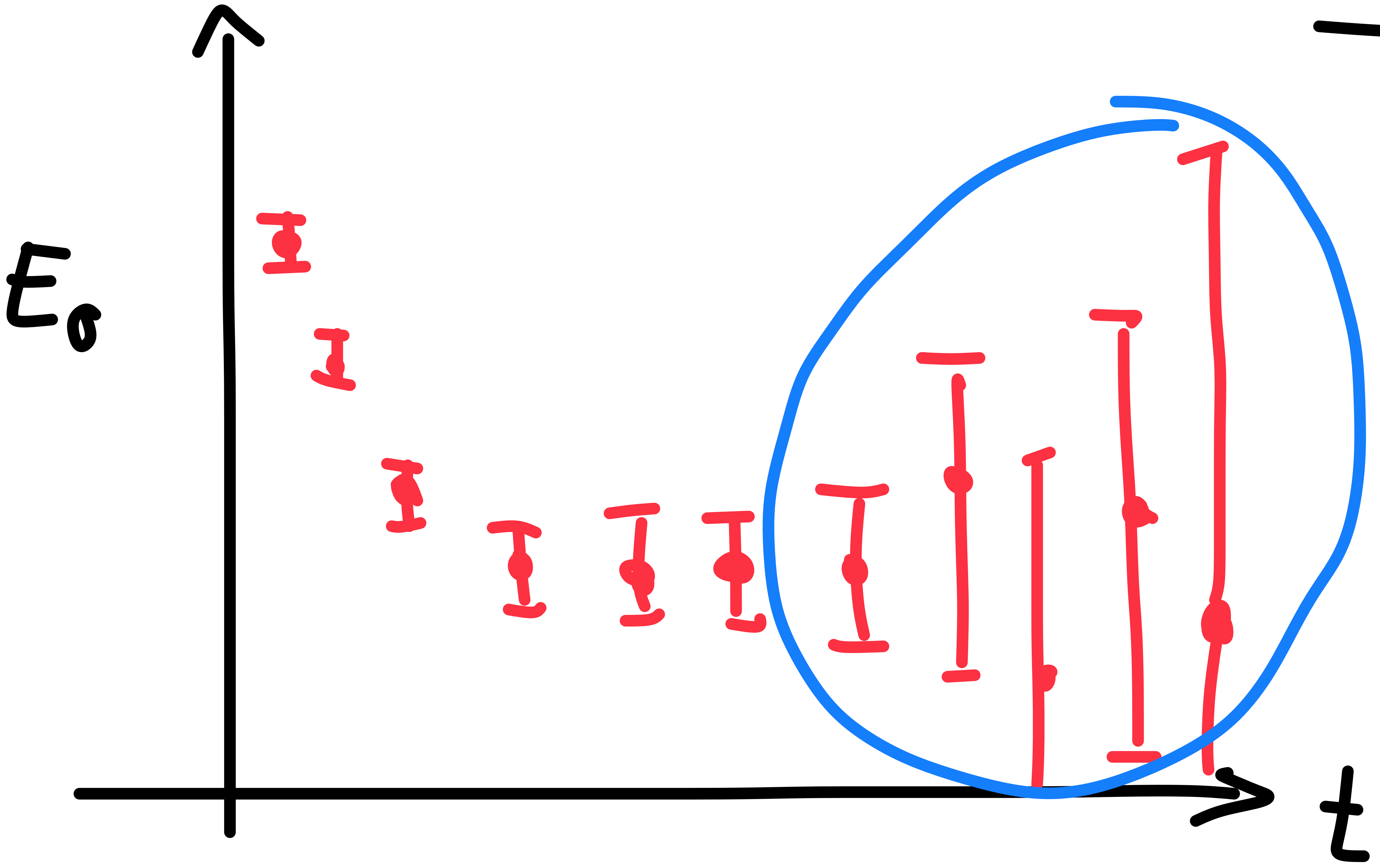
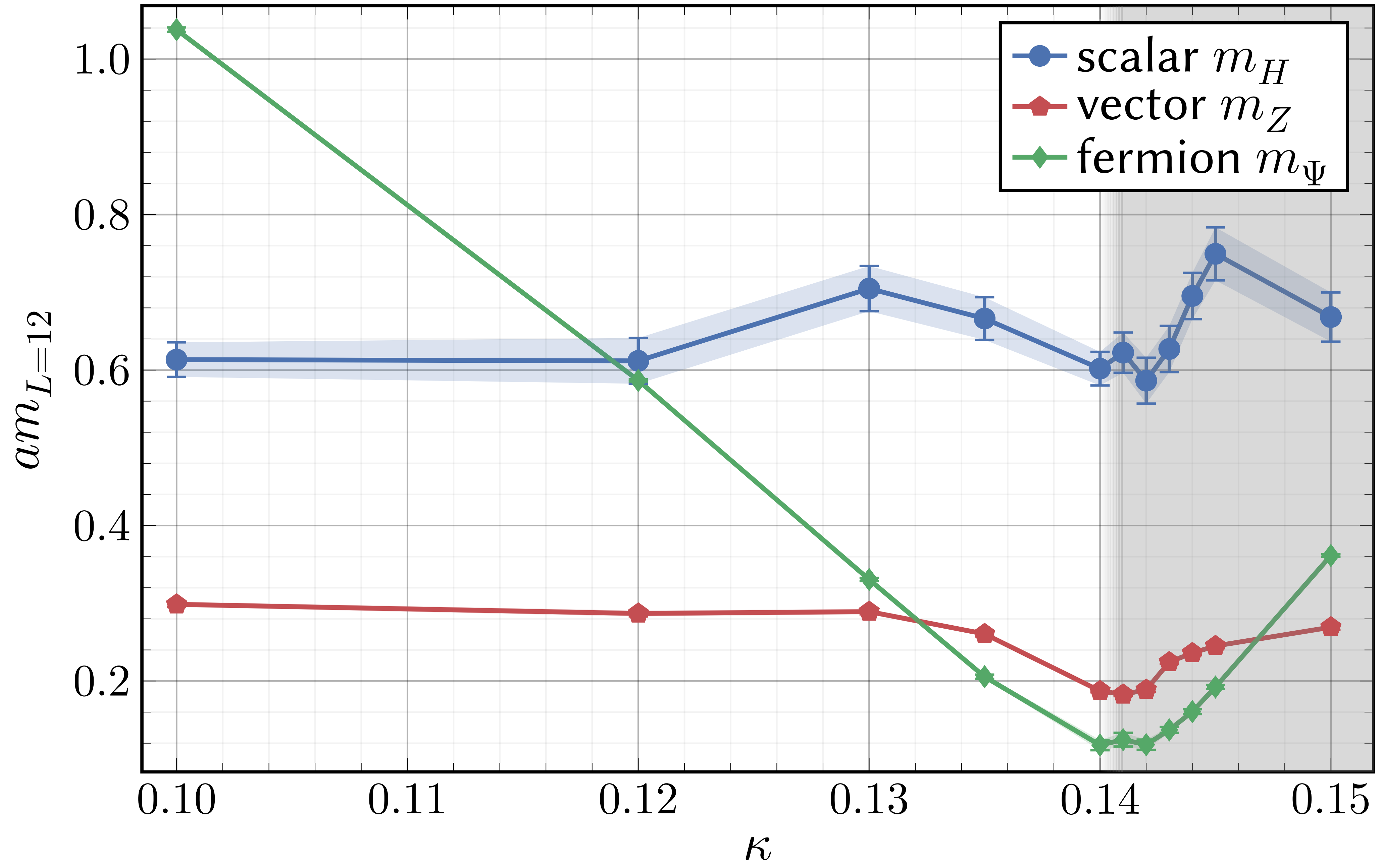


