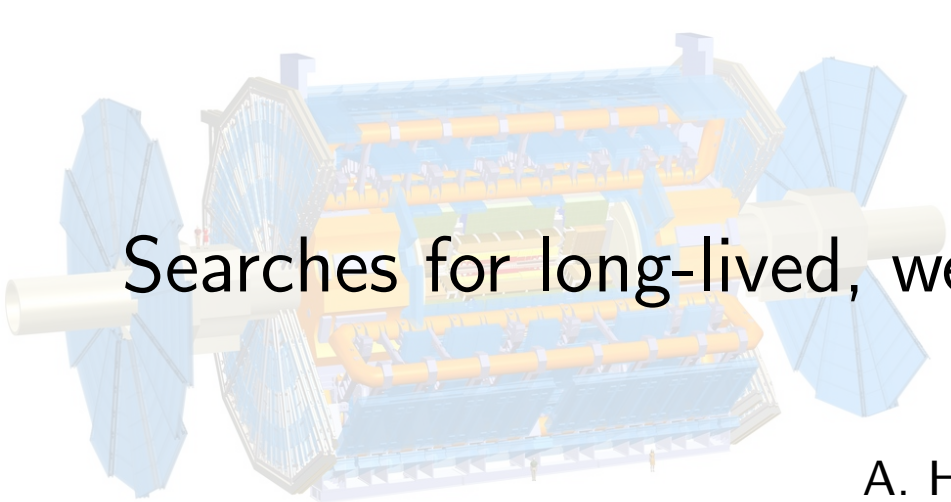
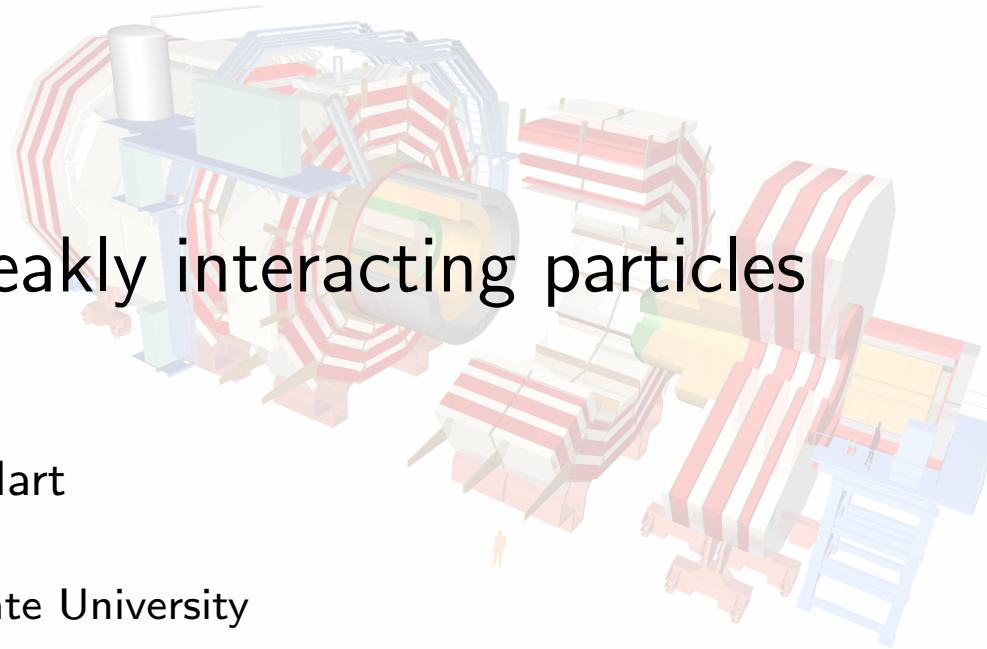



