



FMS on the lattice

The structure of asymptotic states in weak physics (Part I)

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Quasi-PDFs from the lattice

- Lattice: no gauge fixing needed \rightarrow manifestly gauge-invariant calculations
- We cannot achieve the Bjorken limit (infinite momentum)
- Instead we use large but finite momenta

$$\tilde{q}(x, P_3) = \int_{-\infty}^{\infty} \frac{dz}{4\pi} e^{-izxP_3} \langle p | F(z) | p \rangle$$

discretized lattice momenta

gauge-invariant operators

probe current for 0^+ or 1^- channel

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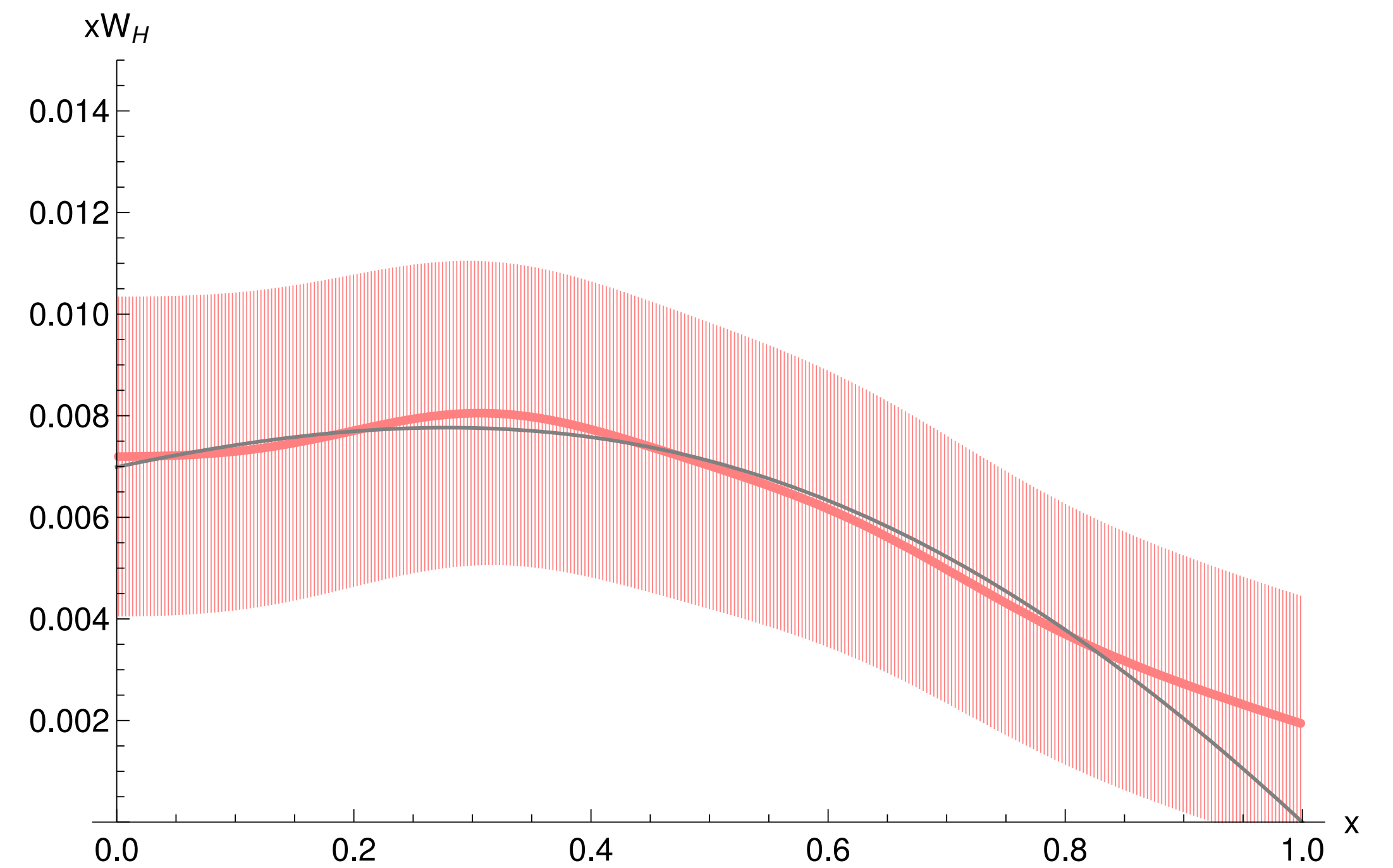
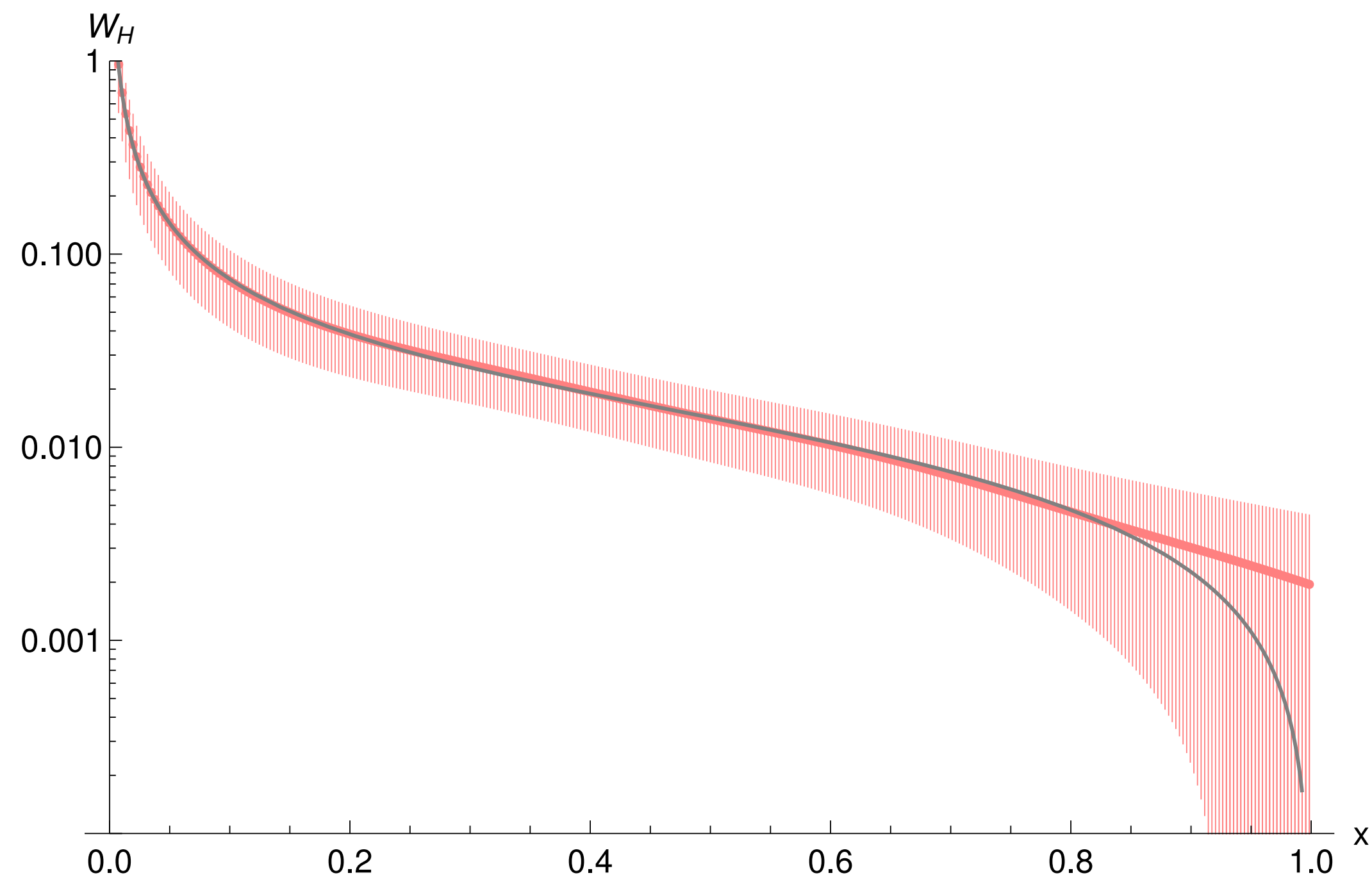
$$q(x) = \tilde{q}(x, P_3) + \mathcal{O}\left(\frac{\alpha}{2\pi}\right)$$