NOISE/
SIGNAL DEGRADATION

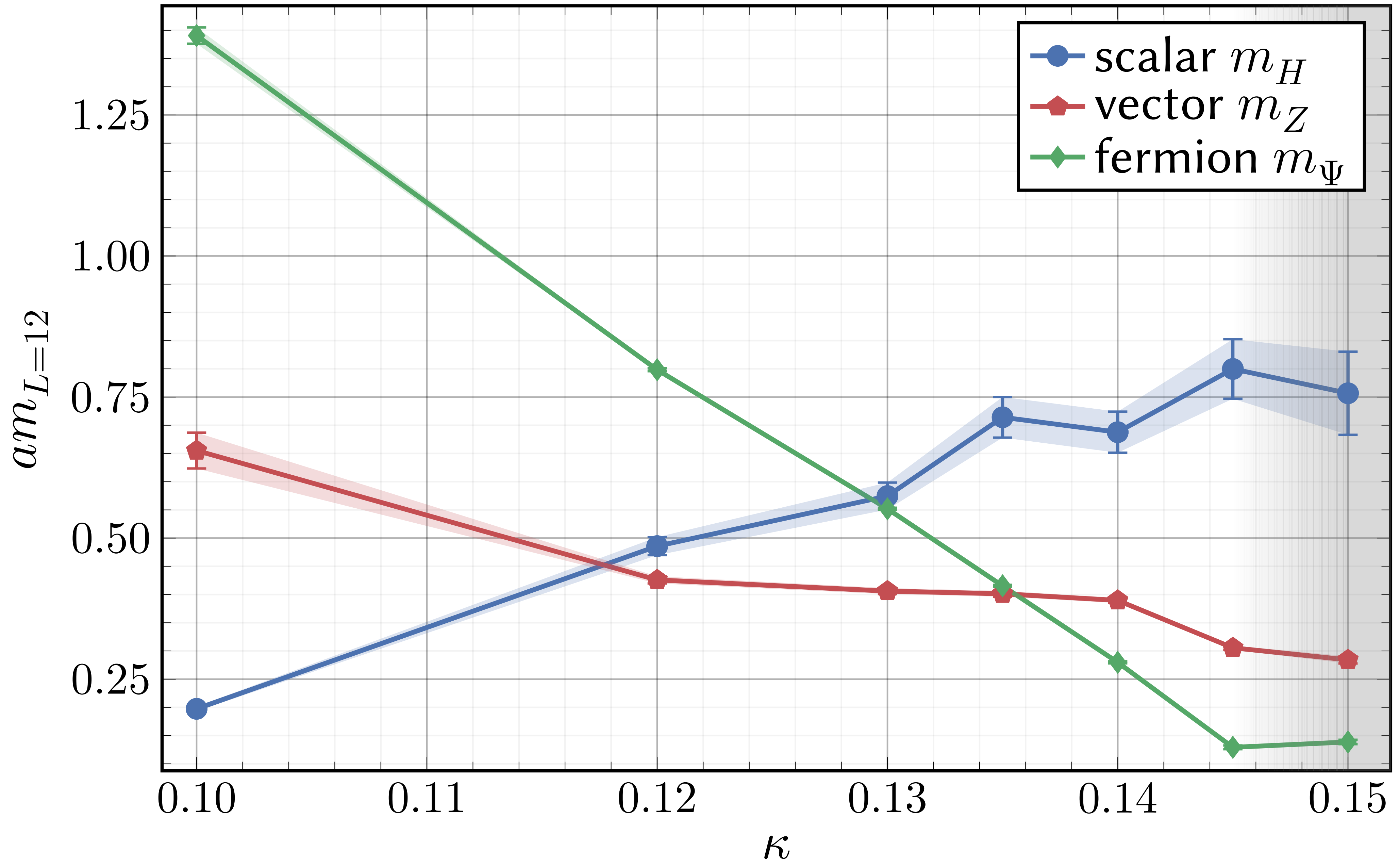
Parameter Regions

Phase space, without GEVP, future precision will be increased



Higgs-like region

stable Higgs
Scalar = Higgs much heavier than vector = W/Z



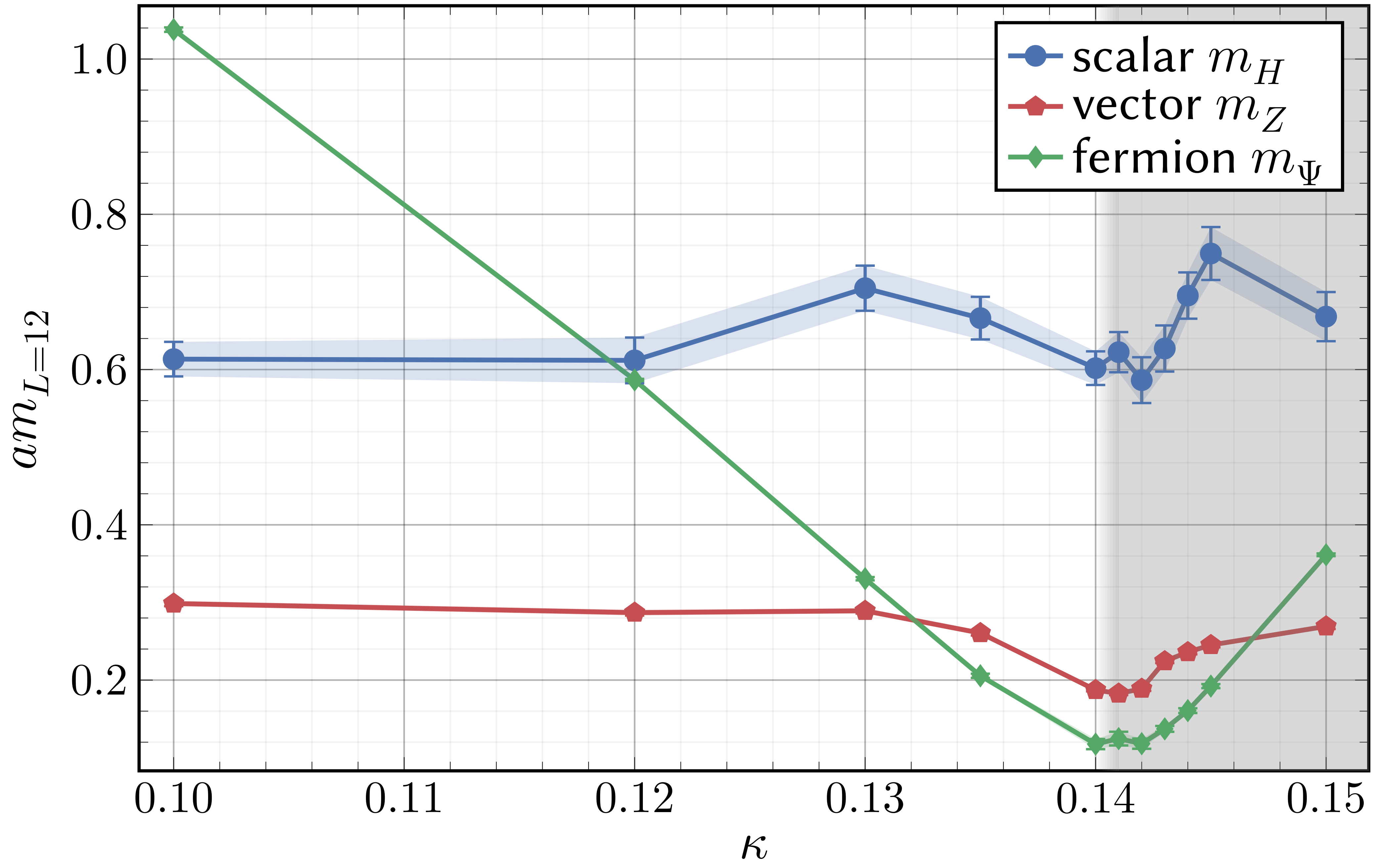
QCD-like region

inverted mass hierarchy with vector heavier than scalar

[Wieland, Maas, PoS, 2025]

