Searches for long-lived particles in ATLAS

LHCP2020 @ Online

28 / 05 / 2020

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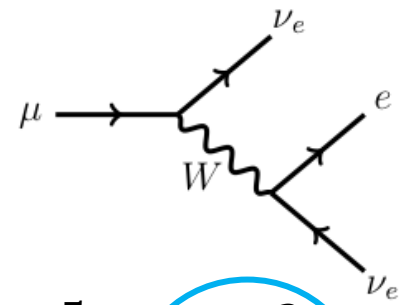
on behalf of the ATLAS Collaboration

Why is it important to search for long-lived particles?

- We have not found BSM yet
- ATLAS searches are designed primarily to find prompt BSM particles
  - We could miss an important phase space



- **Long-lived particles** appear in many BSM models if
  - Small coupling with SM
  - Heavy intermediator
  - Small mass difference
  - …

$$\tau^{-1} = \Gamma \propto g^4 \cdot \frac{m_\mu^5}{m_W^4} \cdot I\left(\frac{m_e^2}{m_\mu^2}\right)$$

$$\lim_{x \to 1} I(x) = 0$$

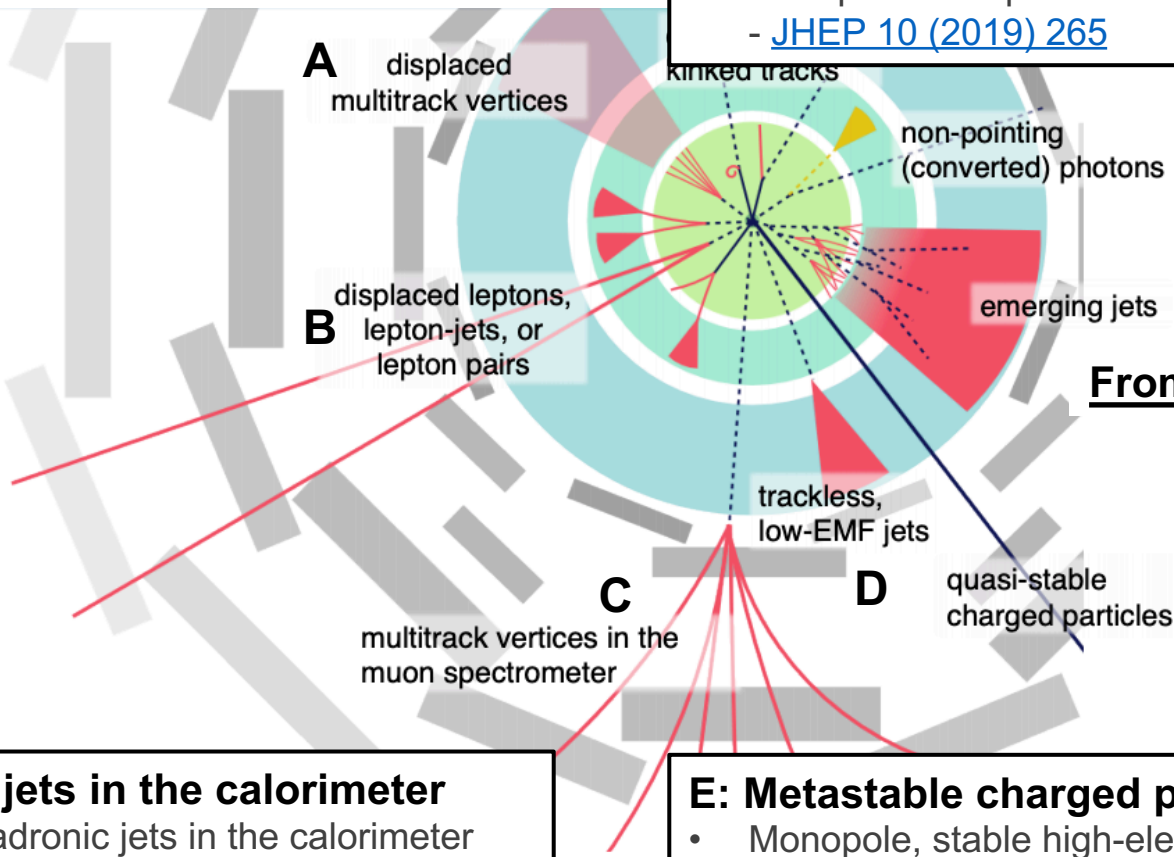
- Long-lived particles leave characteristic signatures in the detector
  - Special trigger, object reconstruction, identification, background estimation

Recent (~ 1 year) results of long-lived searches in ATLAS

A, C: Displaced vertex
- Displaced vertex + displaced muon
  - Submitted to PRD, arXiv: 2003.11956
- Displaced Inner Detector + Muon Spectrometer
  - Phys. Rev. D 101 (2020) 052013

