# Probing Higgs-Portal Dark Matter with VBF Signatures at the HL-LHC

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# Abstract

We investigate current and projected constraints on Higgs-portal dark matter (DM) models, focusing on both scalar and fermionic DM candidates, using vector boson fusion (VBF) production of the Higgs boson at the LHC. By analyzing the parameter space in the plane of DM mass versus the Higgs-DM coupling, we aim to reinterpret existing LHC VBF + MET searches to set bounds on the invisible Higgs decay channels.

To this end, we perform simulations in MadGraph5_aMC@NLO under LHC conditions to compute cross sections for VBF Higgs production followed by invisible decays. Experimental efficiencies are estimated through a recast of public analyses targeting the process $pp \to jj + \text{MET}$. We then rescale the integrated luminosity to project the reach of the High-Luminosity LHC (HL-LHC), identifying both currently excluded regions and those potentially probed with 3 $\text{ab}^{-1}$. Our results provide updated exclusion contours and projections in the Higgs-portal to DM parameter space.

# Outline

# Dark Matter: The Missing Piece

- Evidence for dark matter from cosmological observations
- The need for particle physics models beyond the Standard Model
- Higgs-portal as a minimal and well-motivated framework

# Higgs-Portal Dark Matter Models

- Scalar DM candidate: $\mathcal{L} \supset \lambda_s |H|^2 S^2$
- Fermionic DM candidate: $\mathcal{L} \supset y_f H \bar{\chi} \chi$
- Connection to invisible Higgs decays: $H \to \text{DM} + \text{DM}$
- Parameter space: $(m_{\text{DM}}, \lambda / y_f)$

# Vector Boson Fusion (VBF) Production

- VBF topology: $pp \to jjH$ with forward jets
- Distinctive experimental signature
- Advantages over gluon-gluon fusion for invisible searches

# Invisible Higgs Decay Channels

- $H \to \chi\chi$ (fermionic DM)
- $H \to SS$ (scalar DM)
- Branching ratios and kinematic constraints
- Connection to relic density requirements

# Simulation Setup

- MadGraph5_aMC@NLO for signal generation
- LHC conditions at $\sqrt{s} = 13$ TeV
- Process: $pp \to jj +$ MET via VBF
- Systematic uncertainties and scale variations

# Experimental Recast

- Public LHC analyses targeting $pp \to jj + \text{MET}$
- Efficiency estimation and acceptance calculations
- Background modeling and systematic uncertainties
- Statistical treatment of exclusion limits

# Current LHC Constraints

- Exclusion contours in $(m_{\mathrm{DM}}, \lambda/y_f)$ plane
- Comparison between scalar and fermionic DM
- Sensitivity to different mass ranges

# HL-LHC Projections

- Projected reach with 3 $ab^{-1}$ integrated luminosity
- Improvement over current constraints
- Complementarity with other search strategies

# Parameter Space Analysis

- Currently excluded regions
- Future sensitivity regions
- Comparison with direct detection experiments
- Implications for model viability

# Theoretical Implications

- Constraints on Higgs-portal coupling strength
- Impact on dark matter relic density
- Model-dependent vs. model-independent results

# Experimental Considerations

- Systematic uncertainties and their impact
- Comparison with other Higgs production modes
- Future improvements and detector upgrades

# Summary

- VBF provides competitive constraints on Higgs-portal DM
- HL-LHC will significantly extend the reach
- Both scalar and fermionic DM models constrained
- Complementary approach to direct/indirect detection

# Future Outlook

- Extension to other DM models
- Combination with other search channels
- Implications for future collider experiments
- Connection to cosmological observations

# Thank you for your attention!

Questions?