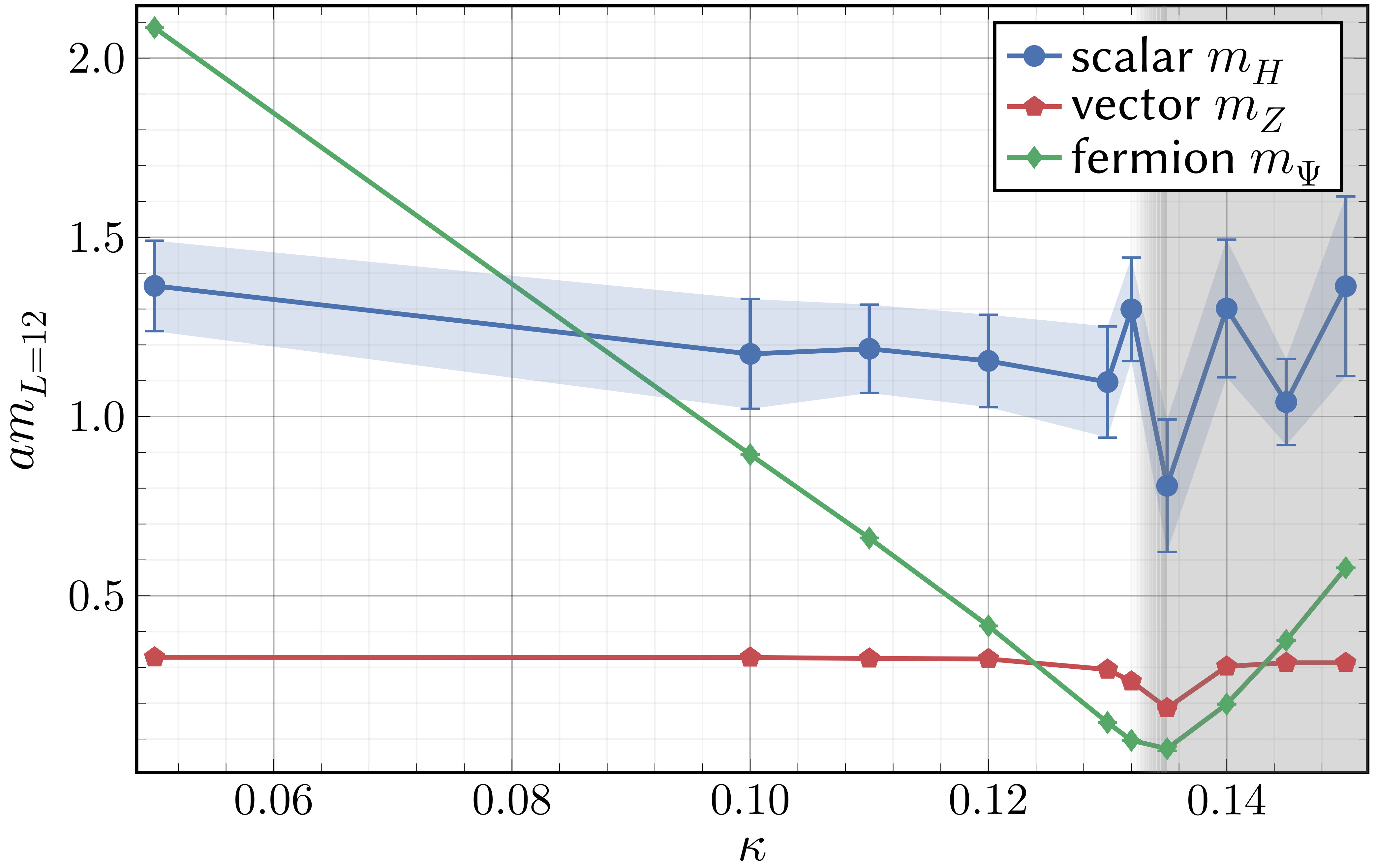
Parameter Regions

Phase space, without GEVP, future precision will be increased



Stable Higgs

Scalar = Higgs much heavier than vector = W/Z



Unstable Higgs

inverted mass hierarchy with vector heavier than scalar

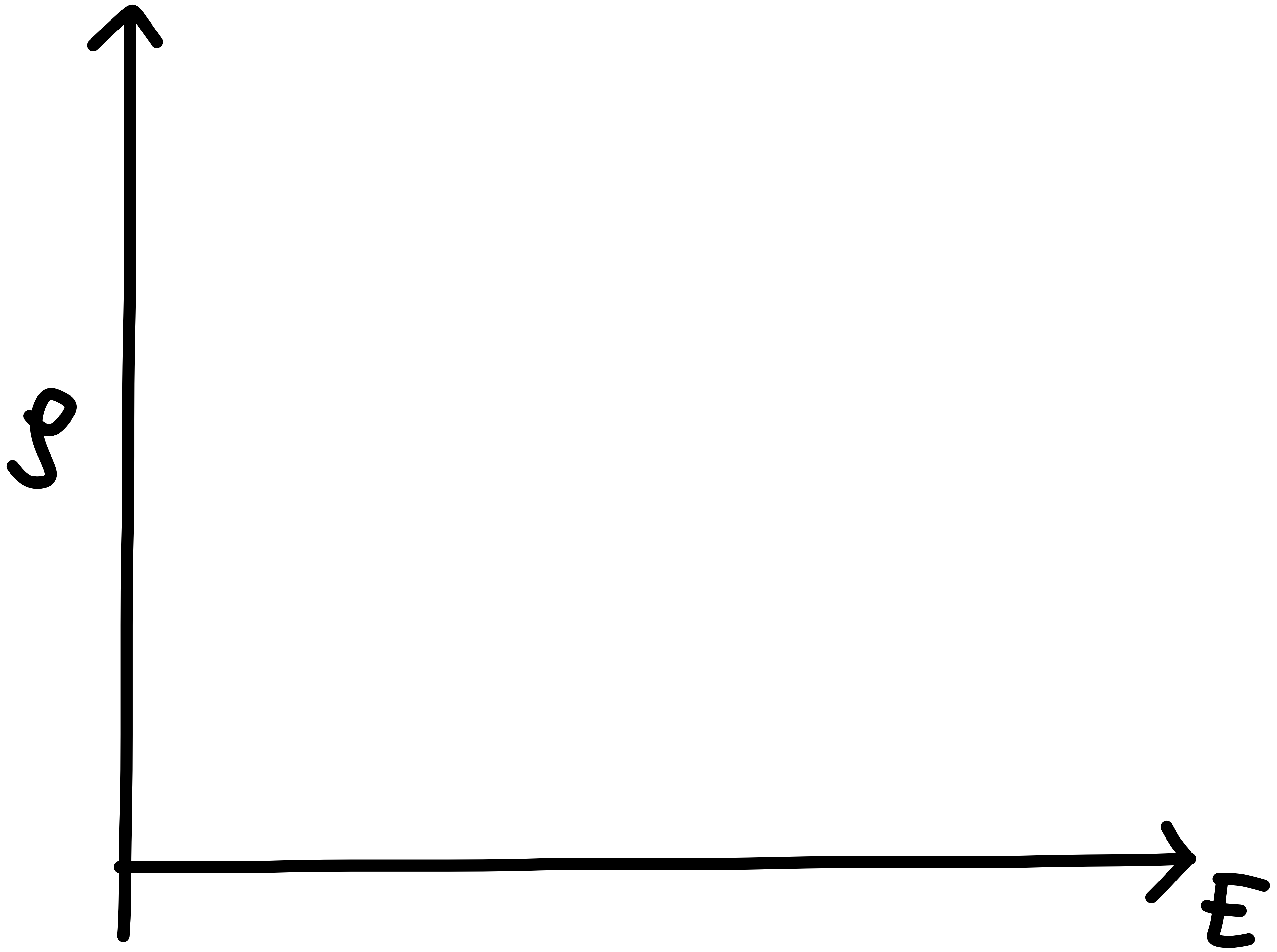
[Wieland, Maas, PoS, 2025]

Spectral densities

Backus Gilbert Approach

[Backus, Gilbert, 1968 & 1970]

Continuum



Lattice / Finite Volume

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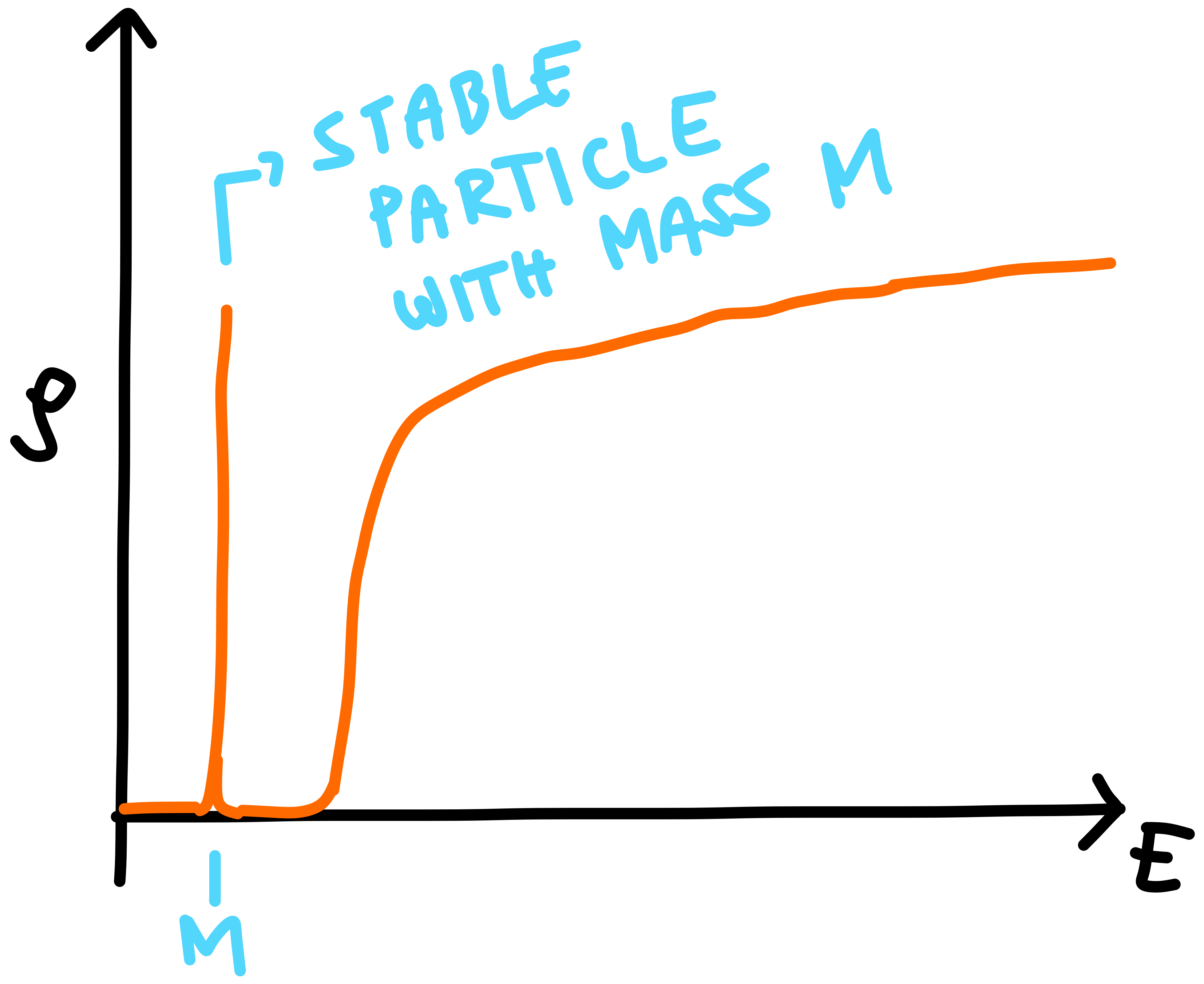
[Backus, Gilbert, 1968 & 1970]



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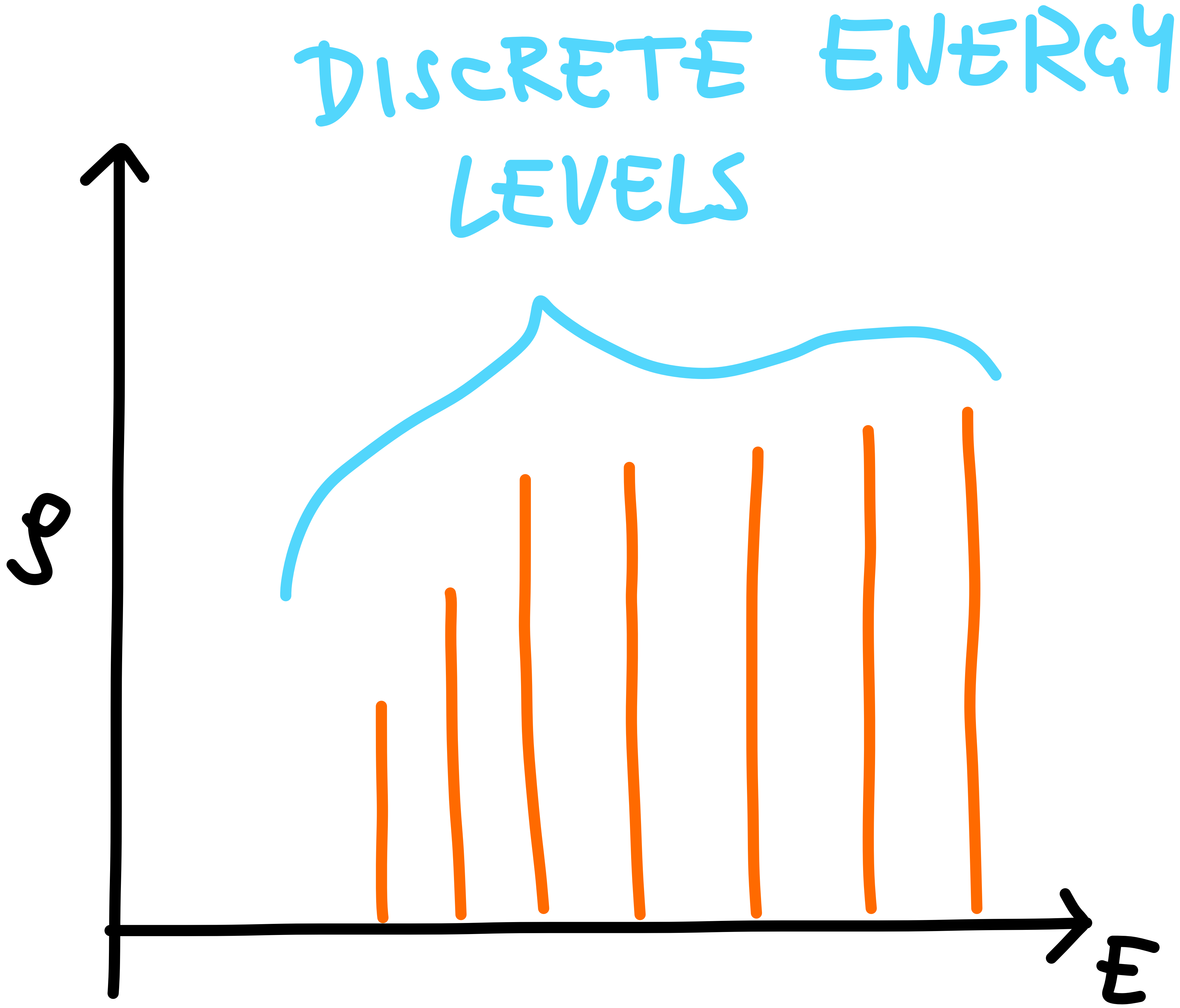