B: Displaced leptons
- Search for displaced lepton-jets
  - EPJC-19-09-019, arXiv: 1909.01246
- Displaced lepton pairs
  - Phys. Lett. B 801 (2020) 135114
- Prompt and Displaced Heavy Neutral Lepton
  - JHEP 10 (2019) 265

This talk



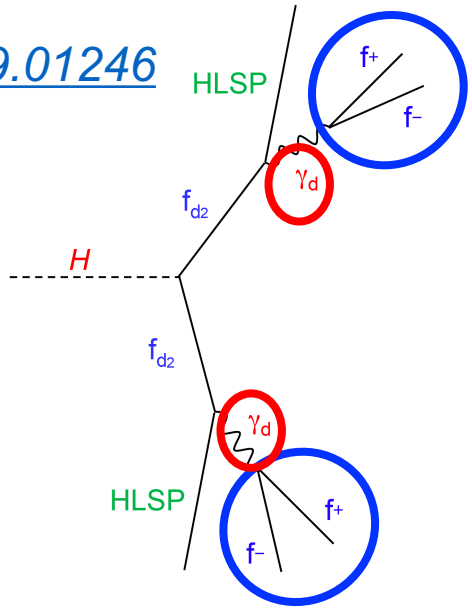
From Heather Russell

D: Displaced jets in the calorimeter
- Displaced hadronic jets in the calorimeter
  - Eur. Phys. J. C 79 (2019) 481
- CalRatio jet reinterpretation
  - ATL-PHYS-PUB-2020-007

E: Metastable charged particles
- Monopole, stable high-electric-charge objects
  - Phys. Rev. Lett. 124 (2020) 031802
- Pixel dE/dx Calorimeter and muon timing
  - Phys. Rev. D 99 (2019) 092007

Displaced lepton-jets

2015-2016 data, 36.1 fb^{-1}
Accepted by EPJC , arXiv: *1909.01246*



Vector portal model

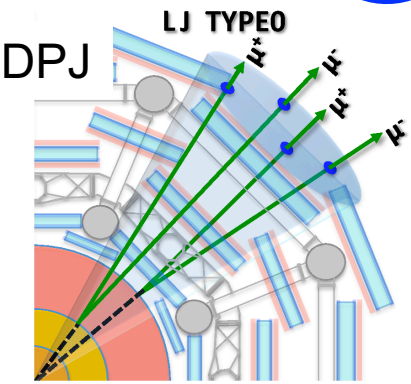
FRVZ model as a benchmark

- Dark photon couples with the SM. Small mixing results in a long-lived dark photon
- Assuming dark photon mass of 400 MeV, resulting in collimated fermions: Dark Photon jet (DPJ)

Dark Photon Jet Reconstruction

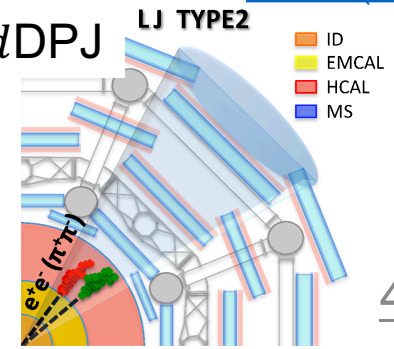
- Muonic DPJ (μDPJ) ($\gamma_d \rightarrow \mu\mu$)
  - Collimated muon tracks (>=2) in Muon Spectrometer
  - No Inner Detector tracks and jets around DPJ
- Hadronic DPJ (hadDPJ) ($\gamma_d \rightarrow ee, \pi\pi$)
  - Jets with large E_{had}/E_{em} ratio (CalRatio)
  - No Inner Detector tracks and muons around DPJ
- Background rejection using BDT
  - cosmic muon (μDPJ), multi-jets (hadDPJ)