QCD: strong effect

weak physics: better control

W boson PDF from the lattice

For large P_3 and $L = 28$



W boson PDF from the lattice

Fit for large P_3

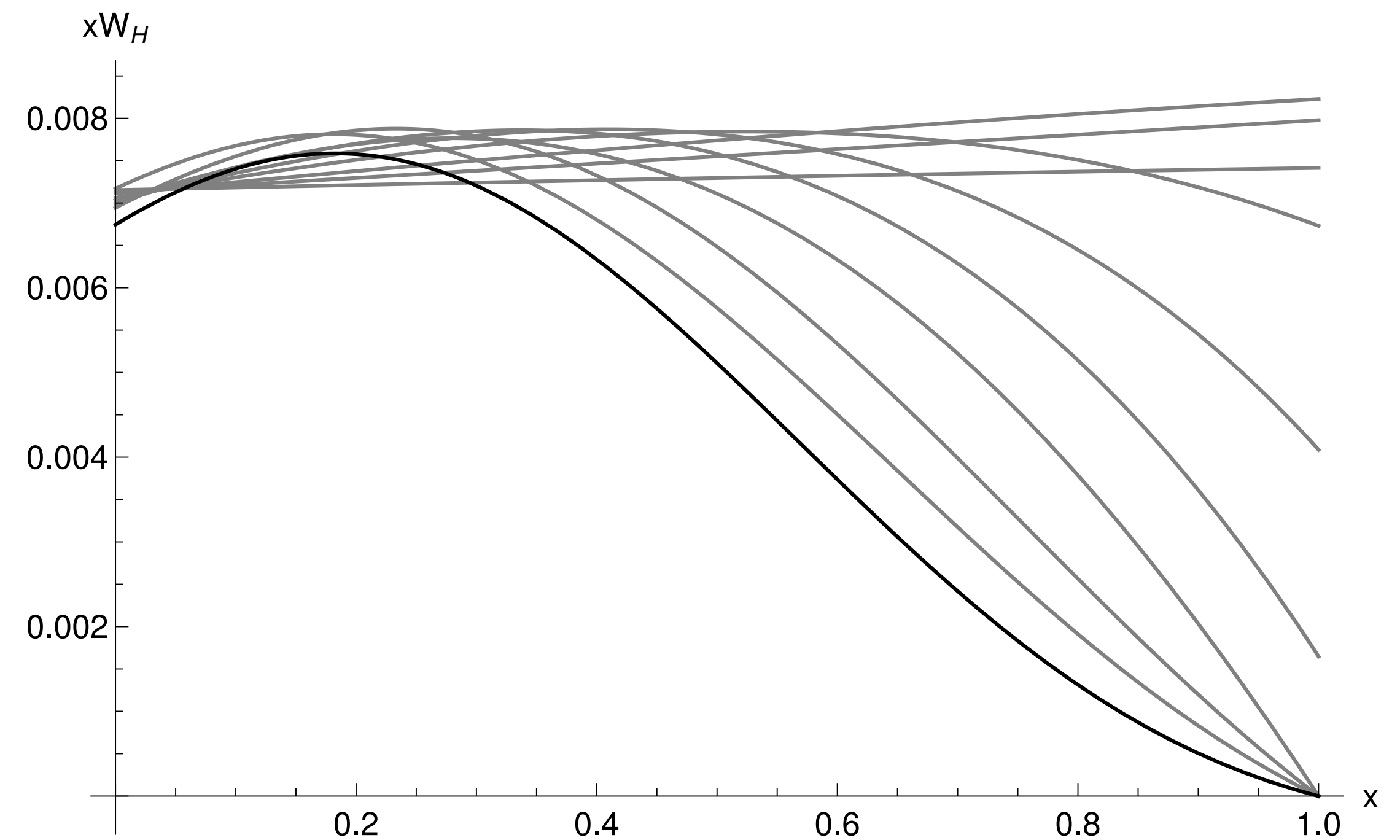
- Shows the internal structure of the physical state