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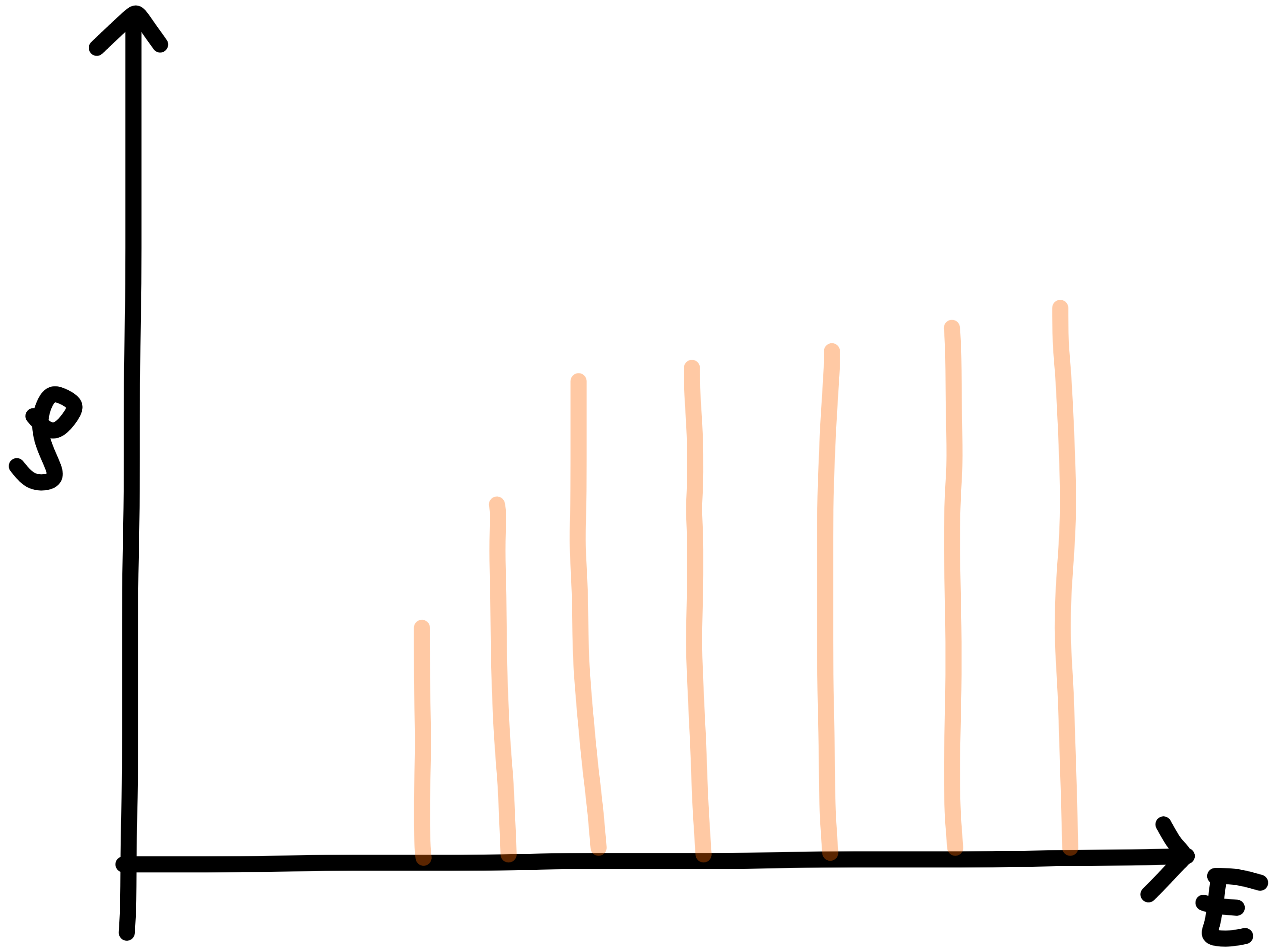

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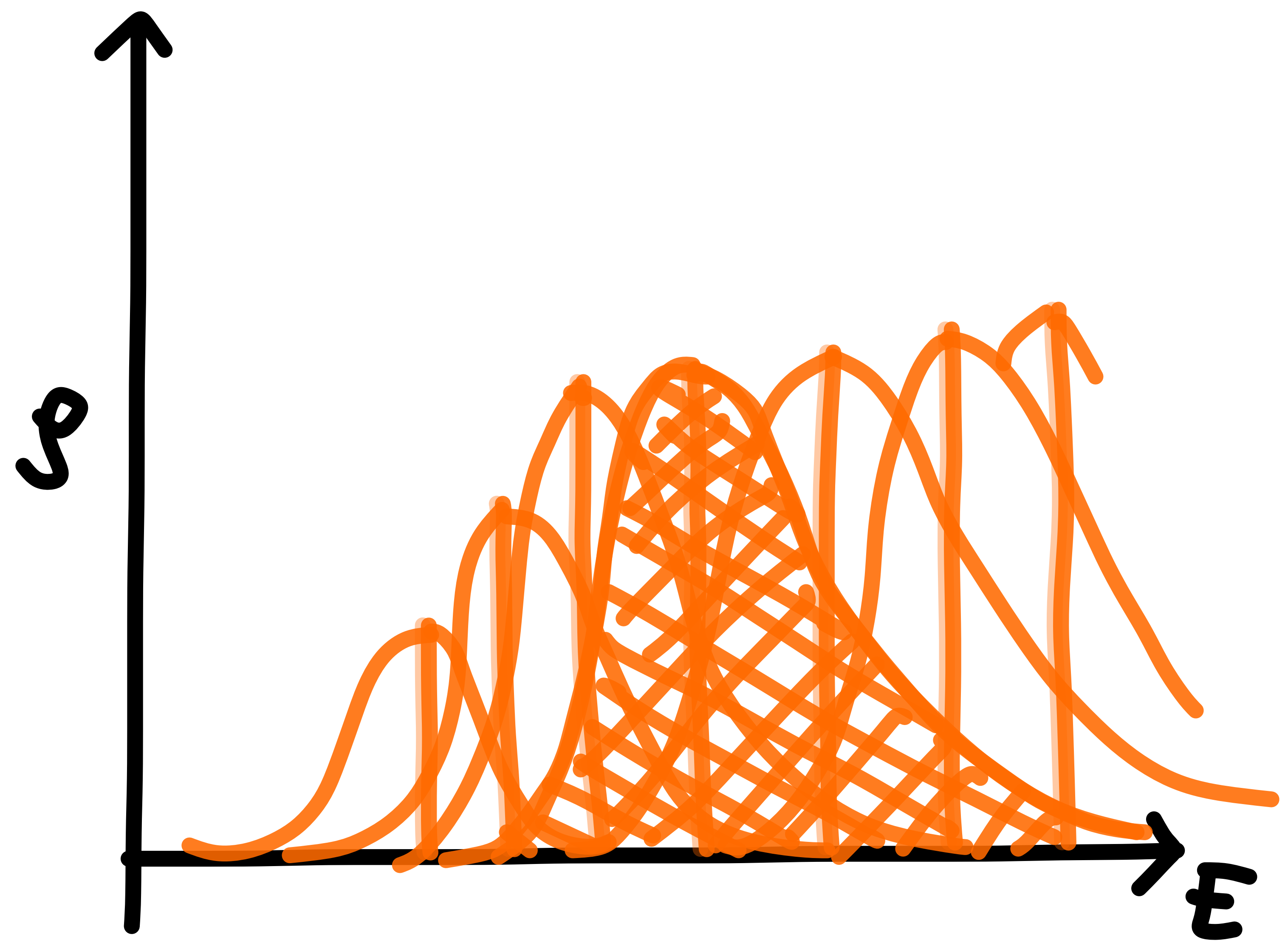


Backus Gilbert Approach

[Backus, Gilbert, 1968 & 1970]