μDPJ



JHEP11(2014)088

hadDPJ



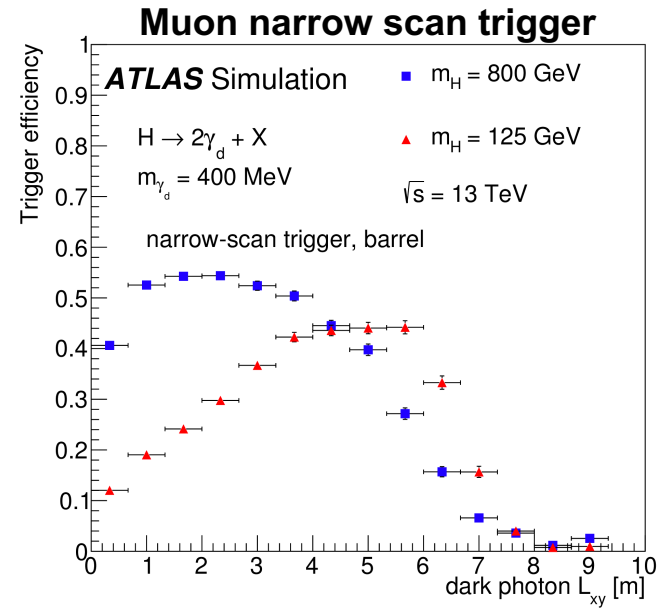
Displaced lepton-jets

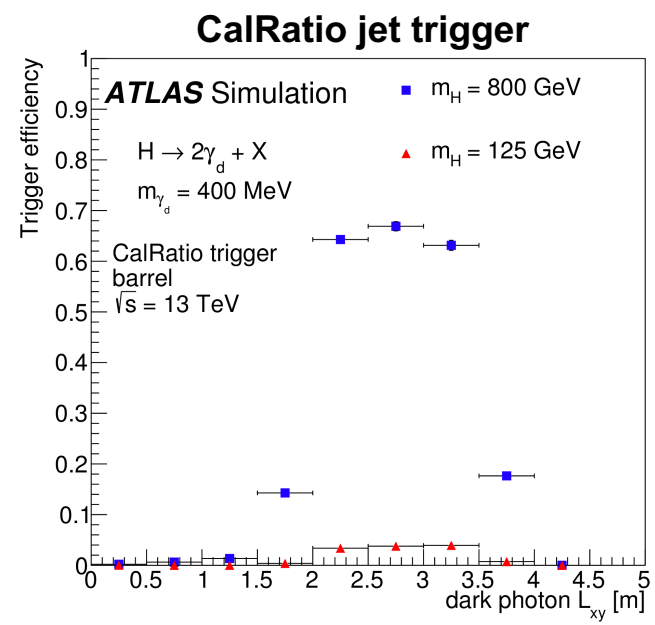
Trigger

- Three Muon Spectrometer tracks (pT > 6 GeV)

- Muon narrow scan trigger:
  - Single muon at L1 (pT > 20 GeV)
  - At HLT, search a 2nd muon (pT > 6-15 GeV) in a cone of ΔR = 0.5 around L1 candidate

- CalRatio jet trigger:
  - Single jets (pT > 60 GeV) with large E_{had}/E_{em}
  - No Inner Detector tracks within ΔR < 0.2

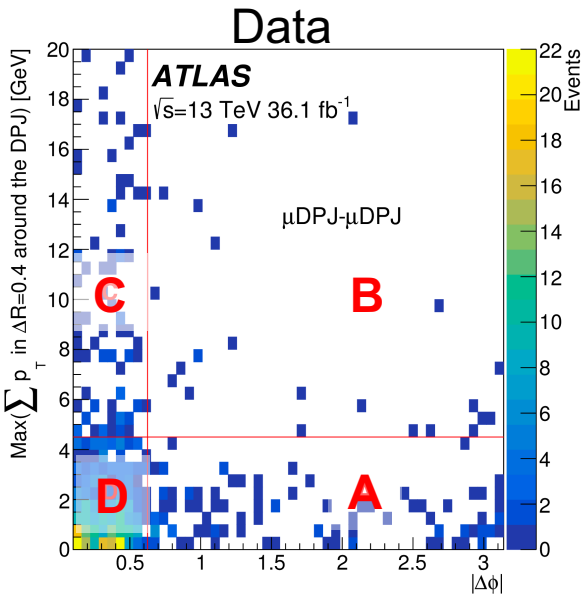


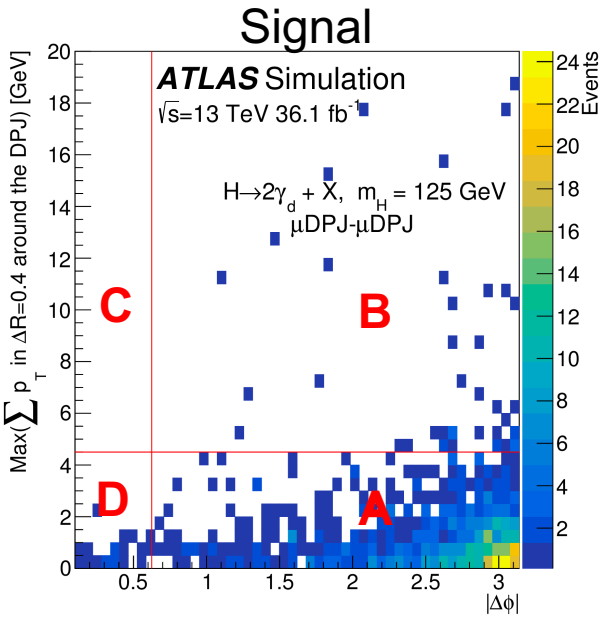


Displaced lepton-jets

Background estimation

- ABCD method:
  - Track isolation (sum of track pT around DPJ) (signals are isolated) (A, D)
  - Opening angle($\Delta\phi$) between the 2 DPJs (signals are back-to-back) (A, B)