# Searches for long-lived, weakly interacting particles

A. Hart

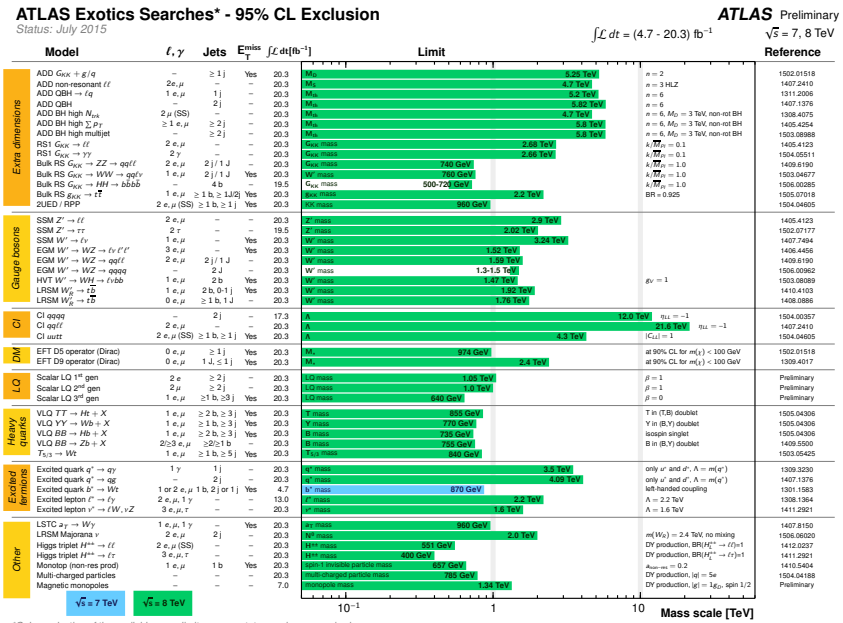
The Ohio State University

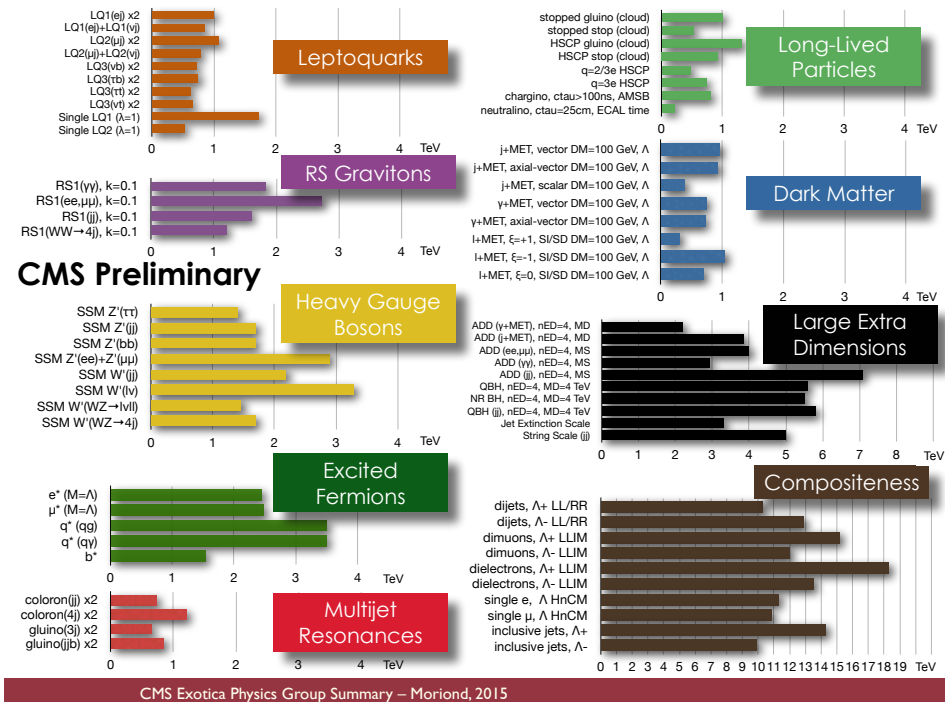
July 23, 2015



# Status of new physics after LHC Run 1

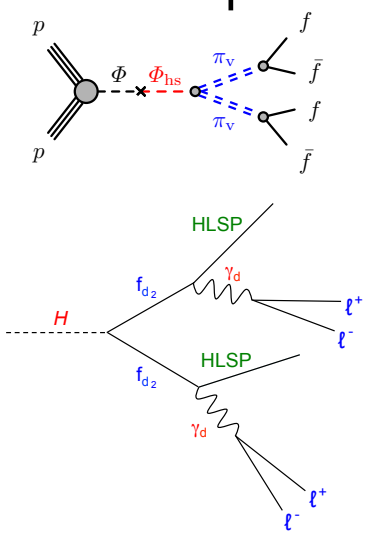
- A lack of signs of new physics, despite extensive searches, is one of the most important results from Run 1.
- But we must keep in mind the assumptions we make in all these searches.
- One of the most common is that new particles will decay promptly.

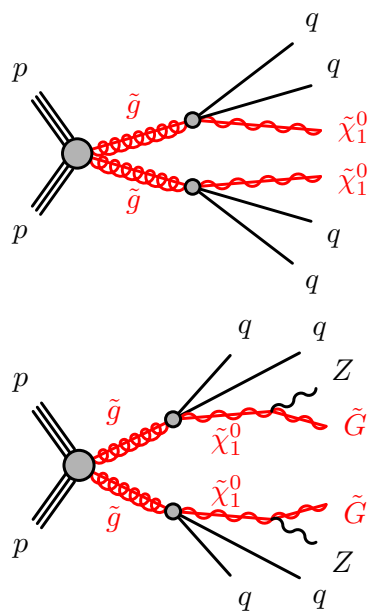


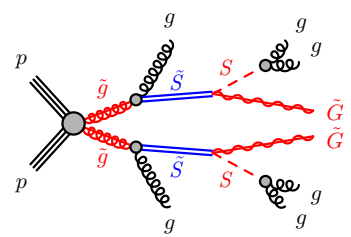



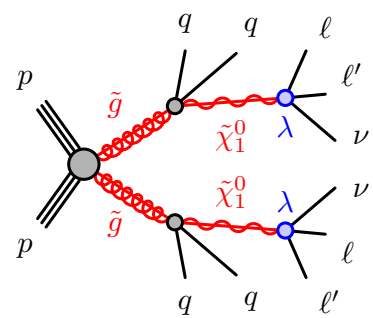
# Motivations for long-lived particles

- Assuming new particles are long-lived (LL) complicates analysis stategies, background estimation, systematic uncertainties, etc.
- But there are several reasons this could be and a plethora of models that realize them:
  - heavy intermediate particles (hidden valley models, split SUSY, etc.)
  - weak couplings (couplings to $\tilde{\mathrm{G}}$, RPV couplings, etc.)
  - very limited phase space (e.g. AMSB $\tilde{\chi}_1^{\pm}$ decays)
- This talk summarizes searches for weakly interacting, LL particles; i.e., searches for decay products displaced to various degrees from the interaction point.



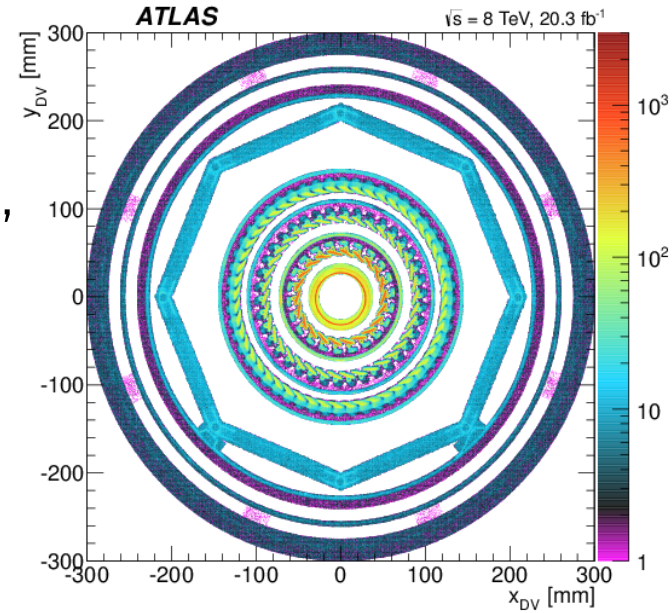



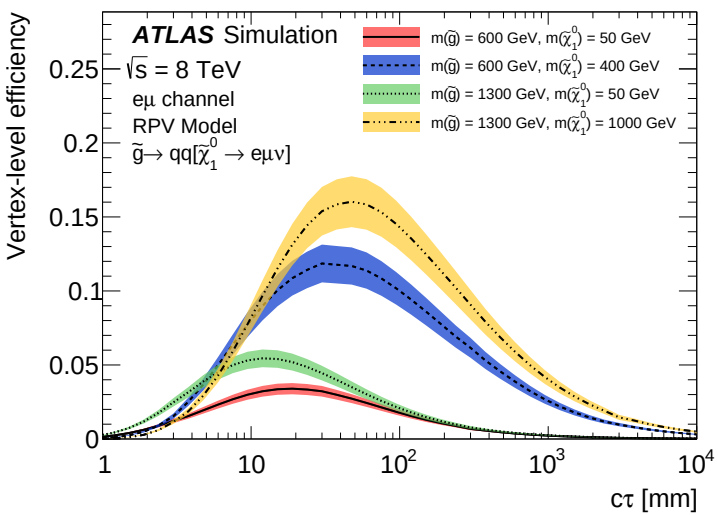




# Displaced vertices ($c\tau \sim 1\,\mathrm{cm}$)

- Displaced vertices (DV) formed from clusters of $\geq$5 tracks.
- Dilepton vertices formed from $\mathrm{e}^{\pm}\mathrm{e}^{\mp}$, $\mu^{\pm}\mu^{\mp}$, $\mathrm{e}^{\pm}\mu^{\mp}$ pairs.
- Density map of ATLAS used to veto vertices in dense material.
- Backgrounds from accidental crossings and merged vertices taken from data.




- No events observed in any of the seven signal regions.

| Channel | No. of background vertices ($\times 10^{-3}$) |
|---|---|
| DV+jet | $410 \pm 7 \pm 60$ |
| DV+$E_{\mathrm{T}}^{\mathrm{miss}}$ | $10.9 \pm 0.2 \pm 1.5$ |
| DV+muon | $1.5 \pm 0.1 \pm 0.2$ |
| DV+electron | $207 \pm 9 \pm 29$ |

| Channel | No. of background vertices ($\times 10^{-3}$) |
|---|---|
| $e^+e^-$ | $1.0 \pm 0.2\ ^{+0.3}_{-0.6}$ |
| $e^{\pm}\mu^{\mp}$ | $2.4 \pm 0.9\ ^{+0.8}_{-1.5}$ |
| $\mu^+\mu^-$ | $2.0 \pm 0.5\ ^{+0.3}_{-1.4}$ |

