Referee Report on "Unravelling New Physics Signals at the HL-LHC with Low-Energy Constraints"

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SUMMARY

The manuscript investigates whether low-energy measurements (fixed-target Drell-Yan, EIC projections, and forward neutrino data) can prevent Beyond-the-Standard-Model (BSM) effects from being absorbed into parton distribution functions (PDFs) in global fits that include HL-LHC high-mass Drell-Yan data. The analysis is performed using closure-test fits within the NNPDF framework, with BSM effects injected through a heavy flavour-universal W' model.

While the topic is timely and technically sophisticated, the manuscript suffers from fundamental conceptual and methodological flaws that undermine its physical interpretation. The central conclusions rely on assumptions that are not physically well-defined and on a circular statistical construction that cannot support claims of "unravelling new physics."

MAJOR CONCEPTUAL ISSUES

1. Misinterpretation of Closure Tests as Physical Diagnostics

Closure tests are designed to assess the internal consistency of a fitting methodology when the underlying law is known by construction. In this work, closure tests are instead elevated to the role of physical diagnostics for BSM detectability.

This is conceptually incorrect. The fact that PDFs can absorb or fail to absorb injected BSM effects in a closure-test environment does not establish a physical criterion for the presence or absence of new physics. It only reflects the flexibility of the PDF parametrisation under artificial data generation.

The manuscript repeatedly interprets changes in χ^2 distributions as "flagging" BSM-induced inconsistencies, but such inconsistencies are entirely framework-dependent and do not correspond to observable physical contradictions.

2. Circular Logic in the Definition of Consistency

The criteria used to identify inconsistencies ($\chi^2/N_{\rm dat} > 1.5$ and $n_\sigma > 2$) are purely conventional thresholds internal to the NNPDF methodology. These thresholds are then used to justify weighted fits and dataset exclusion.

As a consequence, the analysis becomes circular: the framework defines what counts as inconsistency, enforces it via reweighting, and then interprets the resulting degradation as physical evidence of BSM effects. No independent physical principle is invoked to justify this procedure.

3. Lack of a Physical Notion of Scale Separation

The core claim of the paper is that low-energy data are "not susceptible" to the BSM effects considered and therefore provide an external anchor. This assumption is asserted but never derived.

In the presence of a heavy W' integrated out into SMEFT operators, the notion that low-energy observables are immune to BSM-induced distortions is not guaranteed. The manuscript implicitly assumes a clean separation of scales without demonstrating that this separation is stable under PDF evolution and matching.

METHODOLOGICAL ISSUES

4. Overreliance on Projected Data

A substantial fraction of the conclusions depends on projected datasets (HL-LHC, EIC, FPF). While projections are useful for exploratory studies, the manuscript treats them on the same footing as real data when drawing strong conclusions about detectability of new physics.

This weakens the physical relevance of the results and limits their interpretability beyond the specific simulation setup adopted.

5. Model Dependence and Lack of Generality

All conclusions are tied to a single flavour-universal W' model with fixed coupling. The manuscript does not demonstrate that the identified effects persist across different classes of BSM scenarios. As a result, the conclusions cannot be regarded as generic statements about BSM detectability in global PDF fits.

INTERPRETATIONAL OVERREACH

The manuscript claims to "unravel" BSM effects by combining low- and high-energy data. In reality, it demonstrates that adding constraining datasets reduces the flexibility of PDFs to absorb injected signals. This is a statistical statement about fit rigidity, not a physical mechanism for isolating new physics.

No observable, model-independent signature is identified that would survive changes in parametrisation, fitting strategy, or statistical criteria.

RECOMMENDATION

For the reasons outlined above, I cannot recommend this manuscript for publication.

The work does not establish a physically well-defined criterion for identifying BSM effects, relies on circular statistical logic, and overinterprets closure-test results beyond their legitimate scope. While technically competent, the analysis lacks the conceptual foundation required for a contribution to fundamental high-energy physics.

FINAL VERDICT

Reject