Result

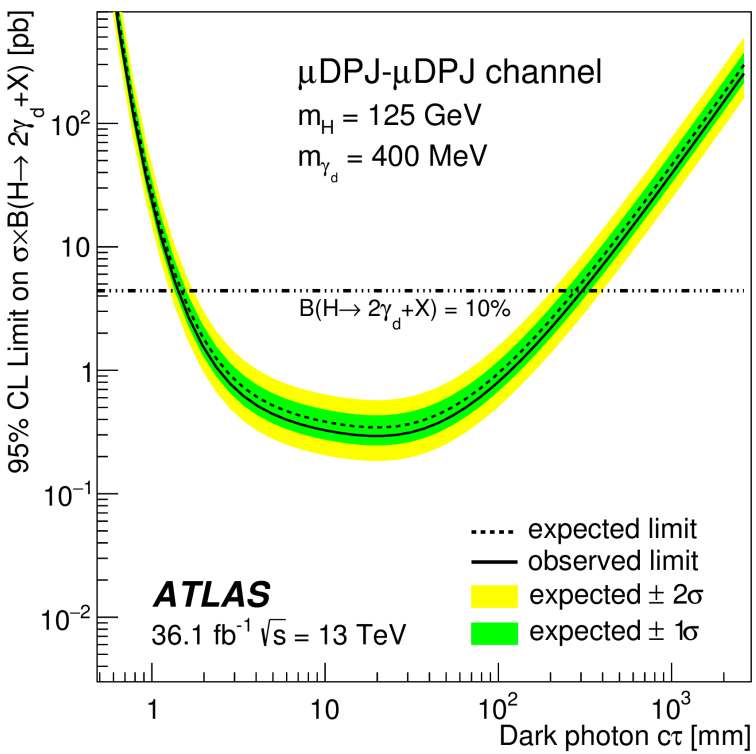
DPJ pair type	B	C	D	Expected A	A
μDPJ–μDPJ	24	92	463	128 ± 26 (stat.) ± 3 (syst.)	113
μDPJ–hDPJ	8	2	45	177 ± 86 (stat.) ± 4 (syst.)	179
hDPJ–hDPJ	13	2	15	97 ± 48 (stat.) ± 2 (syst.)	69

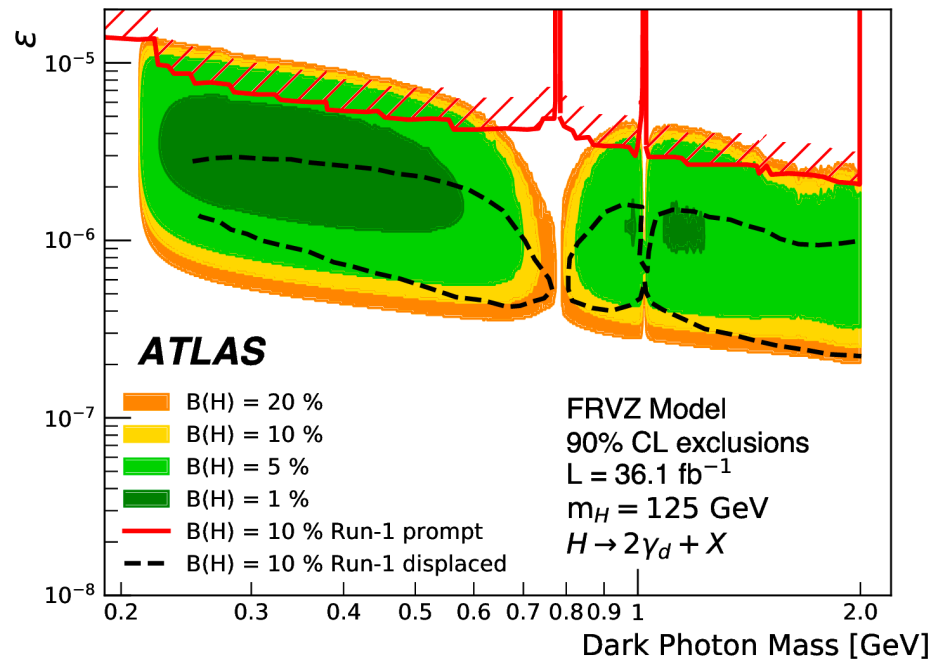
No excess

Displaced lepton-jets

Interpretation

- Set upper limits on $\sigma \times Br$ as a function of the dark photon decay length
  - For $H \rightarrow 2\gamma_d + X$, $\sigma \times Br$ > 4 pb, 1.5 mm < $c\tau$ < 307 mm
- Exclusion limits on dark photon mass vs kinetic mixing parameter (ϵ)
  - Excluded lower ϵ region (longer lifetime) seamlessly not covered in the previous prompt/displaced lepton-jet analysis in Run-1