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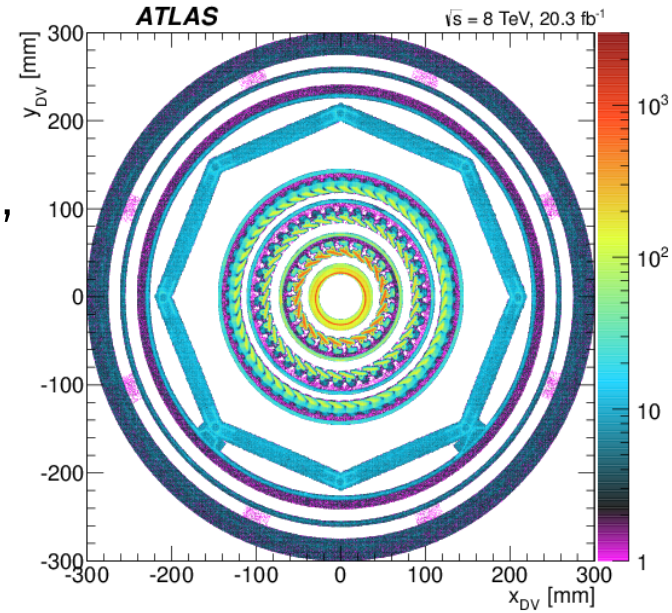
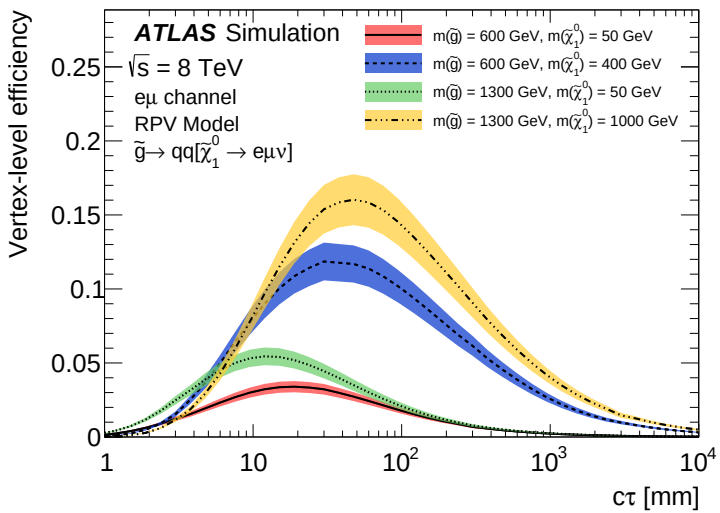
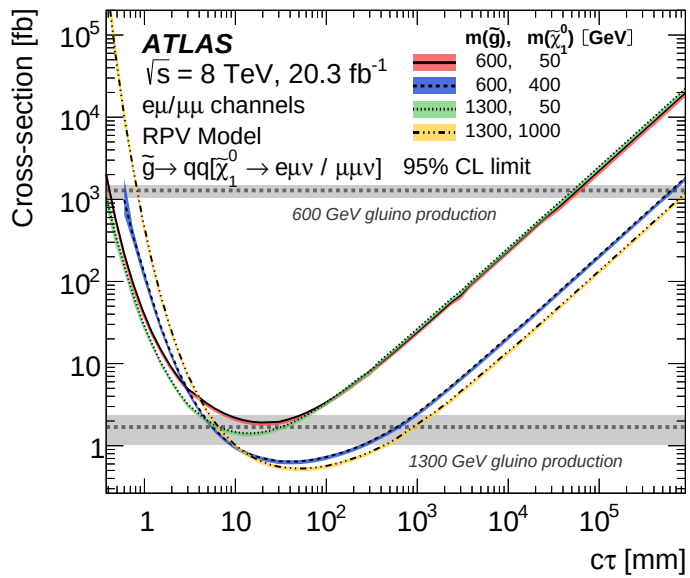
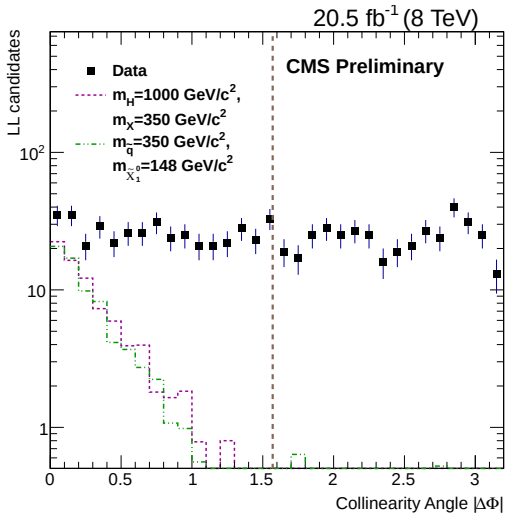



- Limits set on several SUSY models.



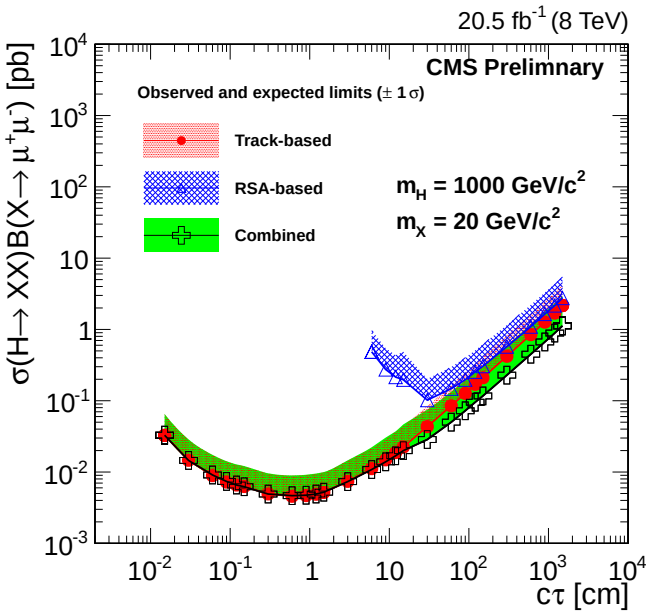



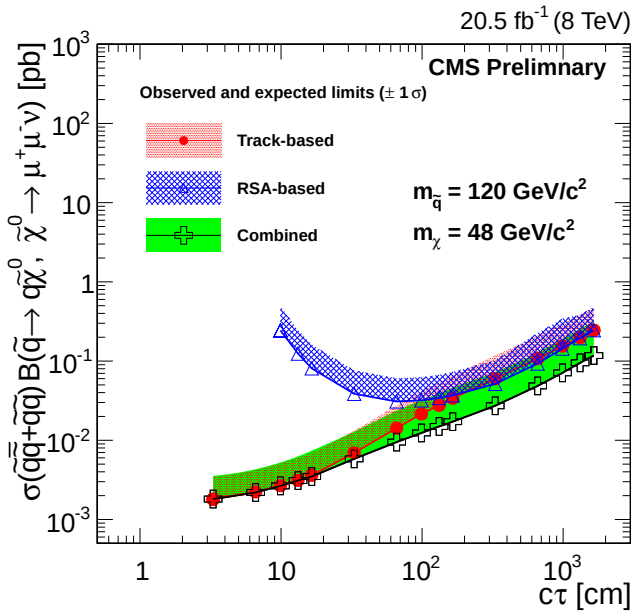
# Displaced $\mu\mu$ (muon chambers only) ($c\tau \sim 100\,\mathrm{cm}$)