$$xW_H \approx c_1 e^{c_2(x_1+x)^2} (x_2 - x)$$

- Generic form is compatible with results from phenomenology

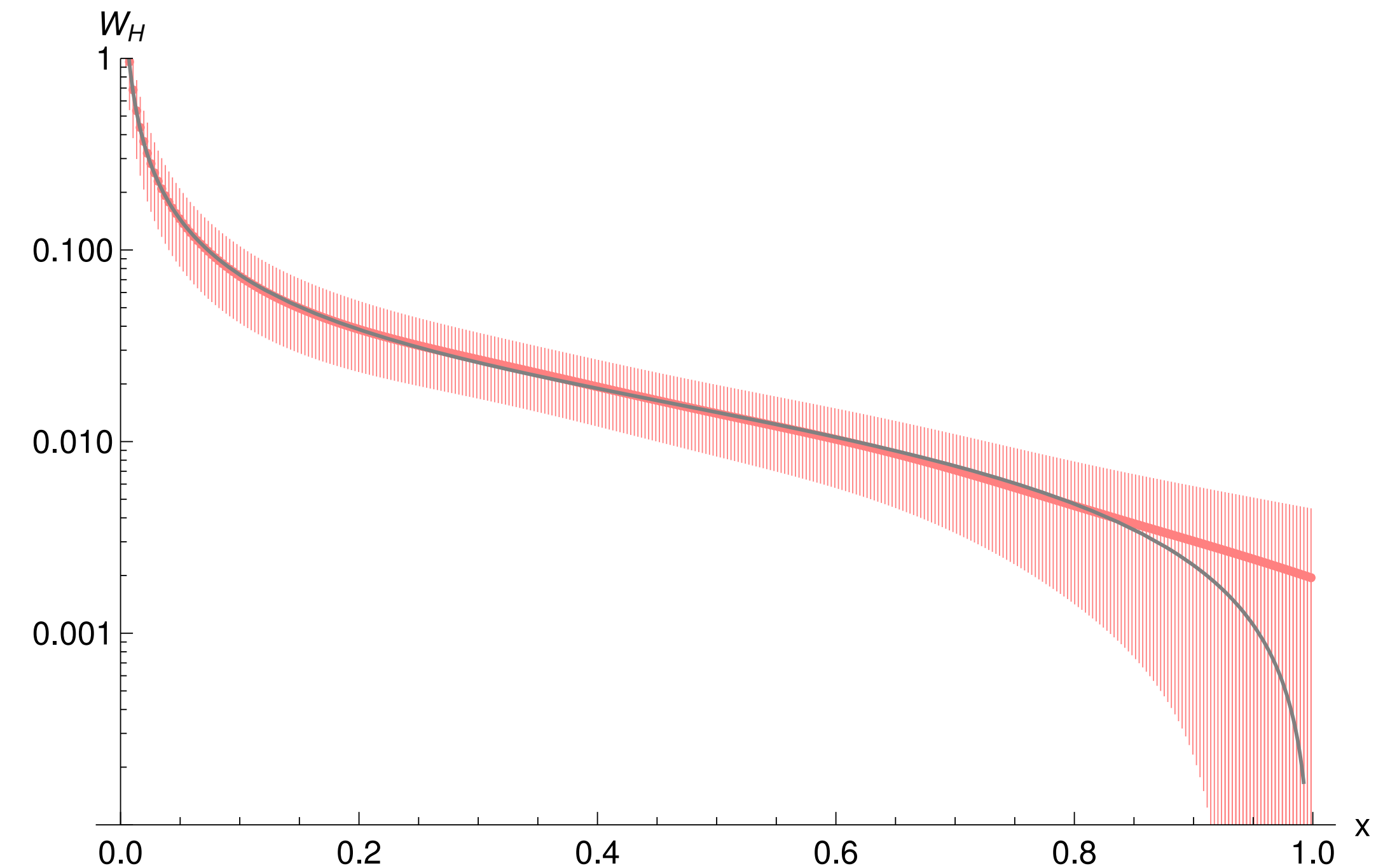
Fernbach et al., Phys. Rev. D 101 (2020), 2002.01688

