Search for long-lived Higgs decays in CMS:

\[ H \rightarrow \pi_\nu \pi_\nu \rightarrow b\bar{b}b\bar{b} \]

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Theoretical motivation and experimental signatures

Motivation:
- Hierarchy problem of the Standard Model
- Strong constraints on new colored particles

Higgs portal models:
- Dark sector, neutral under all SM gauge groups.
- Higgs boson mixing with its dark partner → predicted to decay to dark particles ($\pi_{\nu}$)

Benchmark model:
- Dark neutral scalars $\pi_{\nu}$ are long-lived → Travel finite distance in CMS, then decay back to SM particles (dominantly $b\bar{b}$)
- Depending on $c_T$ and $m_{\pi_{\nu}}$, decays can manifest in different experimental signatures

Vector-Boson Fusion:
→ Large production cross section

<table>
<thead>
<tr>
<th>$c_T$</th>
<th>Signature at CMS</th>
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<tbody>
<tr>
<td>$&lt; 1\text{mm}$</td>
<td>very short lifetimes → $b\bar{b}$-quark like</td>
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<tr>
<td>$1\text{mm to }1\text{m}$</td>
<td>decay in tracker → displaced vertices</td>
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<tr>
<td>$1\text{m to }2\text{m}$</td>
<td>decay in calorimeters → trackless jets</td>
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<tr>
<td>up to $\sim5\text{m}$</td>
<td>decay in muon system &amp; no inner detector activity</td>
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Csaki, et al. 
arXiv:1508.01522
Analysis strategies: Cut-based & ML studies

Cut-based benchmark analyses:
- b-tagging inputs as a function of $cT$ and $m_\pi$ for short lifetimes
- Displaced-jet tagging variables for decays in tracker\(^{*}\)
- High-level jet features (e.g. charged hadron energy fraction) for decays in calorimeters

Machine-Learning approach:

Short lifetimes:
- b-tagging variables with relaxed selection criteria as inputs
- Train modified b-tagging algorithm to find double displaced b-jets

Decays in tracker:
- Using the PFCandidates as inputs
- Potentially adapt Deep-Set framework to tag displaced-jets\(^{†}\)

Decays in calorimeters:
- First approach: Using high-level jet features as inputs to BDT’s
- Now, PFCandidates as inputs to LoLa\(^{‡}\)

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\(^{*}\)arXiv:1711.09120
\(^{†}\)New ML approach, taking a variable-length unordered set of features as input (arXiv:1703.06114, arXiv:1810.05165)
\(^{‡}\)DNN architecture working with Lorentz vectors and the Minkowski metric (arXiv:1707.08966)
Thank you!