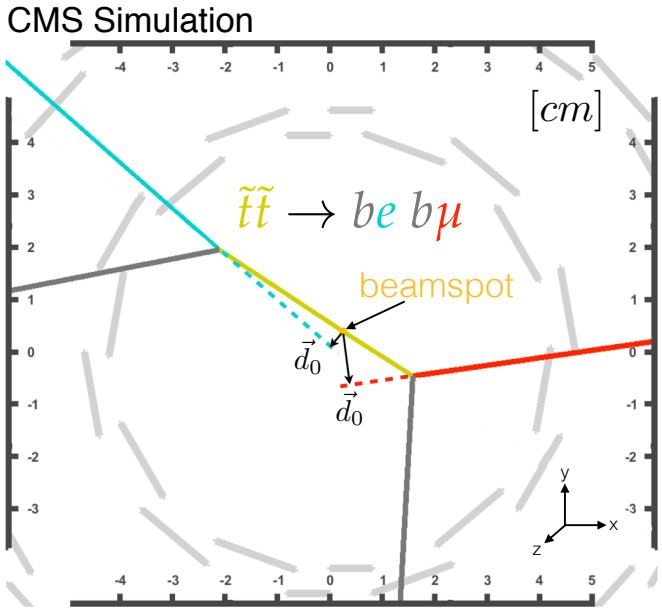

- CMS also looked for dimuon vertices with only muon chambers, vetoing muons matching tracks from the inner tracker.
- Background estimated from candidates in data with anti-aligned momentum and position vectors.

- Zero events predicted and observed; combined with results using inner tracker to set limits on hidden valley scalars (X) and RPV $\tilde{\chi}^0$.



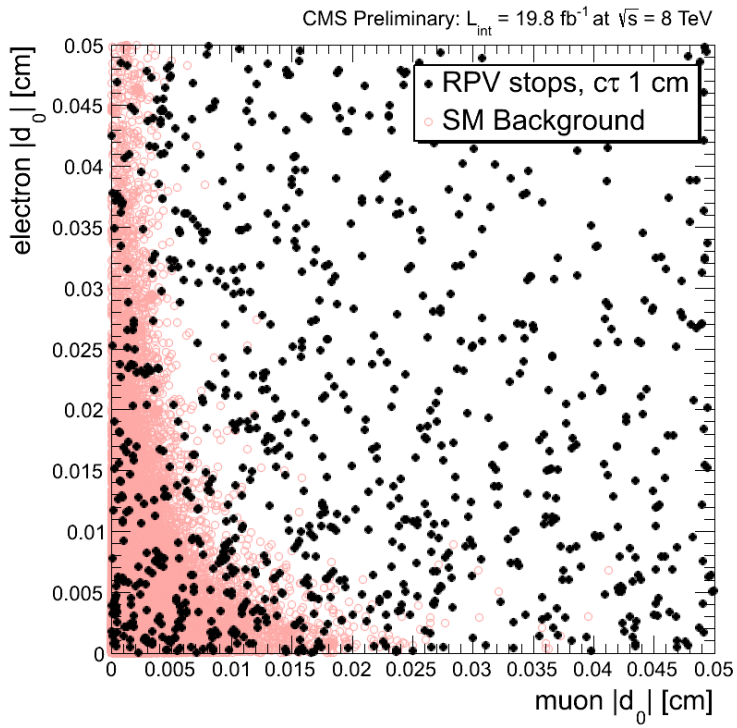
# Displaced SUSY ($c\tau \sim 1\,\mathrm{cm}$)



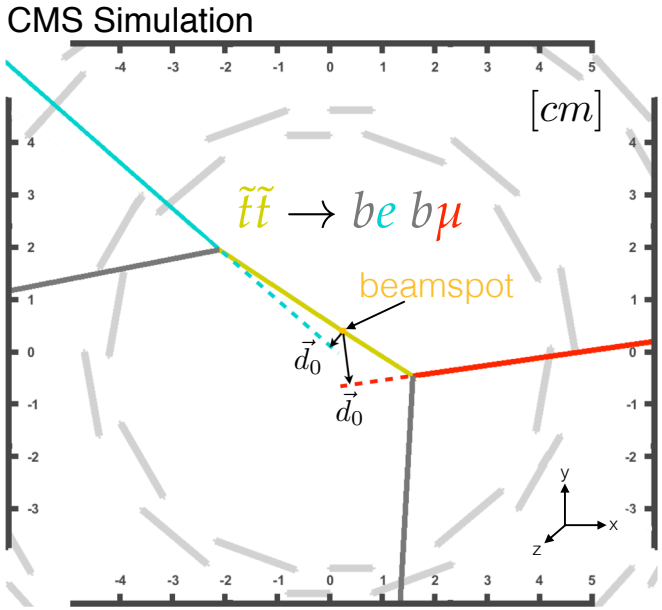

- Isolated $e^{\pm}\mu^{\mp}$ pairs searched for with large transverse impact parameters ($|d_0|$).
- Leptons from LL particle decays have broad $|d_0|$ distributions.
- No common vertex required.

- No excess observed in any of the three signal regions.

| Signal region | Expected | Observed |
|---|---|---|
| $\|d_0\| \in (0.02, 0.05)\,\mathrm{cm}$ | $18.0 \pm 0.5 \pm 3.8$ | 19 |
| $\|d_0\| \in (0.05, 0.1)\,\mathrm{cm}$ | $1.01 \pm 0.06 \pm 0.30$ | 0 |
| $\|d_0\| \in (0.1, 2)\,\mathrm{cm}$ | $0.051 \pm 0.015 \pm 0.010$ | 0 |

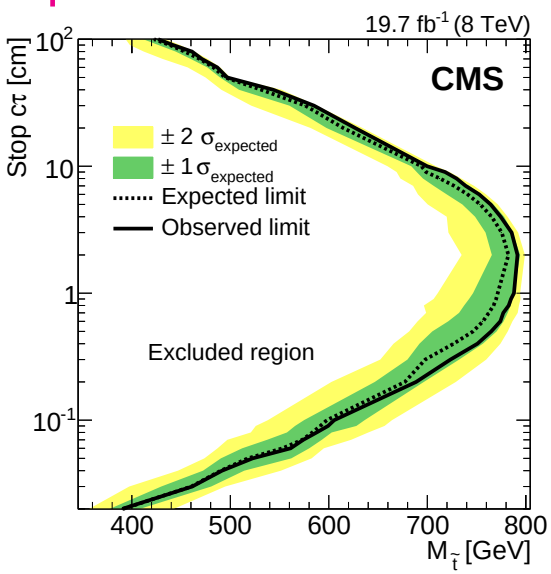


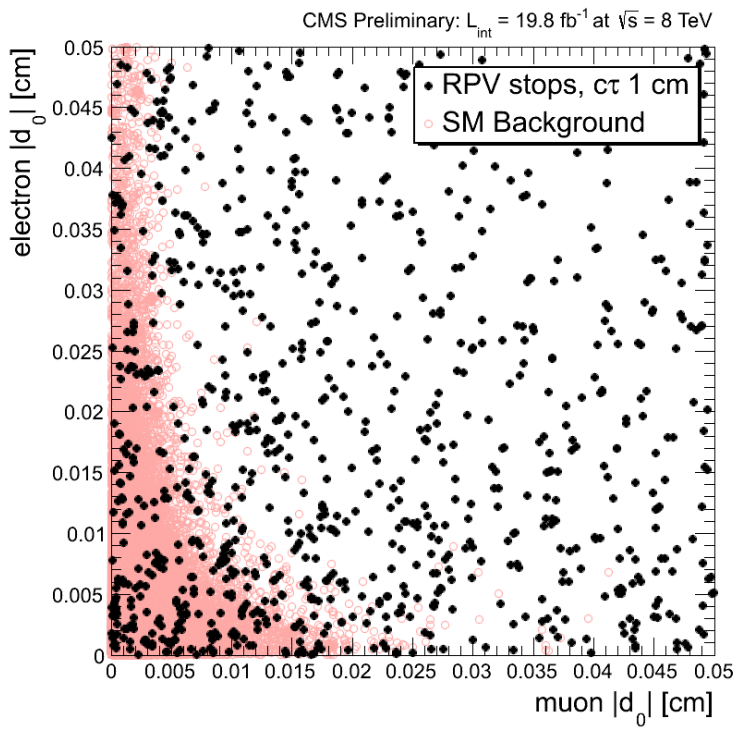
# Displaced SUSY ($c\tau \sim 1\,\mathrm{cm}$)




- Isolated $e^{\pm}\mu^{\mp}$ pairs searched for with large transverse impact parameters ($|d_0|$).
- Leptons from LL particle decays have broad $|d_0|$ distributions.
- No common vertex required.