Evolution of fits to larger momenta



Internal structure of W and Higgs?

- PDFs contain information about the **internal structure** of gauge-invariant operators
- Repeating our calculations with W and Higgs would yield zero or a delta depending on the PDF type
 - **W and Higgs not gauge-invariant**
- **QCD:** asymptotic states are color-singlets (protons, neutrons) and elementary states (quarks, gluons) are unphysical



Weak physics and its challenges

- The standard perturbative approach to Higgs physics has some problems
 - **Elitzur's theorem:** gauge symmetry can never be spontaneously broken
 - **Gribov copies:** explicitly breaks the perturbative BRST construction
 - **Gauge-dependent construction:** the vev and the W mass depend on the gauge choice
- How to avoid these problems?
 - Asymptotic states must be described by gauge-invariant objects
 - Composite operators with the same global quantum numbers as the elementary fields

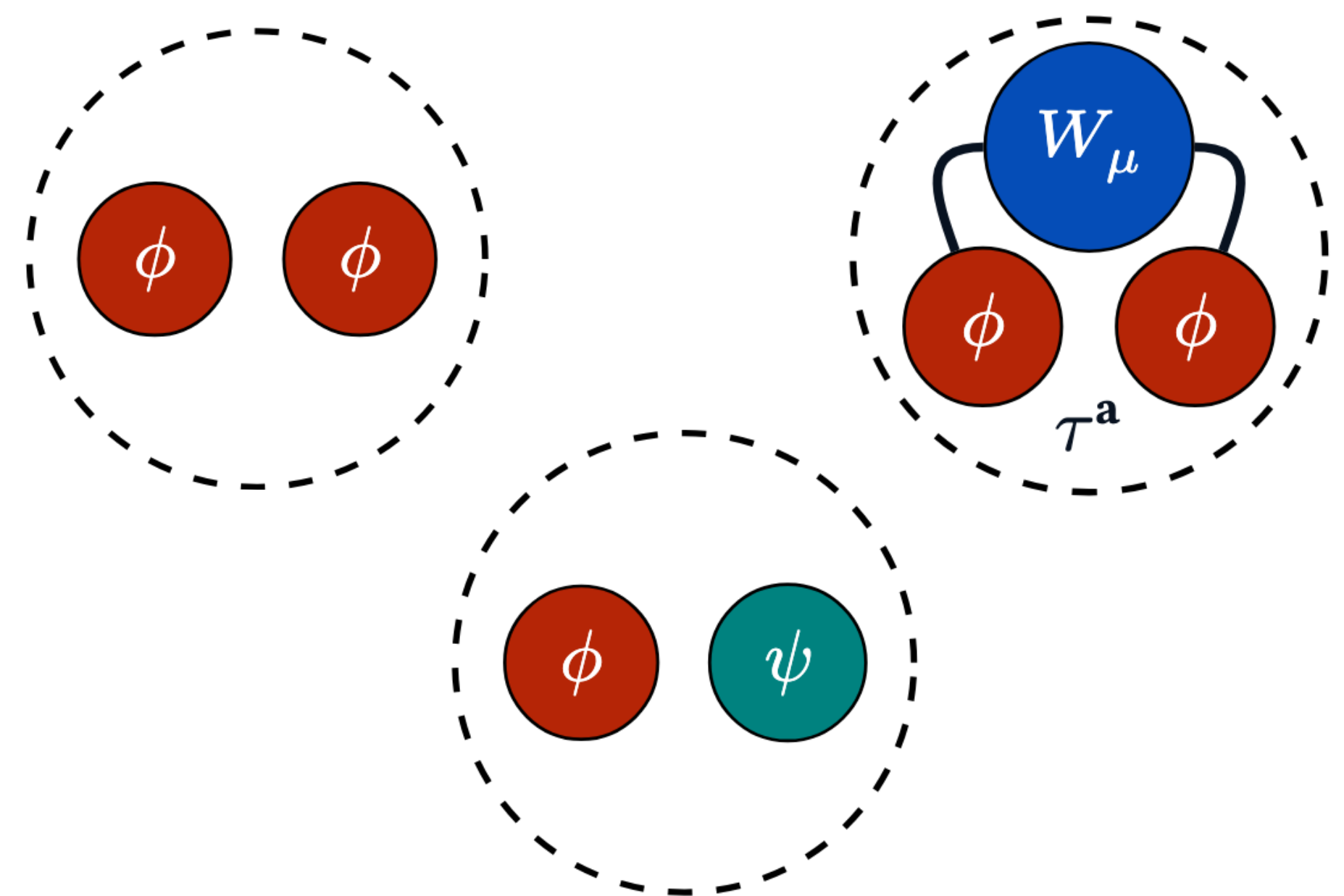
————→ **Gauge-invariant approach to weak physics**

