Emerging jet probes of exotic Higgs decays

Juliana Carrasco Mejia IFIC (Valencia)

in collaboration with Jose Zurita

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Emerging Jets

- Dark showers arise from a new confining dark sector.
 - (Dark) jets containing dark states that may be stable or decay within DS or back to SM with a wide range of lifetimes.
- If all dark mesons decay into \$M with finite lifetimes (0.001-1m)
 - ▶ high multiplicity of displaced vertises a Diit bet a jet.
 → Emerging Jet

Benchmark model (searched by CMS)

- Pair production of heavy bifundamental scalars X_d
- $\quad m_{q_d} = \Lambda_d = 2m_{\pi_d} = 1/2m_{\rho_d}$
- Dark pions decay into SM with finite lifetime
- > Free parameters: $m_{X_{D'}} m_{\pi_D}$, $c\tau_{\pi_D}$



Schwaller et al., 1502.05409



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CMS search for EJs

- Emerging Jet tagging variables: ≻
 - > $\langle IP_{2D} \rangle$: Median transverse impact parameter of associated tracks
 - > α_{3D} : jet pT fraction associated to prompt tracks (there are 6 groups of criteria for EJ-tagging)
- Event selections
 - Four jets with (at least two are EJs or one EJ+large (E_T)
 - Trigger on scalar p_T sum of jets $H_T > 900$ GeV and on p_T of each jet.
- 7 sets of selection requirements are defined, \blacktriangleright optimised for different configurations (the one with the highest expected sensitivity)

No significant excess observed above SM prediction



CMS Collaboration, 1810.10069



Validation (I)



| Set number | Expecte | d | Observed | Signal |
|------------|------------------------------|--------|----------|------------------------------|
| 1 | $168 \pm 15 \pm$ | ± 5 | 131 | 36.7 ± 4.0 |
| 2 | $31.8 \pm 5.0 \pm$ | £ 1.4 | 47 | $(14.6 \pm 2.6) \times 10^2$ |
| 3 | $19.4 \pm 7.0 =$ | £ 5.5 | 20 | 15.6 ± 1.6 |
| 4 | $22.5 \pm 2.5 \pm$ | ± 1.5 | 16 | 15.1 ± 2.0 |
| 5 | $13.9 \pm 1.9 \pm$ | Ł 0.6 | 14 | 35.3 ± 4.0 |
| 6 | $9.4 \pm 2.0 =$ | £ 0.3 | 11 | 20.7 ± 2.5 |
| 7 | $\textbf{4.40} \pm 0.84 \pm$ | ± 0.28 | 2 | 5.61 ± 0.64 |

CMS Collaboration, 1810.10069

► Number for signal events for set *i*: $n_S^i = \sigma_{(pp \to XX)} \times BR(X \to qQ_D) \times \mathscr{A}_i \times L$

With \mathscr{A}_i the signal acceptance, a function of $m_{X'} m_{\pi_{d'}} c \tau_{\pi_d}$.



Validation (II)

Since track reconstruction efficiencies are hard to parametrise. We considered different criteria for the tracking efficiencies, including different iteration levels or requiring r_{trk} < 102mm.</p>



CMS Collaboration, 1405.6569



Validation (III)

| | 1000 - | 34.915 | 10.265 | 3.951 | 2.612 | 1.812 | 1.331 | 1.359 | | - 0 6 |
|----------------|--------|--------|--------|-------|------------------------------------|-------|-------|-------|--|-------|
| <i>cτ</i> [mm] | 500 - | 32.992 | 8.62 | 3.532 | 2.18 | 1.613 | 1.393 | 1.321 | | 0.0 |
| | 300 - | 26.044 | 6.042 | 3.48 | 1.964 | 1.437 | 1.264 | 3.234 | | - 0.5 |
| | 225 - | 31.483 | 8.979 | 5.709 | 3.74 | 3.358 | 3.056 | 2.613 | | |
| | 150 - | 16.606 | 5.446 | 3.472 | 2.797 | 2.344 | 2.325 | 1.955 | | - 0.4 |
| | 100 - | 12.016 | 4.861 | 2.876 | 2.272 | 1.957 | 1.704 | 1.69 | | |
| | 60 - | 8.892 | 2.856 | 1.968 | 1.762 | 1.581 | 1.482 | 1,506 | | - 0.3 |
| | 45 - | 7.416 | 2.862 | 1.827 | 1.531 | 1.514 | 1.456 | 1.431 | | |
| | 25 - | 6.399 | 2.319 | 1.693 | 1.545 | 1.382 | 1.373 | 1.47 | | - 0.2 |
| | 5 - | 12.548 | 2.33 | 1.978 | 1.857 | 1.803 | 1.857 | 1.971 | | |
| | 2 - | 4.785 | 1.377 | 0.854 | 1.071 | 0.982 | 0.98 | 1.201 | | - 0.1 |
| | 1 - | 2.757 | 1.15 | 0.684 | 0.674 | 0.982 | 0.898 | 0.744 | | |
| | | 400 | 600 | 800 | 1000 <i>m_X</i> [GeV] | 1250 | 1500 | 2000 | | |