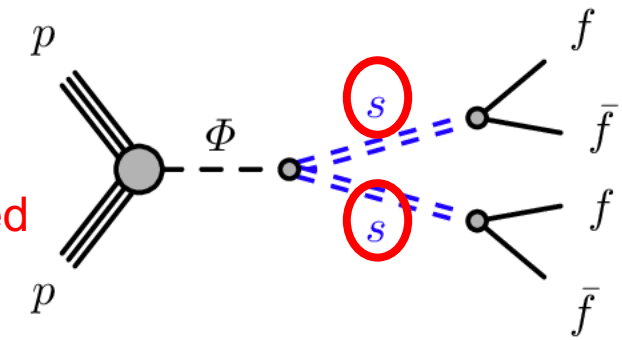


Displaced jets in the ID & MS

2016 data, 33 fb^{-1}
Phys. Rev. D 101 (2020) 052013

Hidden Sector model (HS)

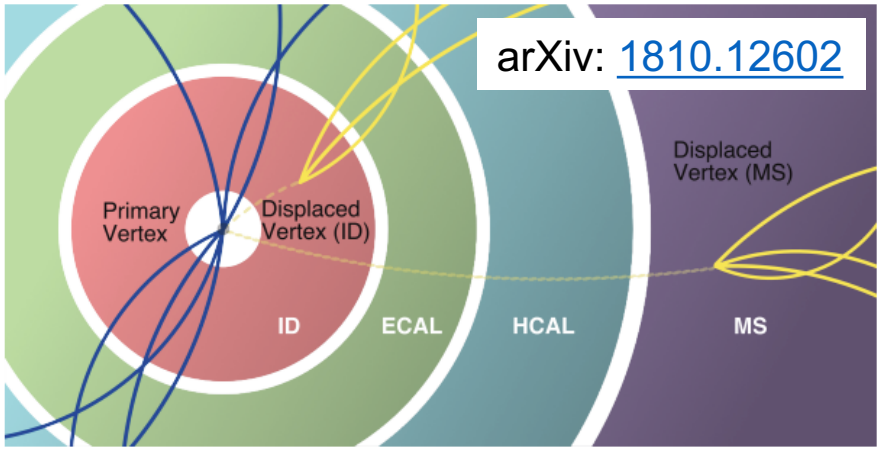
- Neutral scalar (s) decays into a SM fermion pair through their mixing. Small mixing results in long-lived



Target objects

- Displaced vertex in Inner Detector
  - Reconstructed from tracks with a large impact parameter.

Large Radius Tracking (LRT)
- ATL-PHYS-PUB-2017-014,
Displaced Vertex reconstruction
- ATL-PHYS-PUB-2019-013



- Displaced vertex in Muon spectrometer
  - Reconstructed using >=3 MS tracklets

Displaced Muon vertex reconstruction
- 2014 JINST 9 P02001

Muon RoI Cluster trigger
- 2013 JINST 8 P07015

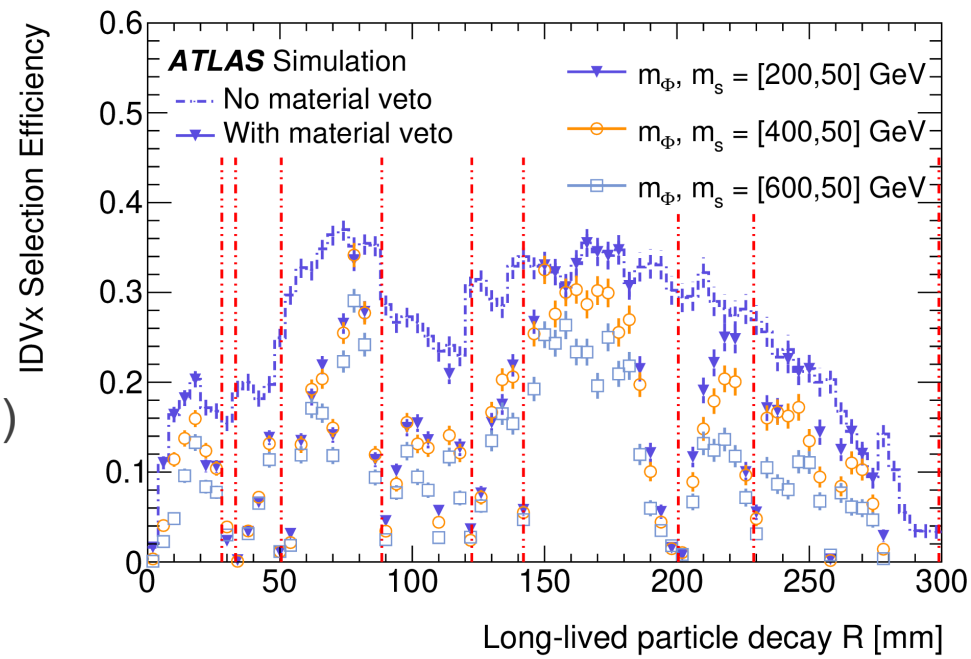
Trigger: Muon RoI Cluster trigger:

Two muons at L1 (pT > 10 GeV). At HLT, require 3-4 muons within ΔR =0.4

Displaced jets in the ID & MS

Displaced jets selection

- Muon spectrometer Vertex (MSVx)
  - Isolated from jets and ID tracks (punch-through jets)
  - minimum n_{MDT}, n_{RPC} and n_{TGC} (cosmic muon, electric noise)
  - maximum n_{MDT} (noise burst)



