Searches for long-lived, weakly interacting particles

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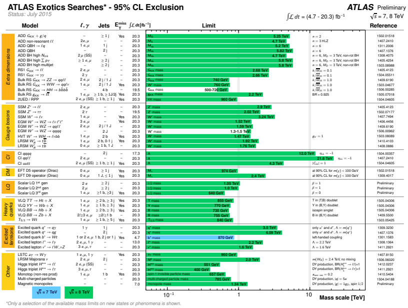
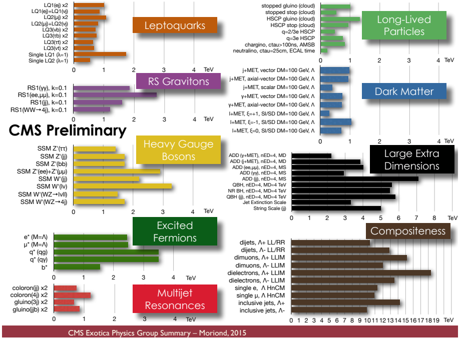
Status of new physics after LHC Run 1

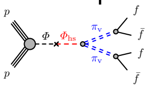
- A lack of signs of new physics, despite extensive searches, is one of the most important results from Run 1.
- But we must keep in mind the assumptions we make in all these searches.
- One of the most common is that new particles will decay promptly.

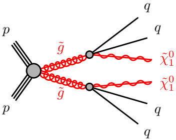


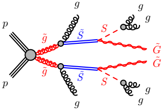


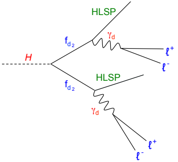
Motivations for long-lived particles

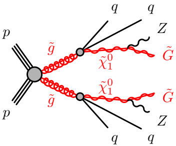
- Assuming new particles are long-lived (LL) complicates analysis stategies, background estimation, systematic uncertainties, etc.
- But there are several reasons this could be and a plethora of models that realize them:
  - heavy intermediate particles (hidden valley models, split SUSY, etc.)
  - weak 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.

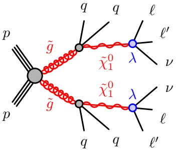






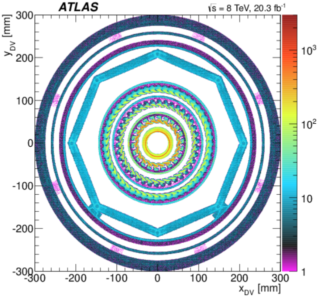


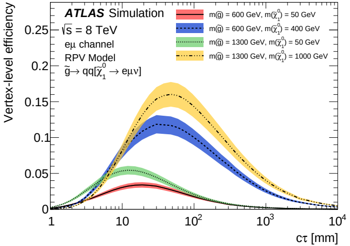




Displaced vertices ($c\tau \sim 1\,\mathrm{cm}$)

- 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^-	$1.0 \pm 0.2\ ^{+0.3}_{-0.6}$
$e^{\pm}\mu^{\mp}$	$2.4 \pm 0.9\ ^{+0.8}_{-1.5}$
$\mu^+\mu^-$	$2.0 \pm 0.5\ ^{+0.3}_{-1.4}$

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

- Displaced vertices (DV) formed from clusters of ≥ 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.
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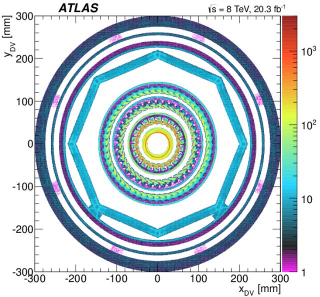
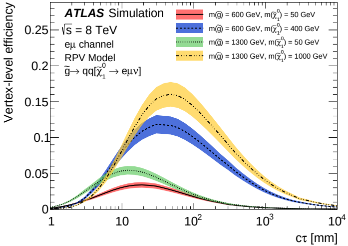
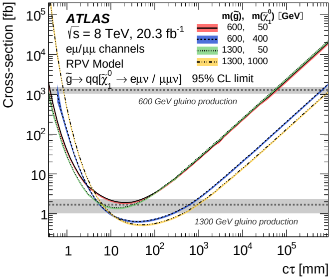
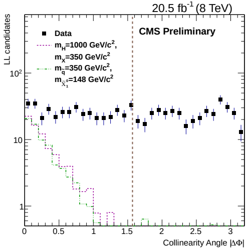


- Limits set on several SUSY models.