Fröhlich-Morchio-Strocchi (FMS) mechanism

- FMS mechanism predicts a **one-to-one mapping** between gauge-dependent and gauge-invariant states and explains why perturbation theory is successful

→ See next talk by **Sofie Martins**

- Physical Higgs (scalar singlet): $\phi(x) \rightarrow (\phi^\dagger \phi)(x)$
- Physical W (vector triplet): $W_\mu^a(x) \rightarrow (\tau^a \phi^\dagger D_\mu \phi)(x)$
- Physical Lepton (spin-1/2 doublet): $\psi(x) \rightarrow (\phi^\dagger \psi)(x)$



Fröhlich, Morchio, Strocchi, Phys. Lett. B97 (1980)

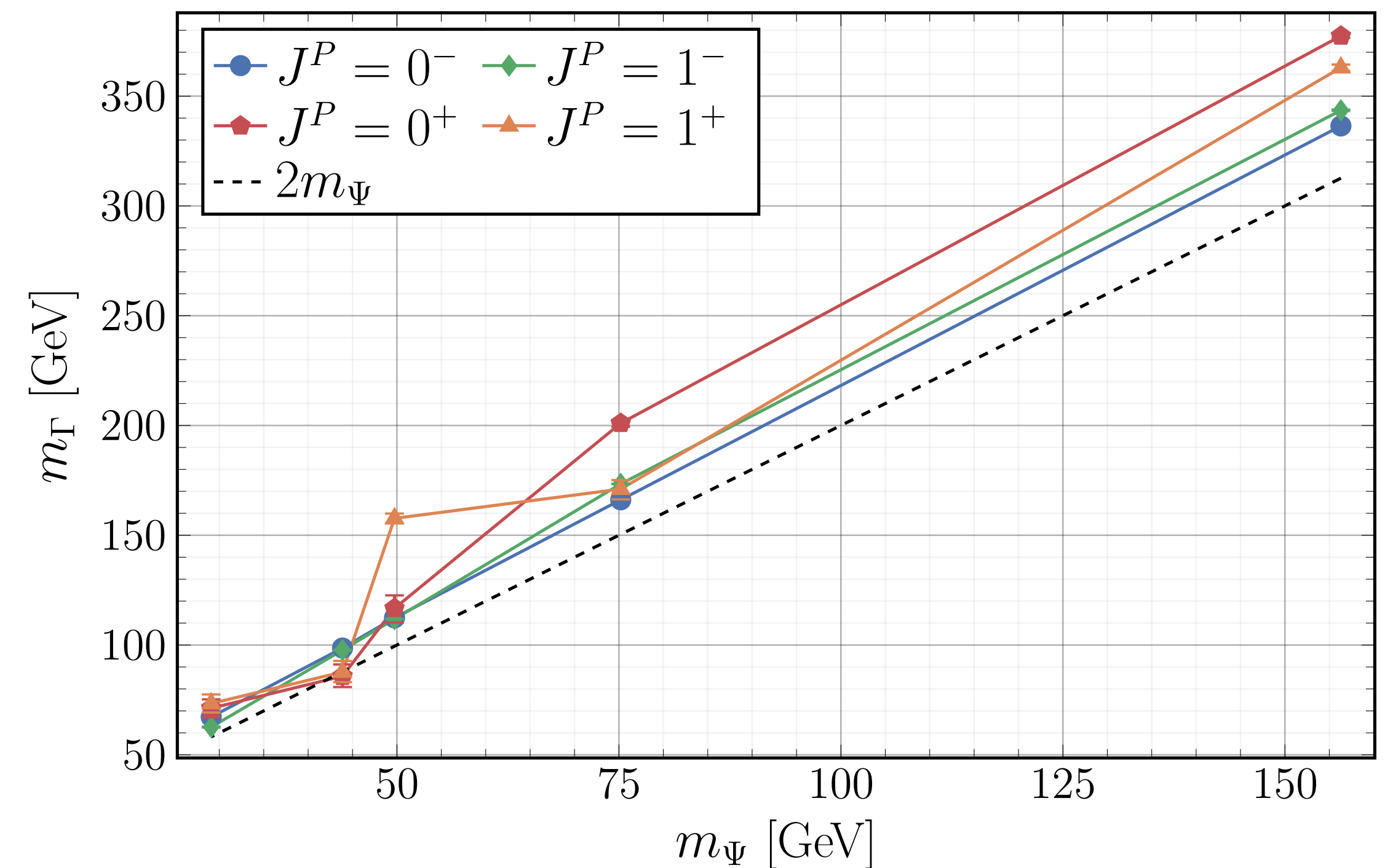
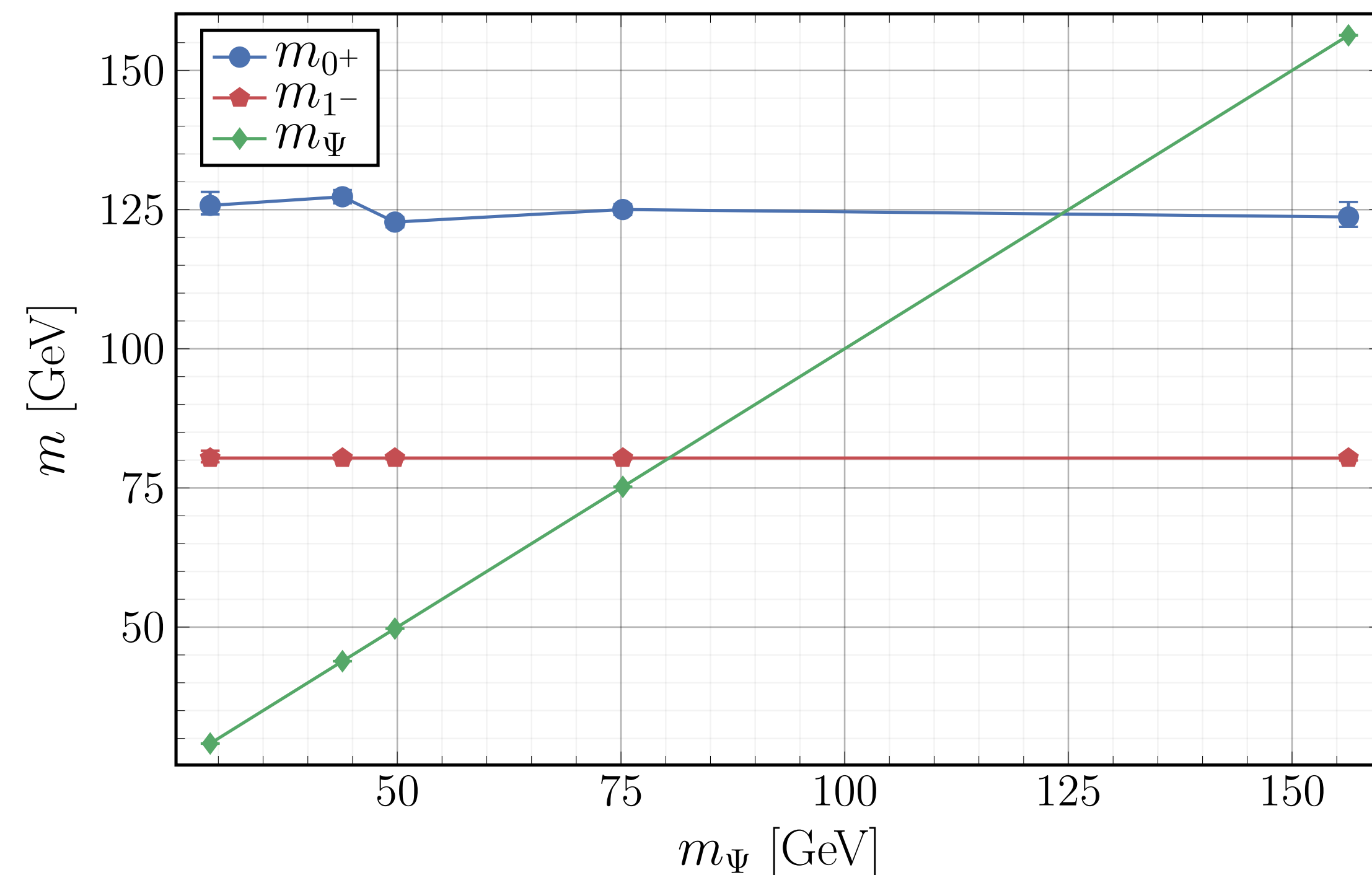
Fröhlich, Morchio, Strocchi, Nucl. Phys. B190 (1981)

Maas, Prog. Part. Nucl. Phys. 106 (2019), 1712.04721

Physical spectrum

Composite FMS operators & leptonium channels

- Results for an SM-like proxy that replaces chiral fermions with **vectorial leptons** (parity violation is not an important part of FMS) & vanishing Yukawa couplings



Why should we care?

- Deviations at higher orders between perturbation theory and a gauge-invariant approach, e.g., vector boson scattering (VBS)

Jenny, Maas, Riederer, Phys. Rev. D 105 (2022), 2204.02756

→ See next talk by **Sofie Martins**

- Deepen understanding of QFT: learn more about the fundamental field-theoretical effects related to gauge invariance → guaranteed discovery
- Implications for future experiments: set baseline for future measurements & avoid false positives regarding new physics
- Phenomenological implications: model building should focus on custodial (global) group

Outlook

- PDFs for fermion bound-states \rightarrow internal structure of leptons
- Scattering analysis
 - Scalar singlet: $e^+e^- \rightarrow H \rightarrow \mu^+\mu^-$
 - Vector triplet: $e^+e^- \rightarrow W \rightarrow \mu^+\mu^-$
 - Fermion bound state: excited states of e / μ
- Compare simulation results with analytical results from augmented perturbation theory
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Thank you for your attention!