- Inner Detector Vertex (IDVx)
  - Material veto (SM hadronic interactions)
  - Vertex fit quality (random crossing)
  - DV d_0 > 4 mm (b-hadron)
  - N of associated tracks (n_{trk}) ≥ 4
  - Vertex mass (m_{vtx}) ≥ 3 GeV

- Angular separation of ΔR (MSVx, IDVx) > 0.4

Displaced jets in the ID & MS

Background events :
- Single muon trigger
- Veto Muon RoI trigger
- Two muons (>25 GeV, >20 GeV)

Background estimation

- Data-driven background estimation

IDVx requirement \ MSVx requirement	Background events	Muon RoI Cluster trigger events with a good MSVx
Has IDVx passing full signal selection	*Bkg+IDVx*	*Sig*
Agnostic to IDVx	*Bkg*	*Sig–IDVx*

$$N_{Sig}^{bkg\ pred} = N_{Sig-IDVx} \times \frac{N_{Bkg+IDVx}}{N_{Bgk}}$$

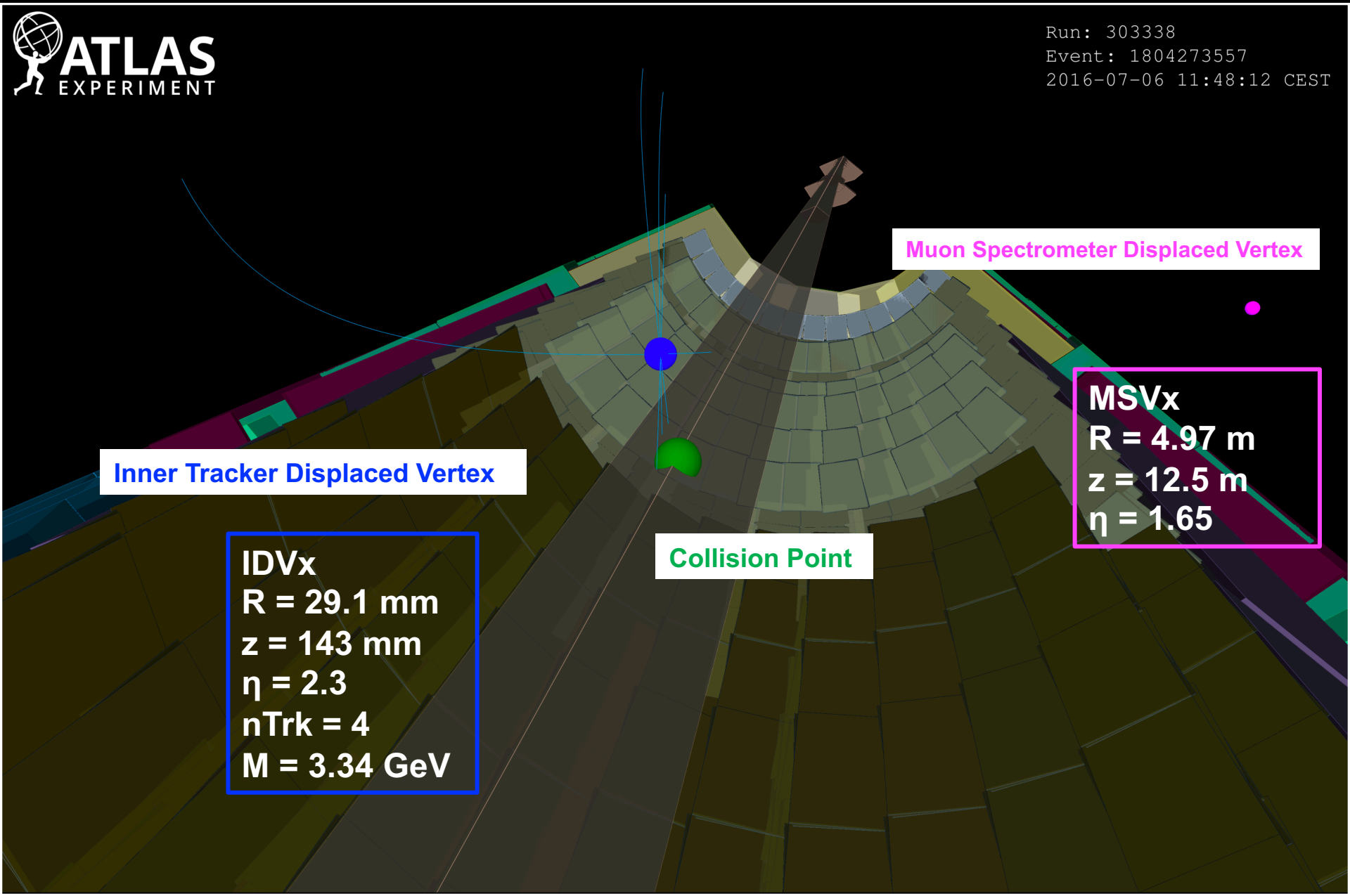
The prob. that background events contain good IDVx $= (7.4 \pm 1.1\ (stat.)) \times 10^{-6}$