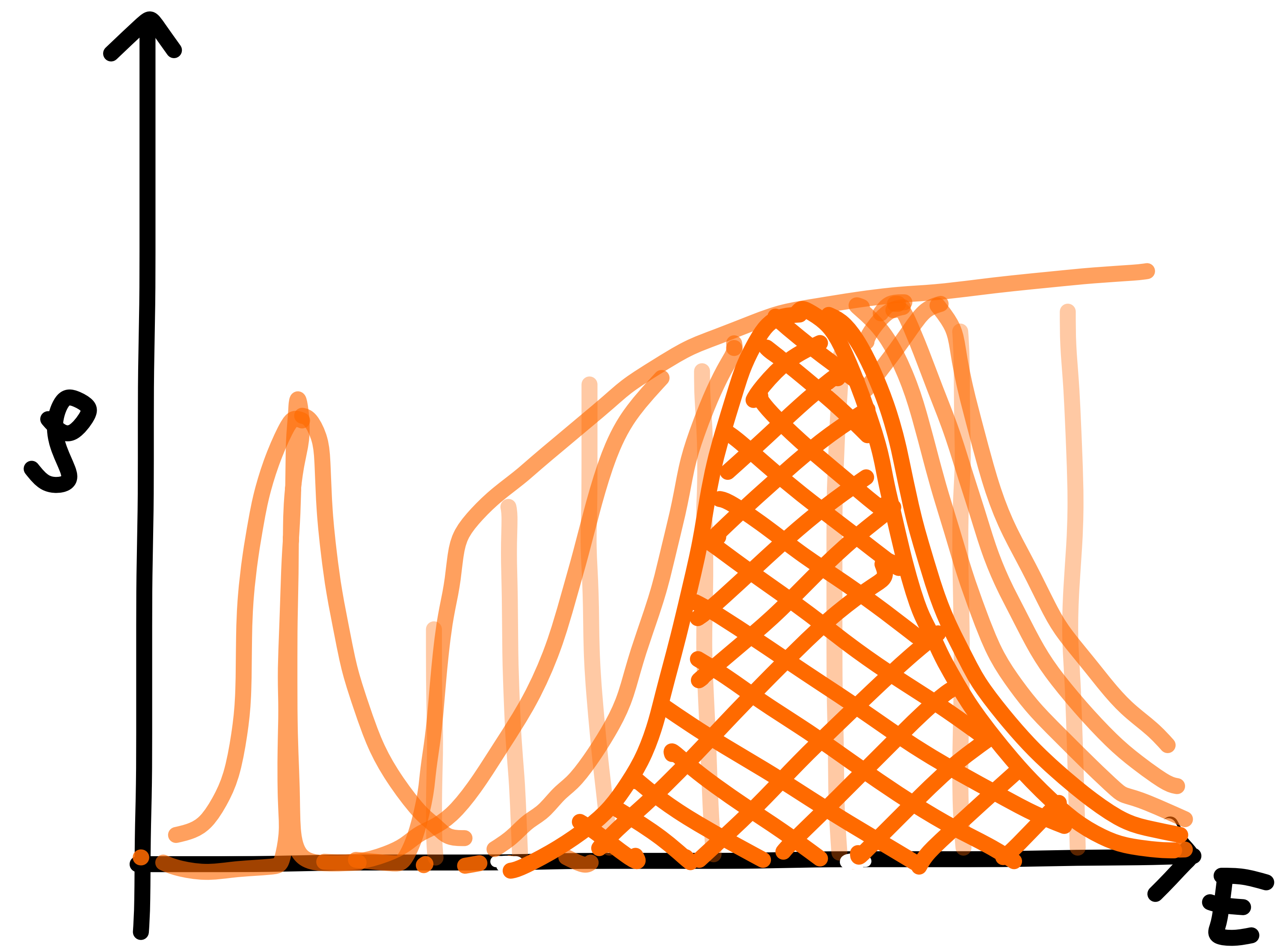
Smearing

$$\hat{\rho}_L(\sigma, E_*) = \int_0^\infty dE\, \Delta_\sigma(E_*, E)\, \rho_L(E)$$

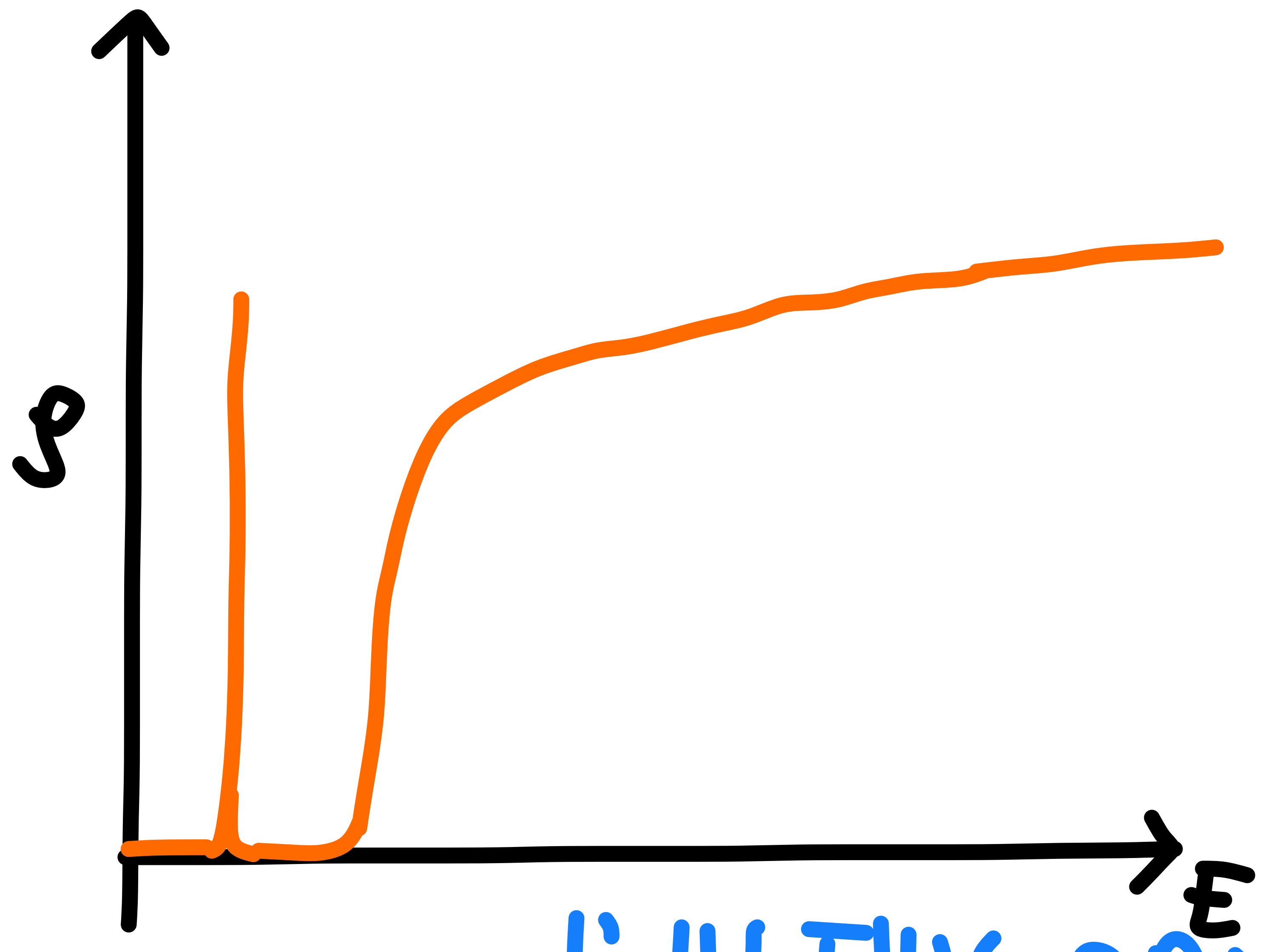
Backus Gilbert Approach

[Backus, Gilbert, 1968 & 1970]

Smearing



$\sigma \to 0$



$$\lim_{L\to\infty} \hat{\rho}_L(\sigma, E_*)$$

!! IN THIS ORDER !!

$$\rho(E_*) = \lim_{\sigma\to 0}\lim_{L\to\infty} \hat{\rho}_L(\sigma, E_*)$$

[Hansen et. al, 2019

Hansen-Lupo-Tantalo Method

Expand kernel in functional basis preserving backpropagation

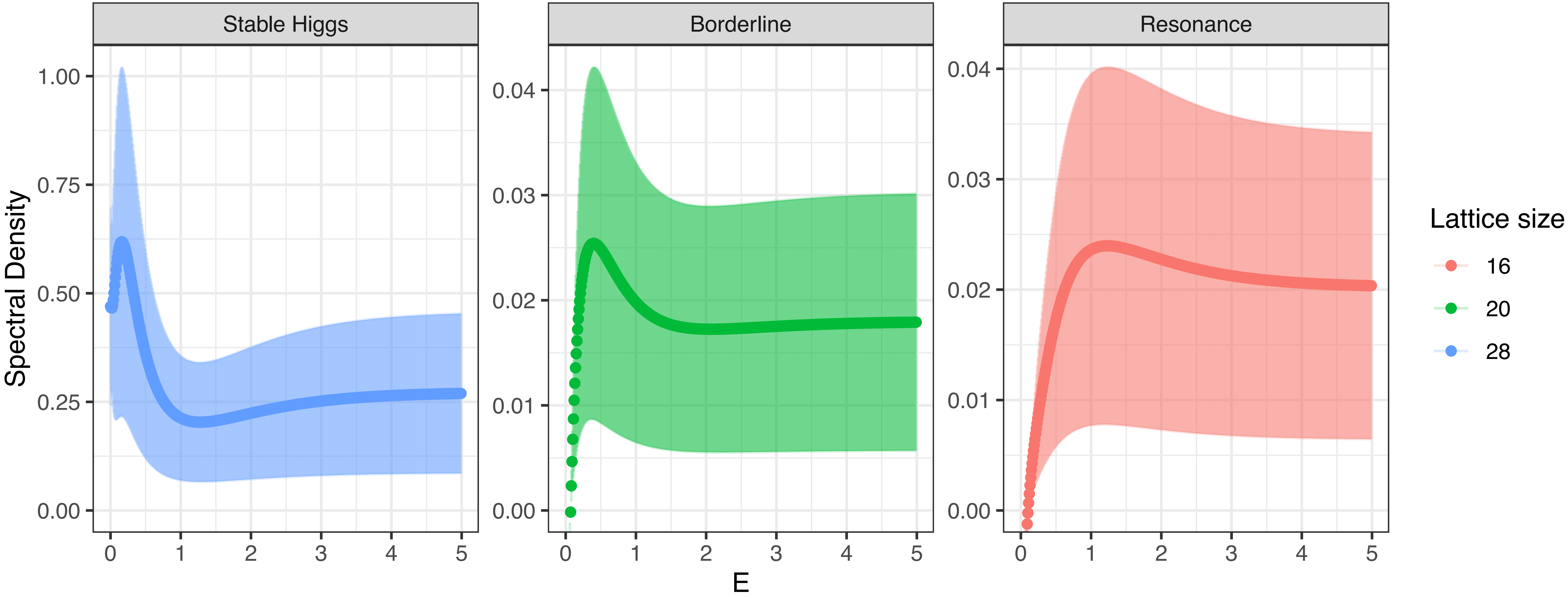
$$\Delta(E_*,E) = \sum_{t=0}^{1} g_t(E_*)\left[e^{-tE} + e^{-(T-t)E}\right]$$