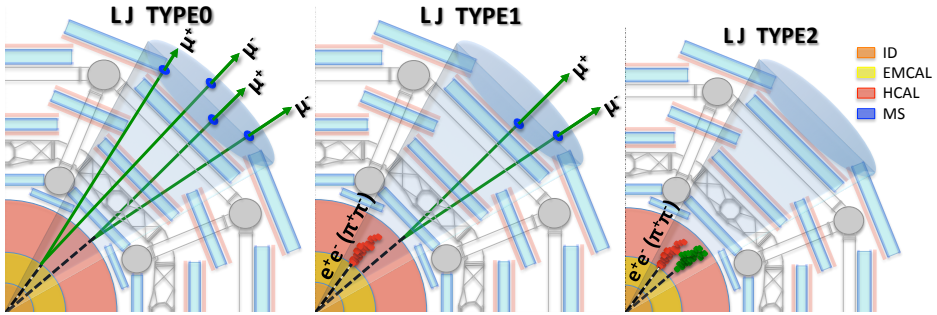
- Limits set on RPV stop pair production in a "displaced SUSY" model.

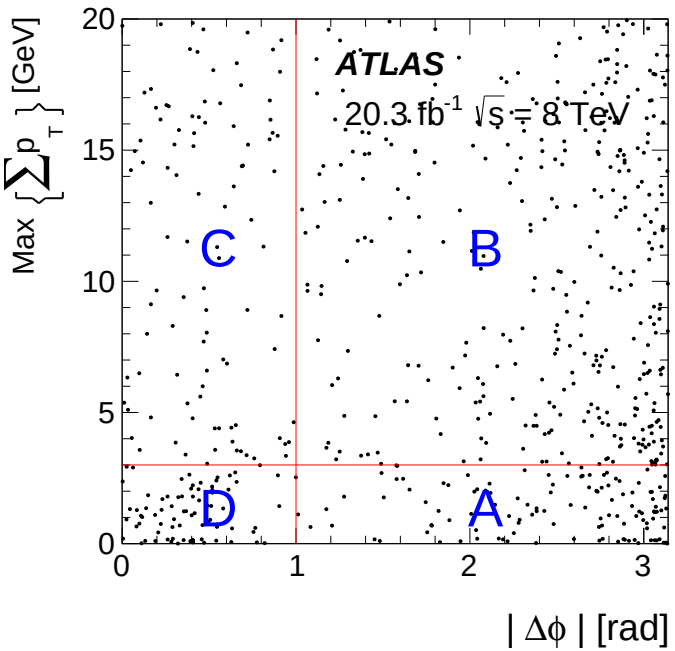


# Displaced lepton jets (LJ) ($c\tau \sim 10\,\mathrm{cm}$)

- Displaced LJs formed by clustering muons and calo. deposits isolated from ID tracks.
- Cosmic background estimated from empty bunch crossing data.
- Multijets estimated with data-driven ABCD method.




- Data well-described by backgrounds.

| | All LJ pair types | TYPE2-TYPE2 LJs excluded |
|---|---|---|
| Data | 119 | 29 |
| Cosmic rays | 40 ± 11 ± 9 | 29 ± 9 ± 29 |
| Multi-jets (ABCD) | 70 ± 58 ± 11 | 12 ± 9 ± 2 |
| Total background | 110 ± 59 ± 14 | 41 ± 12 ± 29 |

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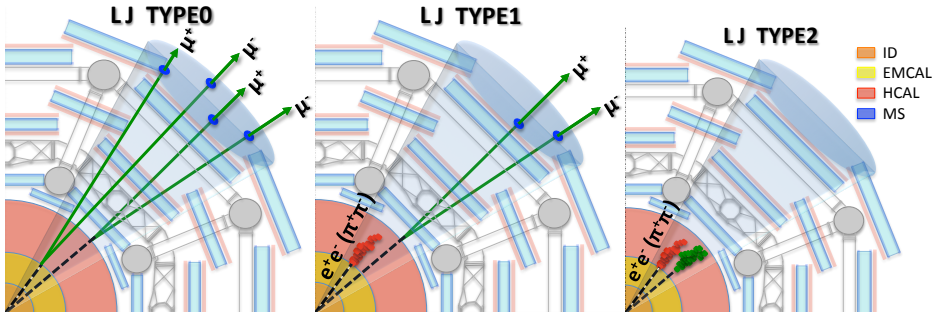
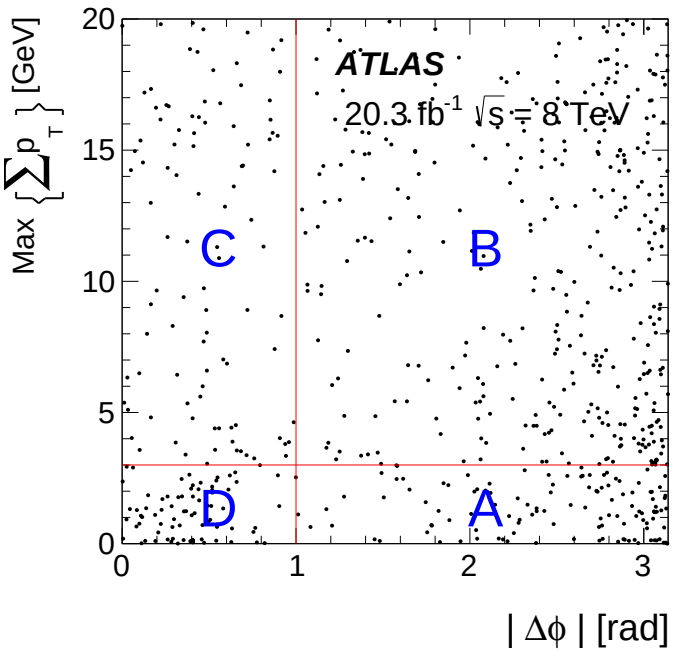
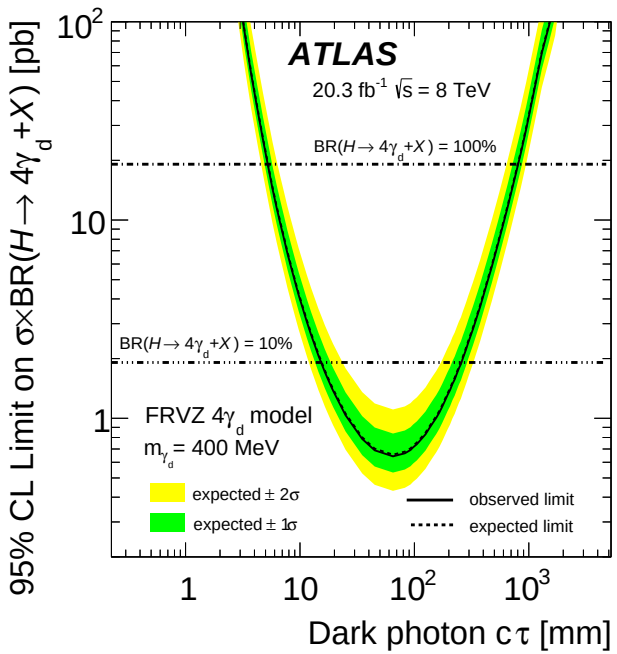
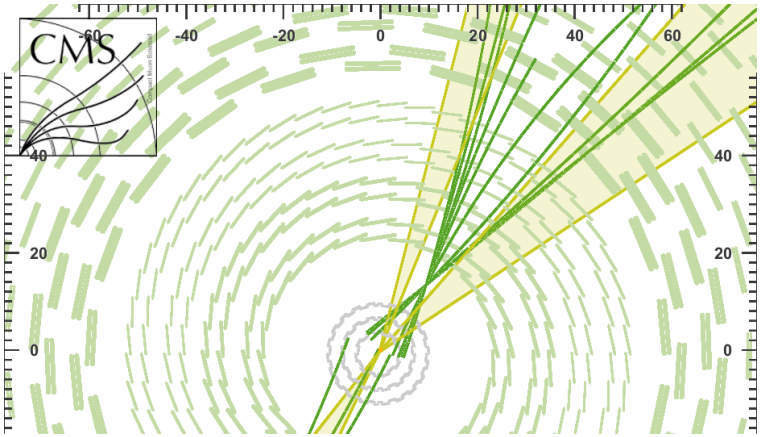