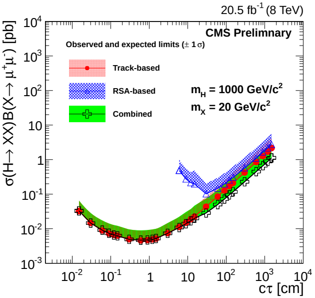


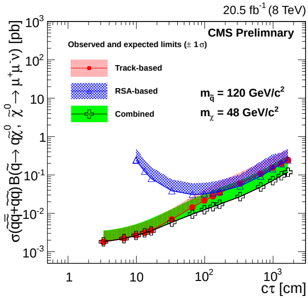


Displaced $\mu\mu$ (muon chambers only) ($c\tau \sim 100\,\mathrm{cm}$)

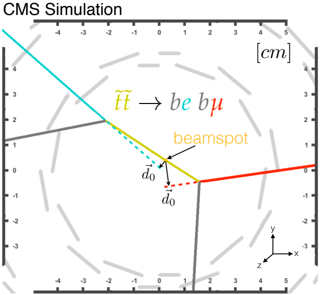


- CMS also looked for dimuon vertices with only muon chambers, vetoing muons matching tracks from the inner tracker.
- Background estimated from candidates in data with anti-aligned momentum and position vectors.
- Zero events predicted and observed; combined with results using inner tracker to set limits on hidden valley scalars (X) and RPV $\tilde{\chi}^0$.

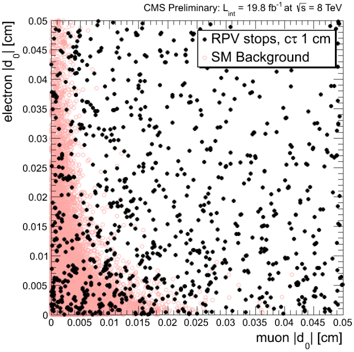




Displaced SUSY ($c\tau \sim 1\,\mathrm{cm}$)



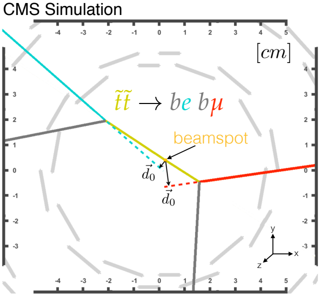
- Isolated $e^{\pm}\mu^{\mp}$ pairs searched for with large transverse impact parameters ($|d_0|$).
- Leptons from LL particle decays have broad $|d_0|$ distributions.
- No common vertex required.



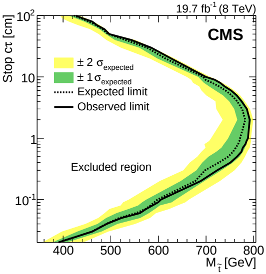
- No excess observed in any of the three signal regions.