Balance systematic and statistical uncertainties

$$[g] = \int_{E_0}^{\infty} dE \left|\bar{\Delta}_\sigma(E_*,E) - \Delta_\sigma(E_*,E)\right|^2 \qquad \frac{\mathrm{Var}(C(t))}{C^2(0)}$$

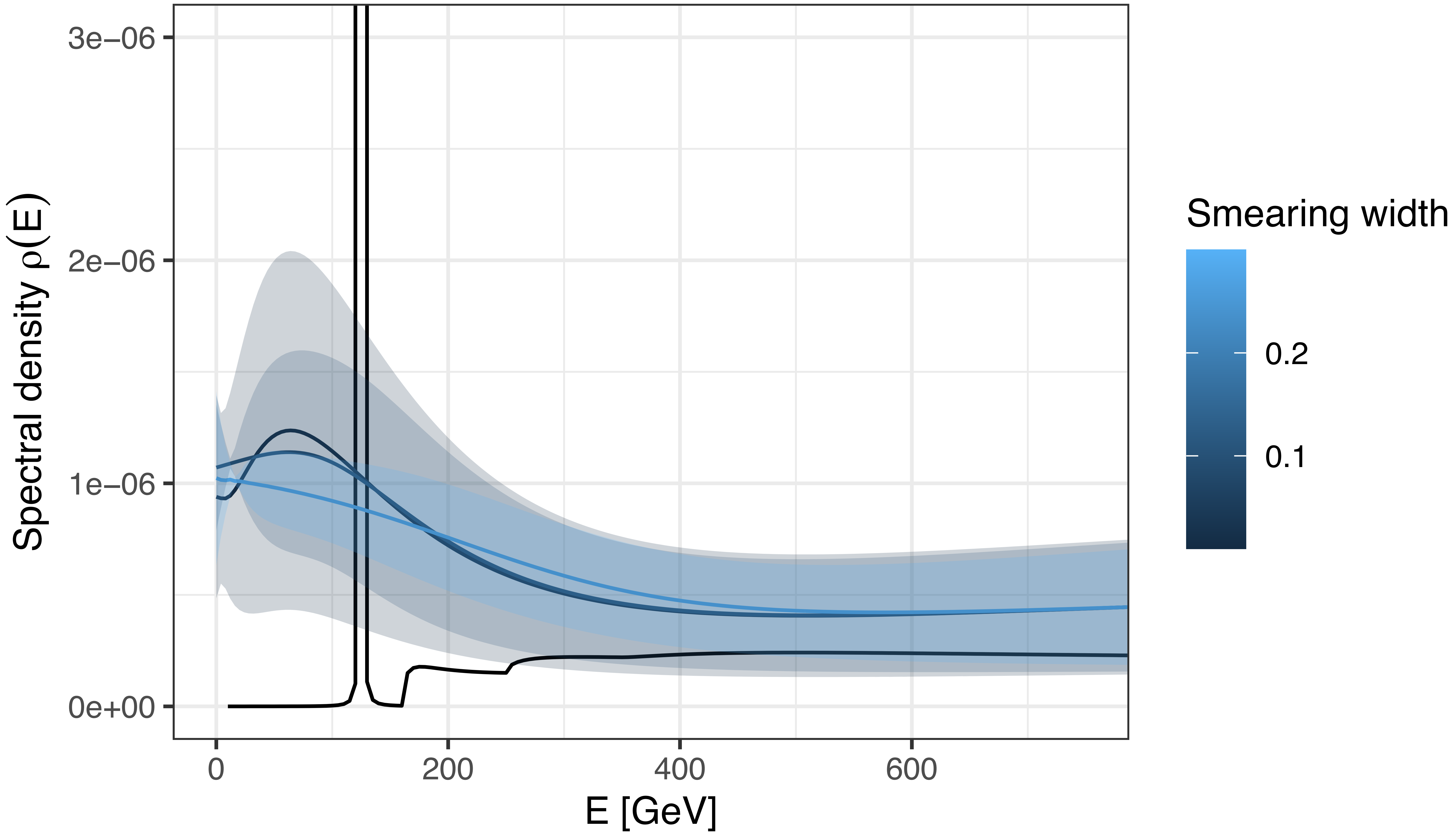
Spectral Density Functions

Obtained using HLT



Technique: [Hansen, Lupo, Tantalo, Phys. Rev. D, 2019, 1903.06476]