- Limits set on dark photons ($\gamma_\mathrm{d}$).

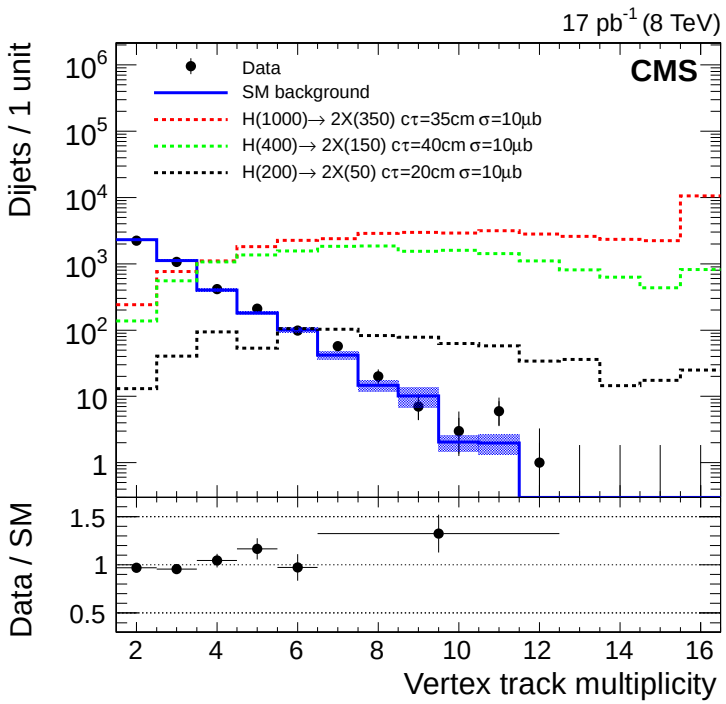


# Displaced dijets ($c\tau \sim 10\,\mathrm{cm}$)

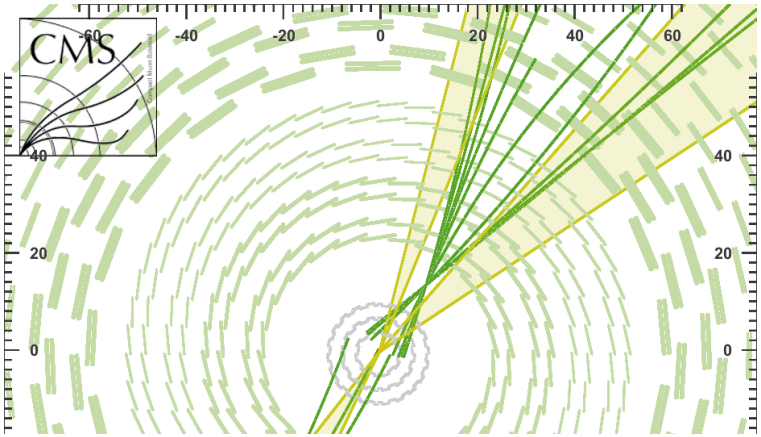



- Displaced vertices formed from tracks in pairs of jets.
- Several variables used to select vertices compatible with signal.
- Multijet background estimated from data with ABCDEFGH method.
- Two sets of selections considered; background describes the data well for both.

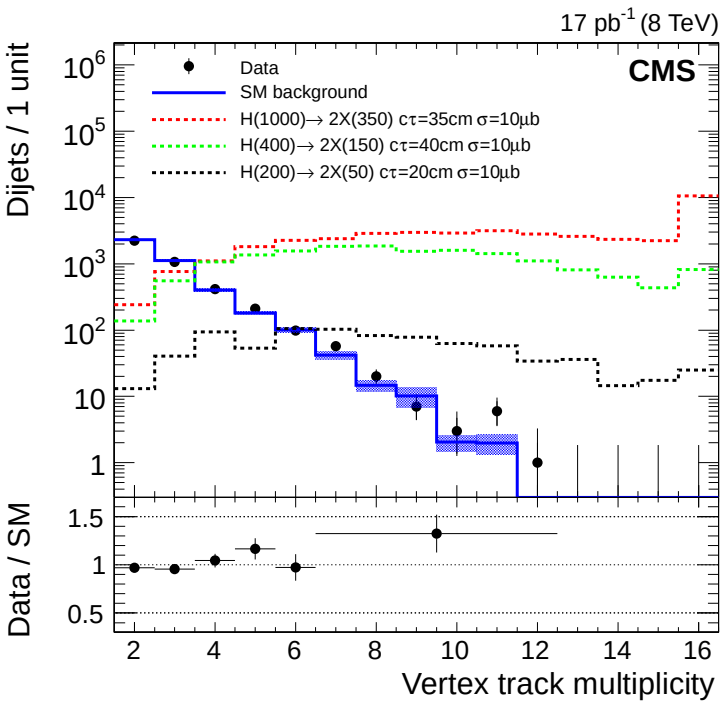


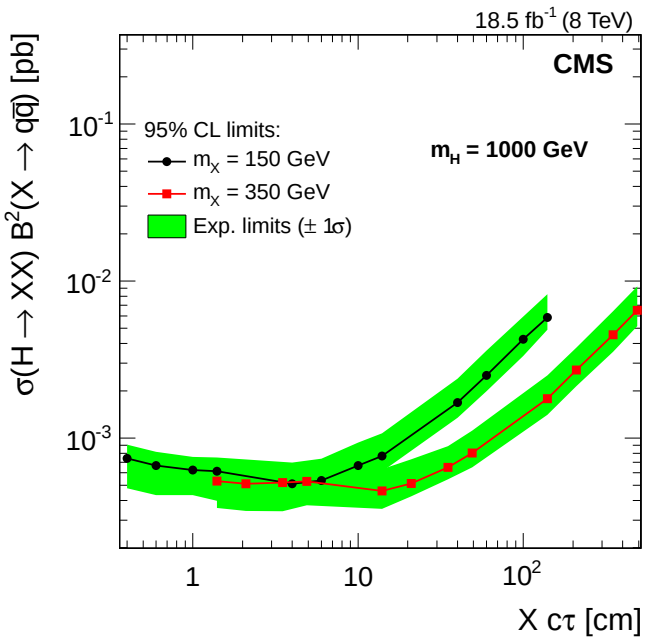

| | Loose selection | Tight selection |
|---|---|---|
| Expected | $1.56 \pm 0.25 \pm 0.47$ | $1.13 \pm 0.15 \pm 0.50$ |
| Observed | 2 | 1 |