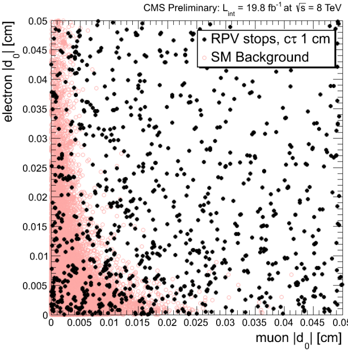
Signal region	Expected	Observed
$\lvert d_0 \rvert \in (0.02, 0.05)$ cm	$18.0 \pm 0.5 \pm 3.8$	19
$\lvert d_0 \rvert \in (0.05, 0.1)$ cm	$1.01 \pm 0.06 \pm 0.30$	0
$\lvert d_0 \rvert \in (0.1, 2)$ cm	$0.051 \pm 0.015 \pm 0.010$	0

Displaced SUSY ($c\tau\sim1\,\mathrm{cm}$)



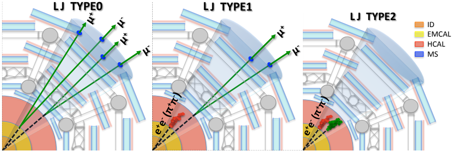
- Isolated $e^{\pm}\mu^{\mp}$ pairs searched for with large transverse impact parameters ($|d_0|$).
- Leptons from LL particle decays have broad $|d_0|$ distributions.
- No common vertex required.
- Limits set on RPV stop pair production in a "displaced SUSY" model.

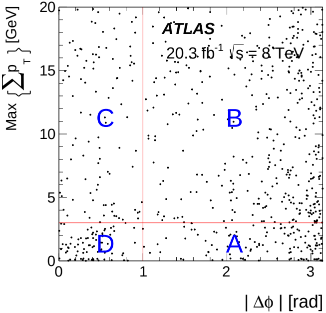




Displaced lepton jets (LJ) ($c\tau \sim 10\,\mathrm{cm}$)

- 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	$40 \pm 11 \pm 9$	$29 \pm 9 \pm 29$
Multi-jets (ABCD)	$70 \pm 58 \pm 11$	$12 \pm 9 \pm 2$
Total background	$110 \pm 59 \pm 14$	$41 \pm 12 \pm 29$

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

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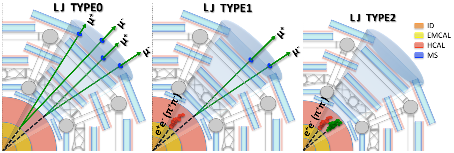
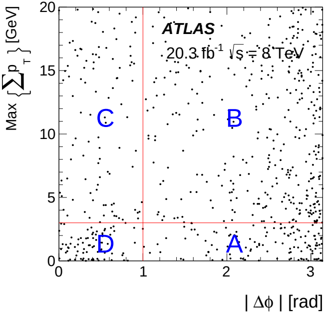
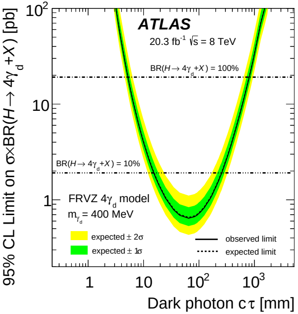
- Cosmic background estimated from empty bunch crossing data.
- Multijets estimated with data-driven ABCD method.

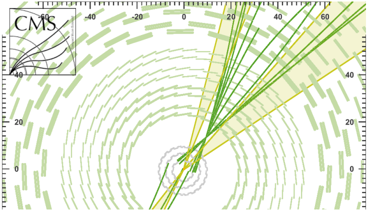


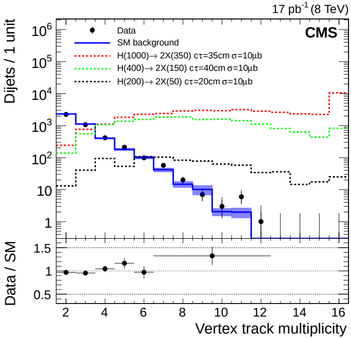
- Limits set on dark photons (γ_d).