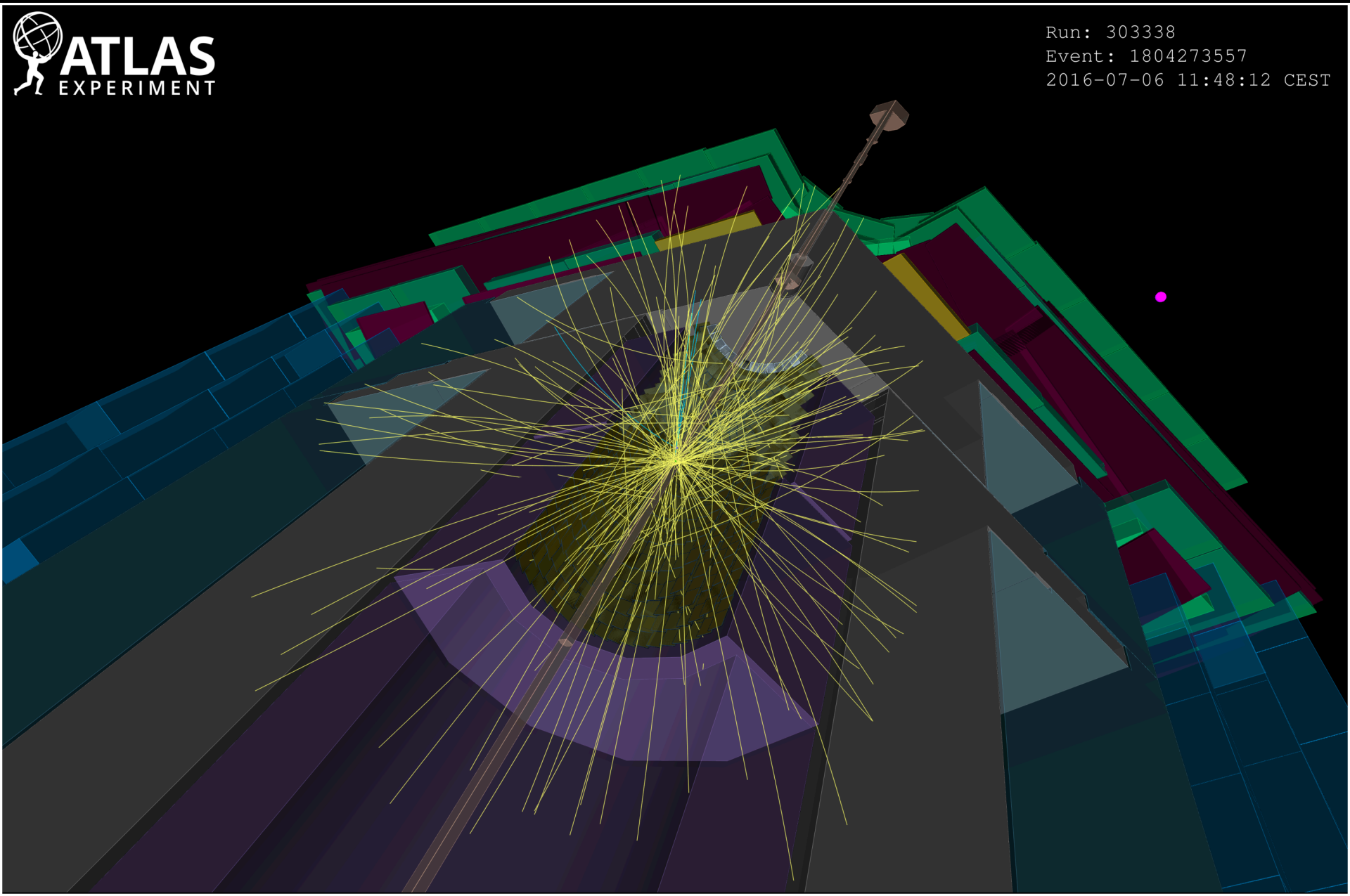
Result

	n_{obs}
Region *Bkg*	6,099,660
Region *Bkg+IDVx*	45
Region *Sig–IDVx*	156,805

	n_{pred}	n_{obs}
Region *Val*, 2-*trk*	11,269 ± 46 (stat.)	11,470
Region *Trig*, 3-*trk*	1750 ± 64 (stat.)	2132
Region *Sig*	1.16 ± 0.18 (stat.) ± 0.29 (syst.)	1