# Displaced dijets ($c\tau \sim 10\,\mathrm{cm}$)



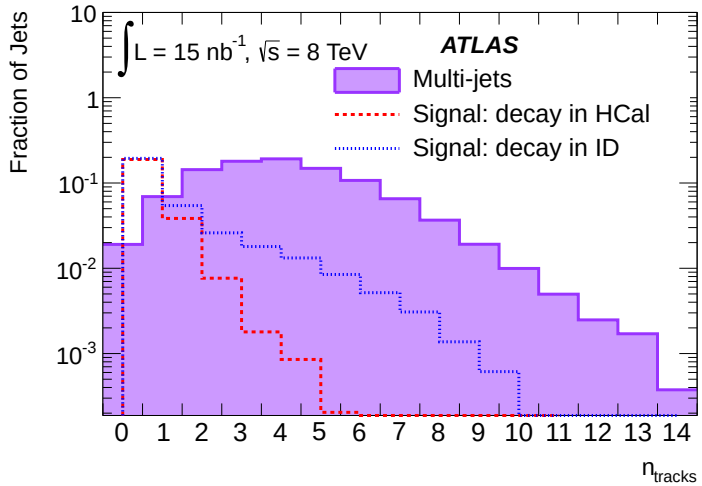

- Displaced vertices formed from tracks in pairs of jets.
- Several variables used to select vertices compatible with signal.
- Multijet background estimated from data with ABCDEFGH method.
- Limits set on hidden valley scalars (X).



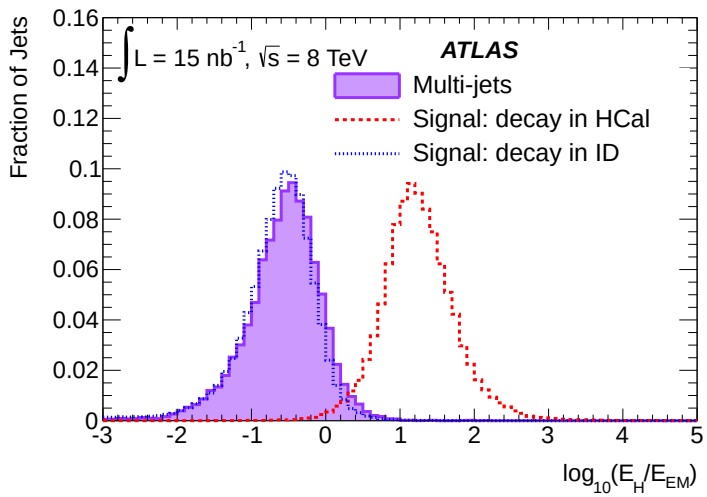
# Trackless jets ($c\tau \sim 100\,\mathrm{cm}$)

- Pairs of trackless jets are used to search for particles decaying in the HCAL.
- No tracks in the ID and little energy in the ECAL.
- Multijet and cosmic backgrounds estimated from data.




- No excess of events observed.

| Background | Expected events |
|---|---|
| SM Multi-jets | $23.2 \pm 8.0$ |
| Cosmic rays | $0.3 \pm 0.2$ |
| Total Expected Background | $23.5 \pm 8.0$ |
| Data | 24 |



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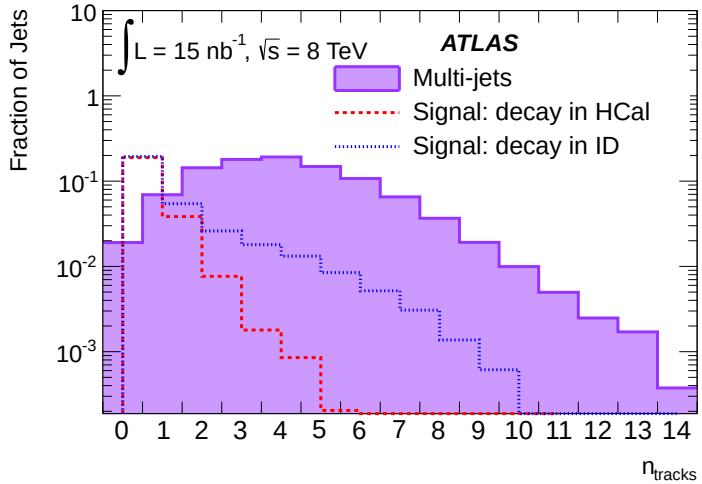
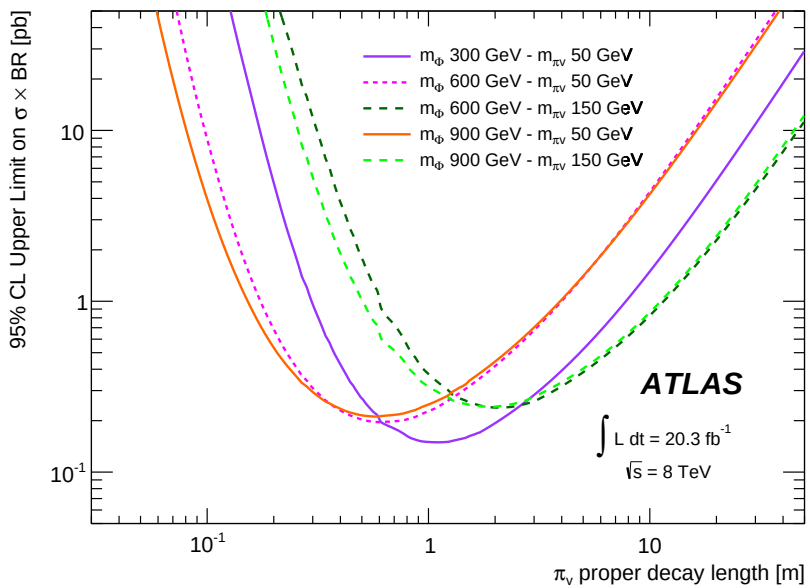
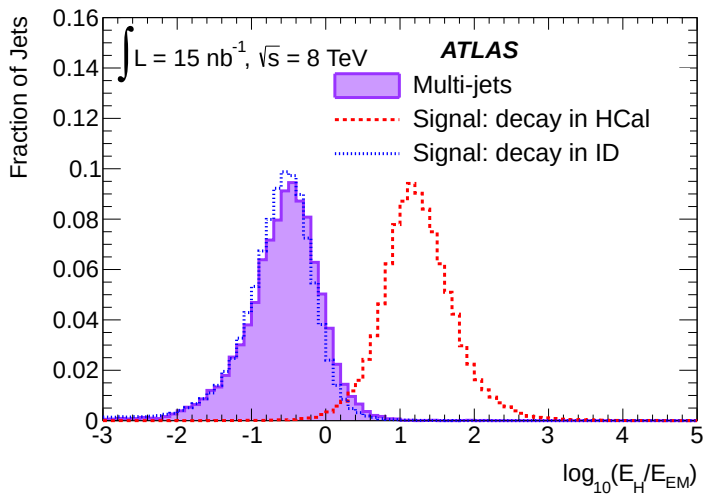
- Limits set on hidden valley pions ($\pi_\mathrm{v}$).