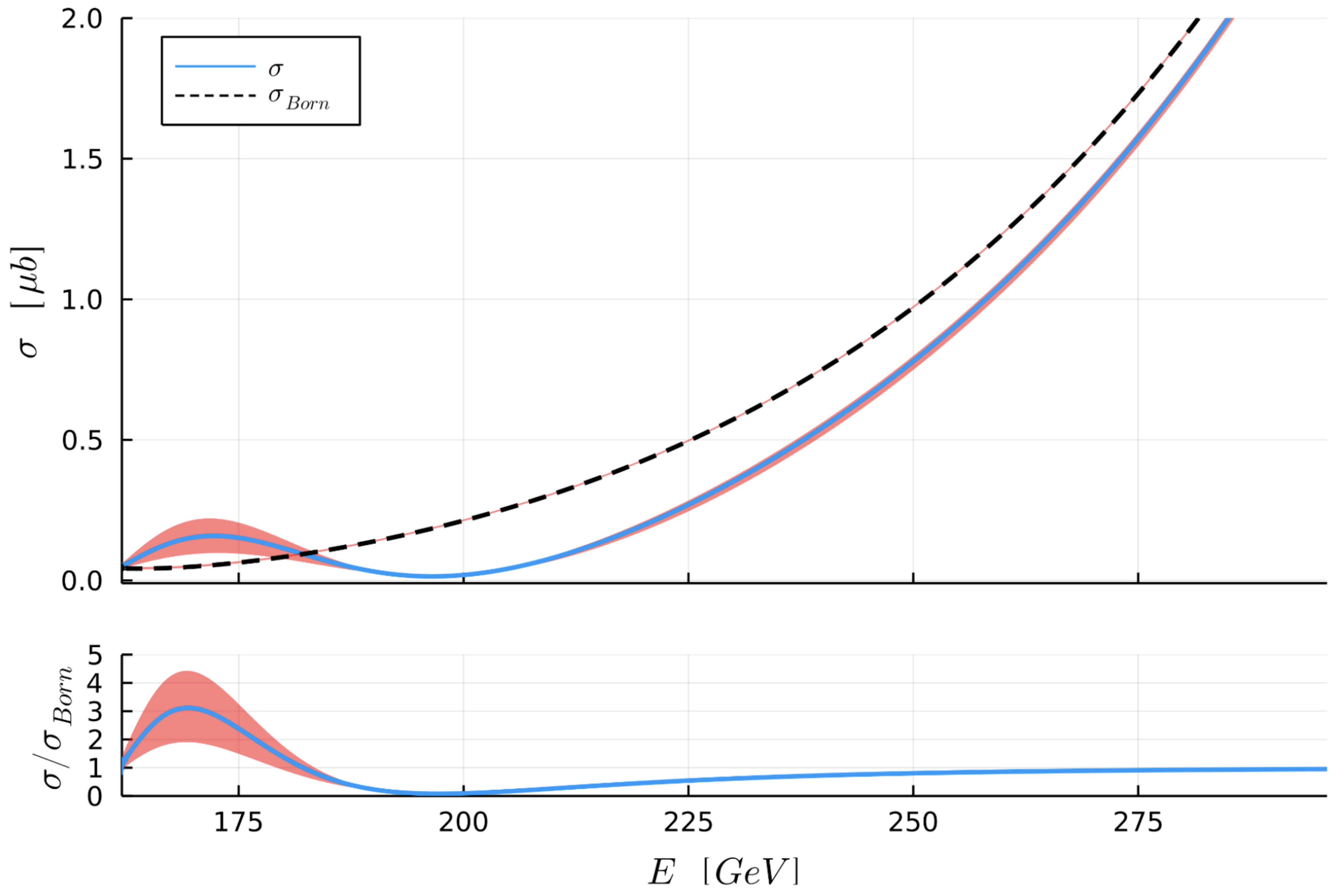
Stable Higgs: Lattice vs. analytic

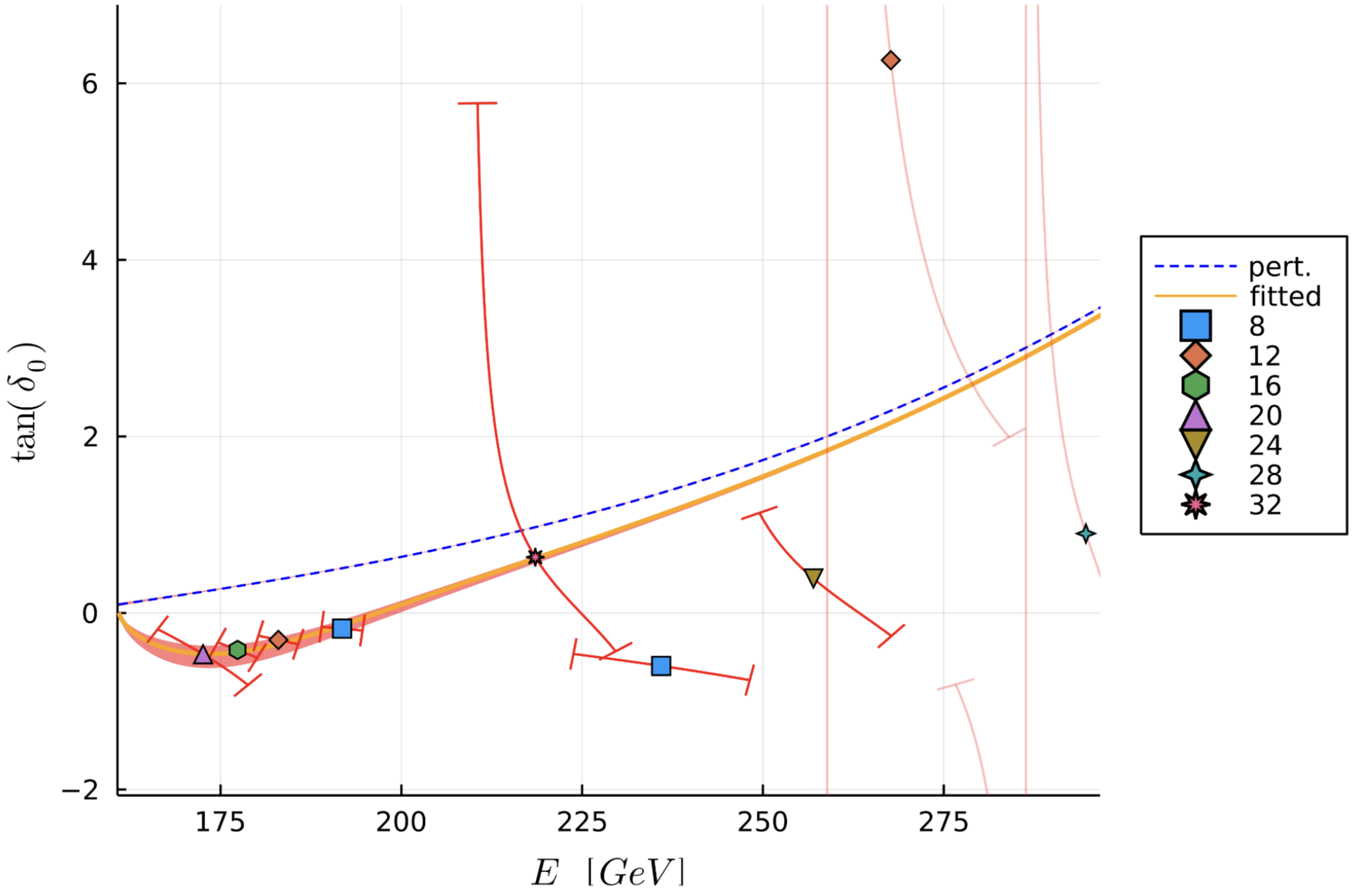


Predictions for cross-sections of Higgs and Vector Boson Scattering

Exclusive Decay Rates

Phenomenology predicts measurable differences in $ZZ \to H \to ZZ$

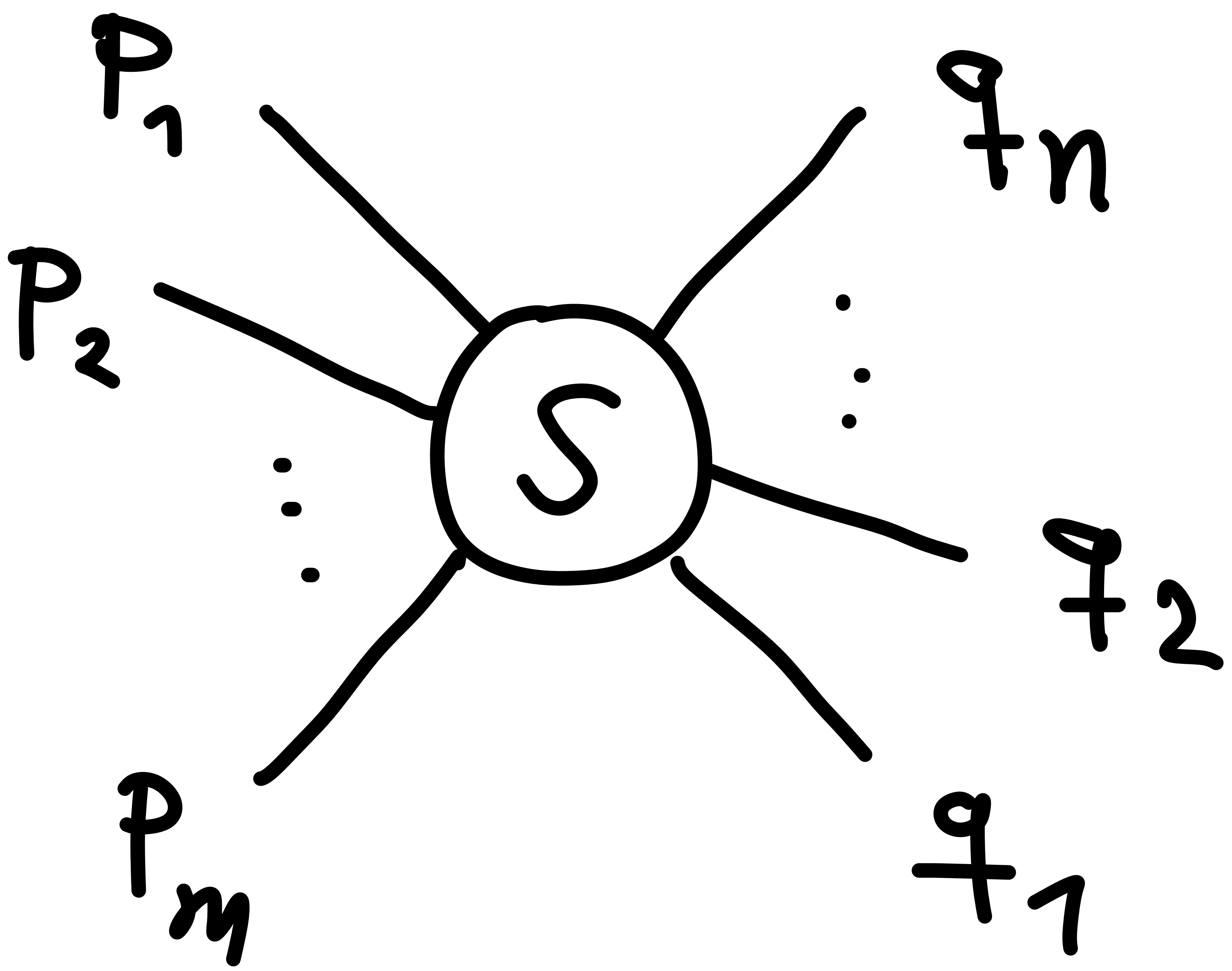




- Expected deviations @ O(100 GeV)
- Avoid mistaking signal for BSM physics

Figures: [Jenny, Maas, Riederer, Phys. Rev. D, 2022, 2204.02756]

Computing a transition probability



$$\rightsquigarrow \quad P = \left|{}_{out}\langle \{p_f\} | \{q_i\} \rangle_{in}\right|^2$$

With definite momenta p_f and q_i

Physical theory encoded in S-Matrix

Bulava/Hansen method

[Bulava, Hansen, 2019]