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| | 1000 - | 5.303 | 2.253 | 0.685 | 0.54 | 0.307 | 0.274 | 0.297 | | |
|---------|--------|--------|-------|-------|------------------------------------|-------|-------|-------|---|-------|
| cт [mm] | 500 - | 8.296 | 2.309 | 0.903 | 0.472 | 0.413 | 0.379 | 0.334 | | 0.4 |
| | 300 - | 8.387 | 1.975 | 1.136 | 0.541 | 0.451 | 0.399 | 1.034 | | - 0.4 |
| | 225 - | 11.315 | 3.212 | 1.896 | 1.243 | 1.128 | 1.143 | 0.954 | | |
| | 150 - | 7.368 | 2.125 | 1.402 | 1.144 | 0.983 | 0.982 | 0.904 | | - 0.3 |
| | 100 - | 5.514 | 2.441 | 1.41 | 1.049 | 0.957 | 0.86 | 0.926 | | |
| | 60 - | 5.114 | 1.83 | 1.143 | 1.05 | 0.949 | 0.911 | 0.977 | | 0.2 |
| | 45 - | 4.272 | 1.977 | 1.135 | 0.991 | 0.998 | 0.971 | 1.005 | | - 0.2 |
| | 25 - | 3.82 | 1.732 | 1.237 | 1.117 | 1.008 | 0.977 | 1.088 | | |
| | 5 - | 9.801 | 1.95 | 1.592 | 1.532 | 1.375 | 1.463 | 1.486 | | - 0.1 |
| | 2 - | 4.154 | 1.183 | 0.753 | 0.959 | 0.837 | 0.821 | 0.894 | | |
| | 1 - | 3.31 | 0.76 | 0.499 | 0.462 | 0.919 | 0.586 | 0.484 | | |
| | _ | 400 | 600 | 800 | 1000 <i>m_X</i> [GeV] | 1250 | 1500 | 2000 | - | |





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Reinterpretation for Higgs mediated dark showers

- Consider production through the SM Higgs boson, through different mechanisms.
- Furthermore, use different decay portals for the dark pion decays into SM: gluon, higgs, darkphoton and vector-portal (defined by Knapen et al. 2103.01238).
 e.g: π_DG^{µν}G̃_{µν} or π_DH[†]H
- ► Expected number of signal events: $n_S^i = \sigma_{(pp \to h)} \times BR(h \to Q_D Q_D) \times \mathscr{A}_i \times L$



Bounds on exotic higgs decays

► Current indirect bounds on branching ratio for exotic higgs decays: $BR(h \rightarrow QdQd) < 0.21$ at 95%CL with 80fb⁻¹ at $\sqrt{s} = 13$ TeV (ATLAS, 1909.02845)





- Strongly interacting dark sector are well motivated scenarios, theoretically and experimentally.
- > At colliders, these give rise to exotic and unexplored signatures, such as Emerging Jets.
- We reproduced with reasonable agreement the published limits of the CMS emerging jets search.
- We performed the reinterpretation of the CMS emerging jet search for exotic decays of the SM Higgs boson. Our limits are competitive with those obtained from the modelindependent searches of the non-standard SM Higgs boson decays (BSM higgs branching fraction) from ATLAS, for certain lifetime ranges.

Thank you!