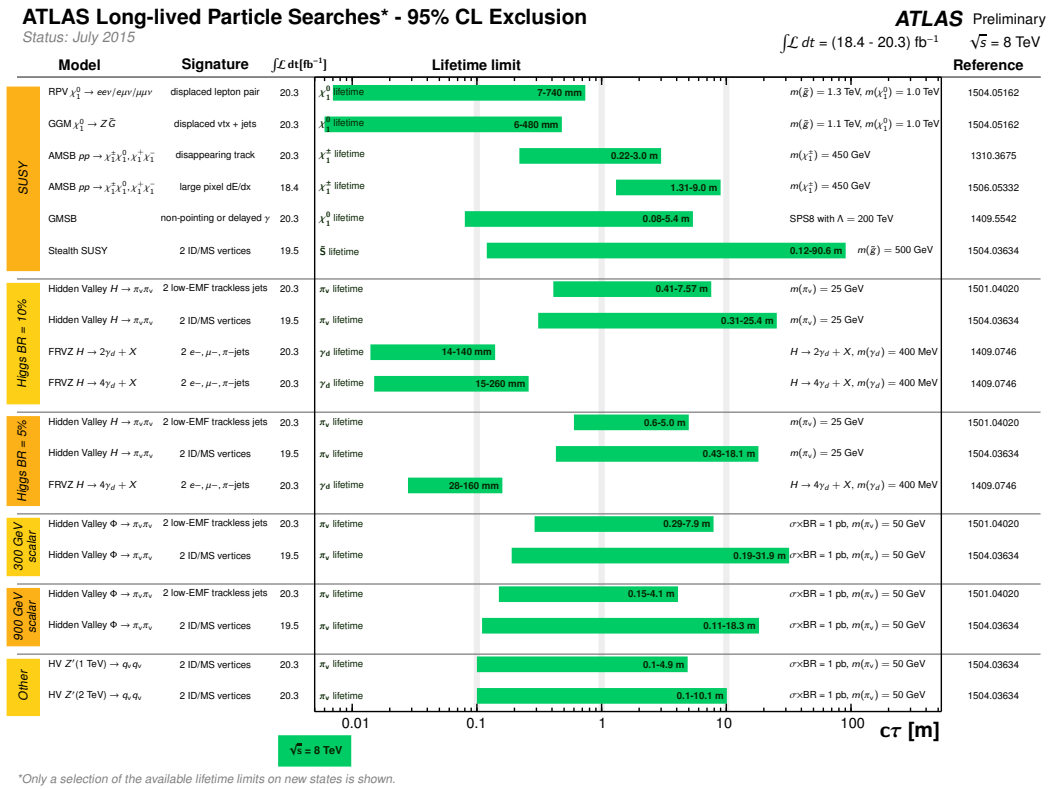


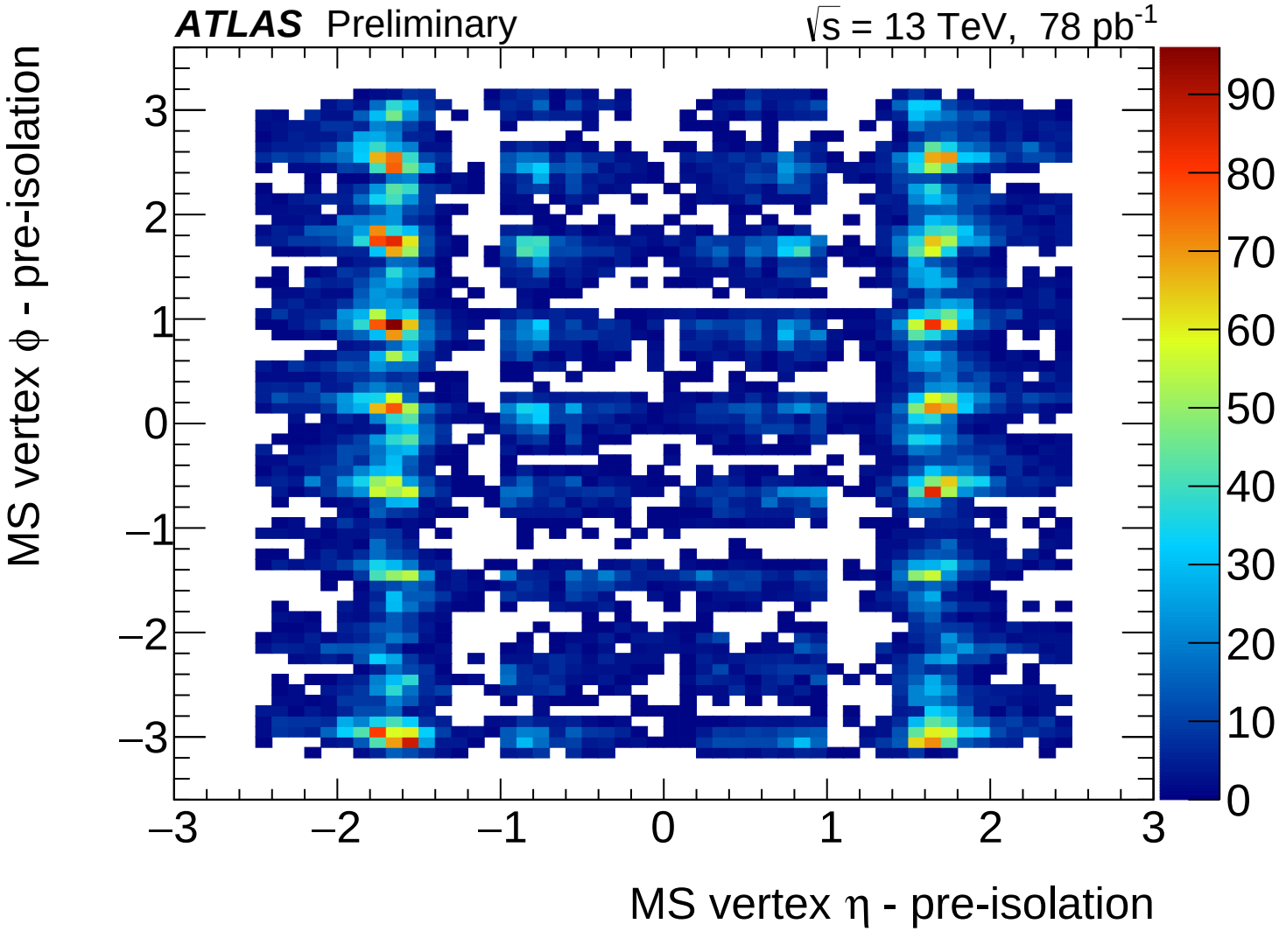



# Conclusion

- ATLAS and CMS have performed several searches for new weakly interacting, LL particles.
- These searches help fill important gaps in coverage left by more traditional searches where new physics could hide.
- Conversely, a future discovery by one of these searches would be a striking sign of new physics.
- Stay tuned for even more exciting results during Run 2!




ATLAS Preliminary
√s = 13 TeV, 78 pb-1
MS vertex ϕ - pre-isolation
MS vertex η - pre-isolation
3
2
1
0
−1
−2
−3
90
80
70
60
50
40
30
20
10
0