m particles out, n particles in

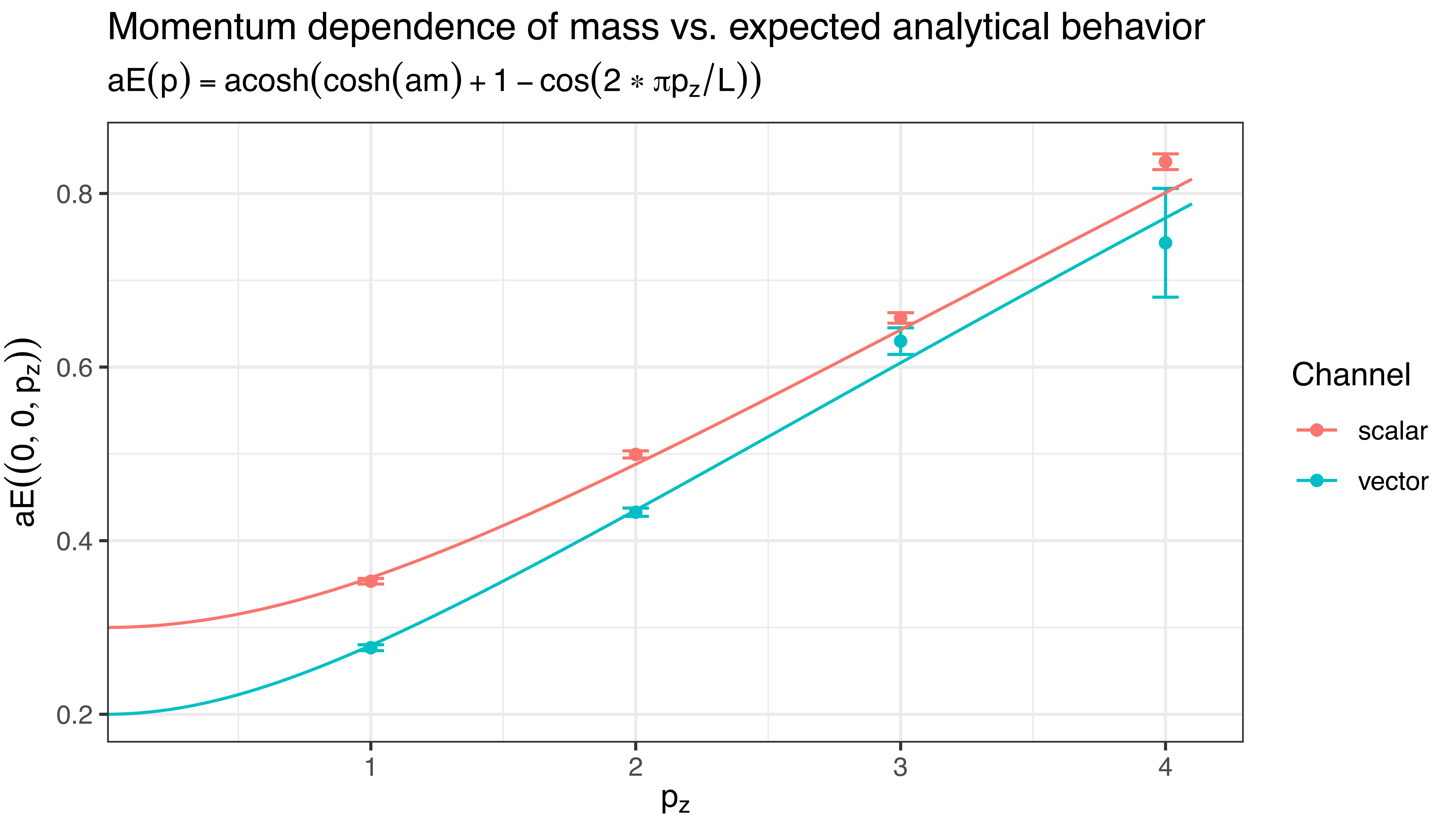
- Disassemble amplitude spectrally

$$i\mathcal{M}_c(\{p_f\}|\{q_i\}) \propto \rho_{p_m q_1}(\{p_f\}\backslash p_m, \{q_i\}\backslash q_1)$$

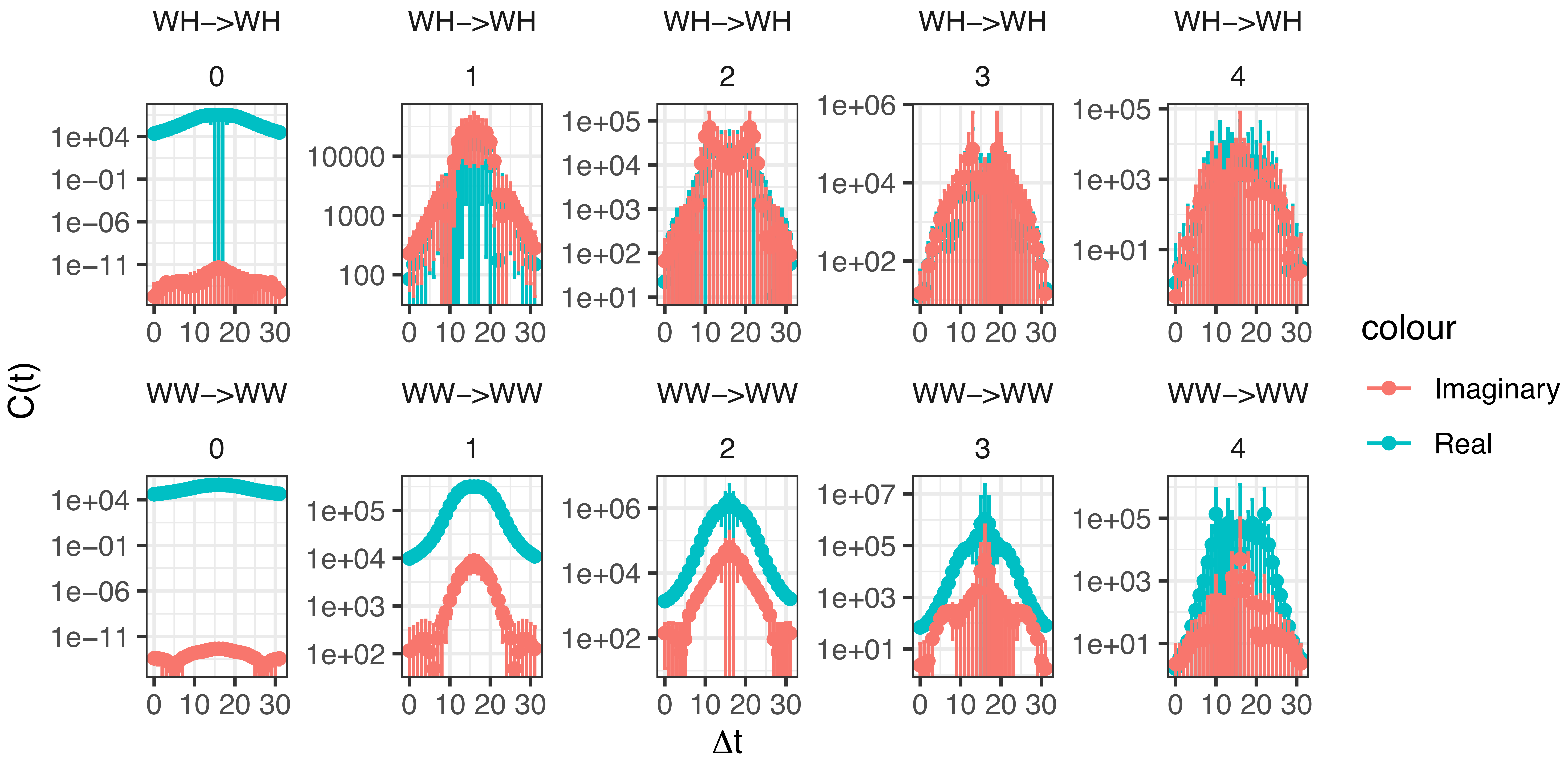
- Compute this spectral function by solving inverse problem

$$C_{p_m q_1}(\{p_f\}\backslash p_m, \{q_i\}\backslash q_1) = \int \frac{d^r E}{\pi^r} e^{-\sum E \Delta t} \rho_{p_m q_1}(\{p_f\}\backslash p_m, \{q_i\}\backslash q_1)$$

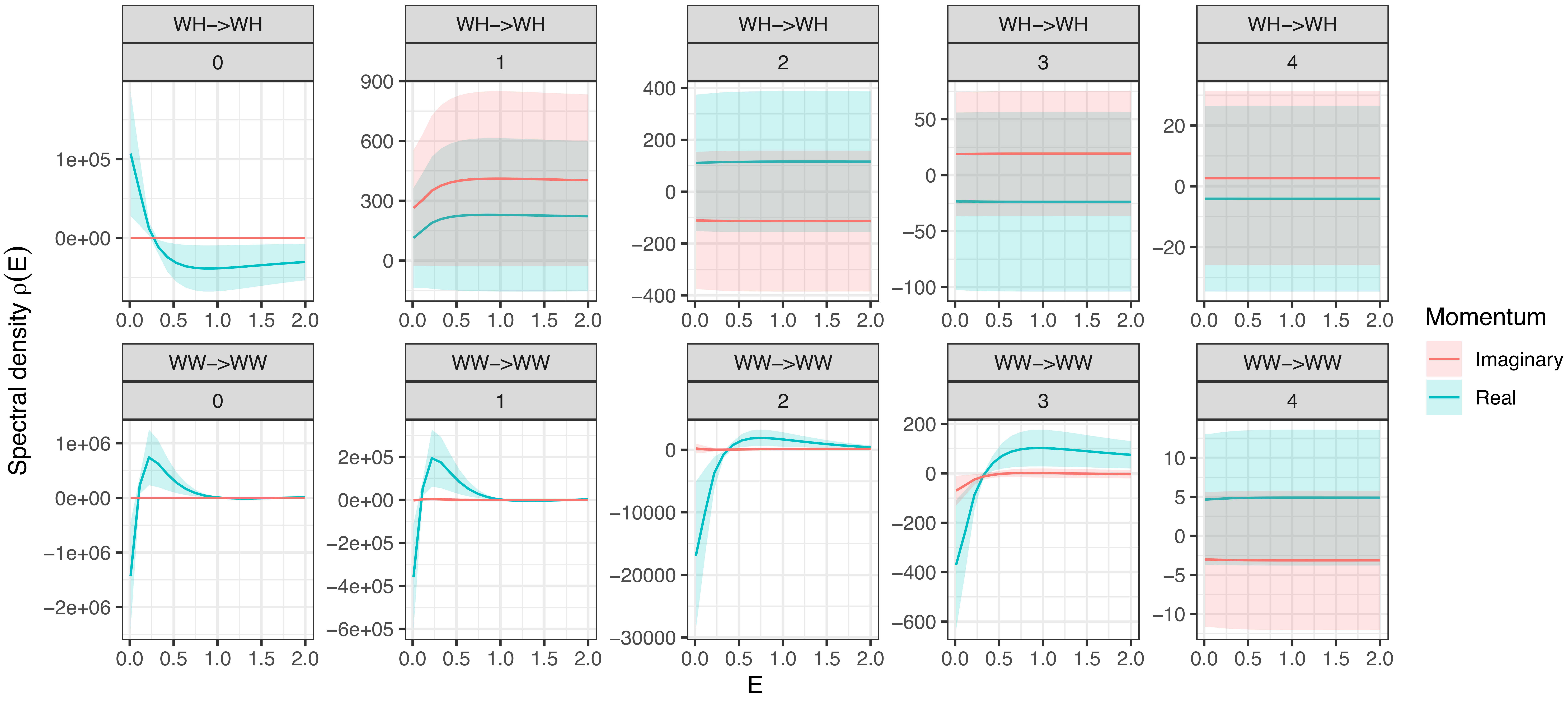
Dispersion relation



Ratio correlators



Matrix element spectral decomposition



Outlook

- Precision on spectral densities + extraction with other methods
- Higher momenta operators
- Yukawa couplings if we find excited states consistent with generations/flavors
- Mixing angles between exited leptonic states

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Thank you for your attention!