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

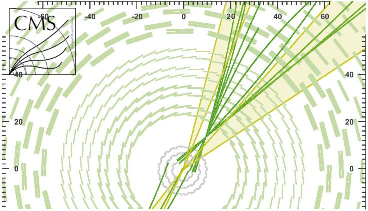




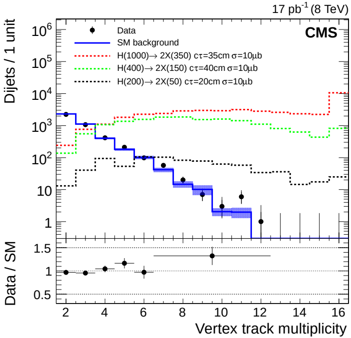
- Displaced vertices formed from tracks in pairs of jets.
- Several variables used to select vertices compatible with signal.
- Multijet background estimated from data with ABCDEFGH method.
- Two sets of selections considered; background describes the data well for both.

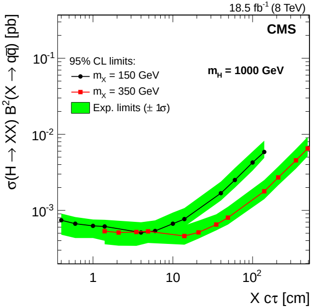
	Loose selection	Tight selection
Expected	$1.56 \pm 0.25 \pm 0.47$	$1.13 \pm 0.15 \pm 0.50$
Observed	2	1

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).





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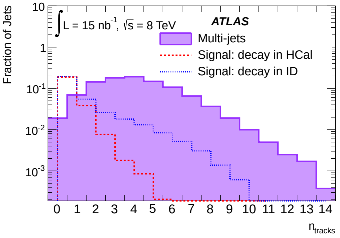
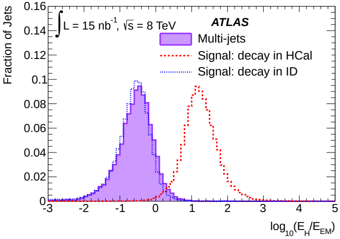
Trackless jets ($c\tau \sim 100\,\mathrm{cm}$)

- 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.



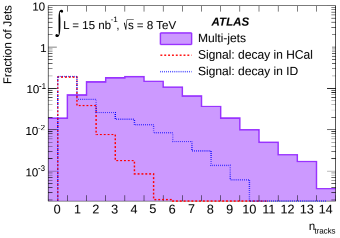
- No excess of events observed.

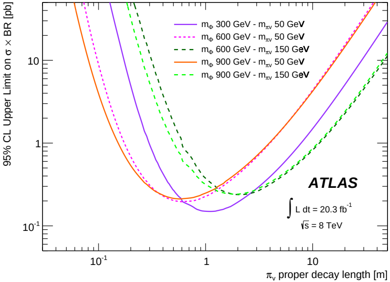
Background	Expected events
SM Multi-jets	23.2 ± 8.0
Cosmic rays	0.3 ± 0.2
Total Expected Background	23.5 ± 8.0
Data	24

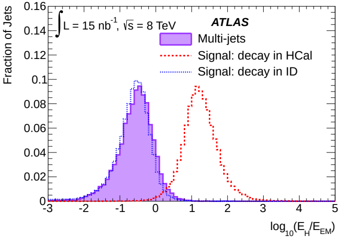


Trackless jets ($c\tau \sim 100\,\mathrm{cm}$)

- 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.
- Limits set on hidden valley pions (π_v).

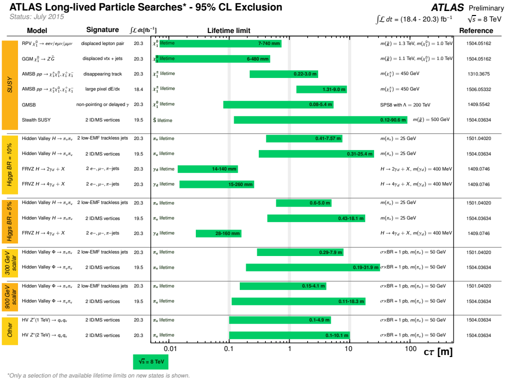






Conclusion

- 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!