Prospects for Searches for invisible Higgs Decays

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on behalf of the ATLAS and CMS collaborations

HE/HL-LHC workshop
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The Higgs could be the portal to Dark Matter.

If a Hidden Valley (+ friends), Higgs could be bridge to BSM.
Current Status - Stable Invisible

Current limit is ~25% dominated by VBF

Challenge:
Systematic uncertainty ~ statistical uncertainty
Current Status - Stable Invisible

Current limit is $\sim 25\%$

dominated by VBF

- large cross-section
- main background is qualitatively different than signal, i.e. $pp \to Z$ for $ggH$ and $pp \to ZZ$ for $VH$, but for VBF, $\sigma(EW \ qqZ) \ll \sigma(QCD \ Z+\text{jets})$

key uncertainty is from modeling $W \to l\nu / Z \to \nu\nu$ ratio (more on this later)

Challenge:
Systematic uncertainty $\sim$ statistical uncertainty
For a given topology, can do (much) better than bounds from $h\rightarrow\text{invisible}$
Projections for HL-LHC

Extrapolations from 2015 analysis; 2016 analysis follows optimistic scaling.

- theory uncerts. drop by 50%
- exp. uncerts. scale with lumi (until a bound)

+ analysis improvements possible over the next 10 years!
Challenges: Trigger

MET trigger heavily affected by pileup

Trigger thresholds will continue to increase

Possible solutions:
- Improve online calibrations
- Multi-object triggers (e.g. VBF + MET)
- Trigger-level PU suppression
- Tracking (+displaced?)
Challenges: Trigger

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Possible solutions:

L1Topo trigger in ATLAS now allows for complex multi-object selections

CMS is already uses MET and jet counting at L1 - further improvements possible with topological selections and also including the forward region
Challenges: Trigger

- Improve online calibrations
- Multi-object triggers (e.g. VBF + MET)
- Trigger-level PU suppression
- Tracking (+displaced?)

Can we improve with deep learning? see e.g. JHEP 12 (2017) 051
Challenges: Trigger

Tracking can generically help calibrations, tagging, etc. For LLP, can significantly enhance acceptance.

Muons at L1 can be used but more general displaced (track) triggers are challenging.

- Improve online calibrations
- Multi-object triggers (e.g. VBF + MET)
- Trigger-level PU suppression
- Tracking (+displaced?)

see also JINST 8 (2013) P07015 for ATLAS displaced triggers
Challenges: Pileup (Jets)

VBF jets tend to be forward.

Due to limited tracker acceptances, forward jets harder to ID as not pileup.

To be seen what role pileup jets play at $\mu \sim 200$ - could make VBF @ HL/HE-LHC much harder than now!

Some ideas already in place to reject forward pileup jets, though composition (QCD/stochastic) between now and HL/HE-LHC will change.
Challenges: Quark/gluon tagging

VBF jets are quark-initiated.

Forward QCD Z+jets are a mix of quarks and gluons.

Interplay with PU jet tagging - gluon jets are easier to distinguish than quark jets as PU/HS
Challenges: Vertexing

Finding the correct vertex is a challenge in $H \rightarrow \text{MET}$ events.

With the wrong vertex, may label HS jets as PU.

Algorithmic improvements possible - also benefit from extended tracker coverage.
Challenges: Systematic Uncertainties

### Table 8: Dominant sources of systematic uncertainties and their impact on the fitted value of $B(H^{\text{inv}})$ in the VBF analysis at 13 TeV.

<table>
<thead>
<tr>
<th>Systematic uncertainty</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common</strong></td>
<td></td>
</tr>
<tr>
<td>W to Z ratio in QCD produced V+jets</td>
<td>13%</td>
</tr>
<tr>
<td>W to Z ratio in EW produced V+jets</td>
<td>6.3%</td>
</tr>
<tr>
<td>Jet energy scale and resolution</td>
<td>6.0%</td>
</tr>
<tr>
<td>QCD multijet normalisation</td>
<td>4.3%</td>
</tr>
<tr>
<td>Pileup mismodelling</td>
<td>4.2%</td>
</tr>
<tr>
<td>Lepton efficiencies</td>
<td>2.5%</td>
</tr>
<tr>
<td>Integrated luminosity</td>
<td>2.2%</td>
</tr>
<tr>
<td><strong>Signal specific</strong></td>
<td></td>
</tr>
<tr>
<td>ggH acceptance</td>
<td>3.8%</td>
</tr>
<tr>
<td>Renorm. and fact. scales and PDF (qqH)</td>
<td>1.8%</td>
</tr>
<tr>
<td>Renorm. and fact. scales and PDF (ggH)</td>
<td>&lt;0.2%</td>
</tr>
<tr>
<td><strong>Total systematic</strong></td>
<td>$^{+15%}_{-19%}$</td>
</tr>
<tr>
<td><strong>Total statistical only</strong></td>
<td>$^{+28%}_{-27%}$</td>
</tr>
<tr>
<td><strong>Total uncertainty</strong></td>
<td>$^{+32%}_{-33%}$</td>
</tr>
</tbody>
</table>

W/Z cross-section ratio is a significant source of uncertainty.

Can contain with leptonic Z decays, but stats are poor.

Theory input here could make a significant impact on results!

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CMS, JHEP 02 (2017) 135
Opportunities - Extended Trackers

- Helps with lepton rejection \((W \rightarrow l\nu)\)
- Improves forward jet calibration
- Improves forward jet PU/qg tagging

Likely that algorithms will need re-optimization to account for worse resolution at high \(|z|\).
Opportunities - Timing

Both ATLAS and CMS are planning on including MIP timing detectors.

These detectors have a lot of promise for rejecting pileup, improving vertexing, etc.
Conclusions and Outlook

BR(H → MET) will be a key measurement from the full HL/HE-LHC program that will benefit from the full dataset and upgraded detectors.

...at the same time, we should strongly support other proposals to enhance / complement LHC sensitivity.
Questions?