No excess

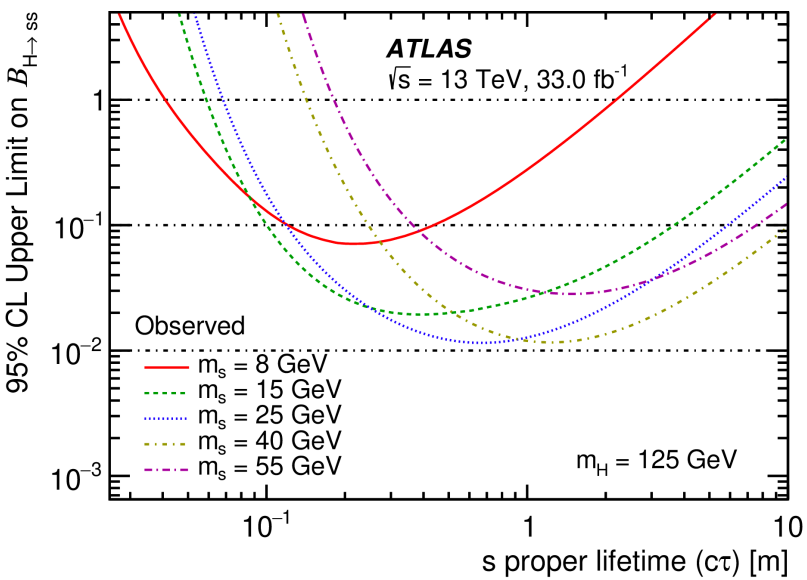

ATLAS EXPERIMENT
Run: 303338
Event: 1804273557
2016-07-06 11:48:12 CEST
Muon Spectrometer Displaced Vertex
MSVx
R = 4.97 m
z = 12.5 m
η = 1.65
Inner Tracker Displaced Vertex
IDVx
R = 29.1 mm
z = 143 mm
η = 2.3
nTrk = 4
M = 3.34 GeV
Collision Point

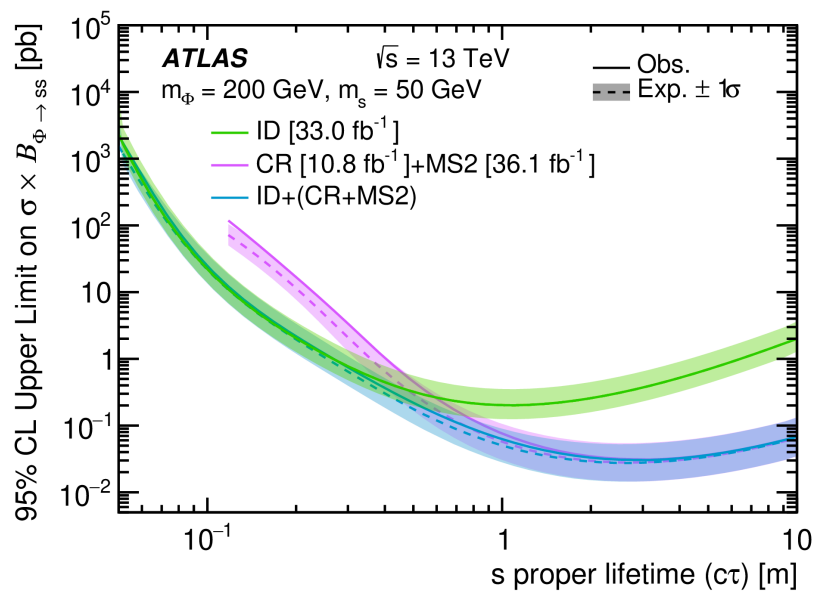

ATLAS
EXPERIMENT
Run: 303338
Event: 1804273557
2016-07-06 11:48:12 CEST

Displaced jets in the ID & MS

Interpretation

- Limits on HS models using a scalar mediator with mass from 125 to 1000 GeV, decaying into pairs of long-lived scalars (s) with mass from 8 GeV to 400 GeV. Extending exclusion limits in 5 cm < $c\tau$ < 1 m
- Greater sensitivity for low-mass, long-lived scalars at shorter lifetimes than the previously published searches.





Complementary to the previous analysis:

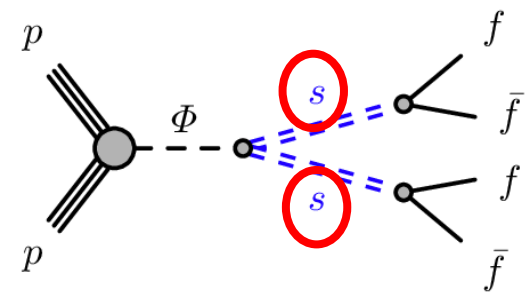
- MS-only analysis (1710.04901)
- Hadronic calorimeter analysis (1902.03094)

Reinterpretation of Displaced hadronic jets in the calorimeter

ATL-PHYS-PUB-2020-007

Displaced jets in the hadronic calorimeter (Eur. Phys. J. C 79 (2019) 481)

- Targeted Hidden Sector model
- Long-lived scalars decay in the hadronic calorimeter
- Key object is a jet with large E_{had}/E_{em} ratio (CalRatio jets)

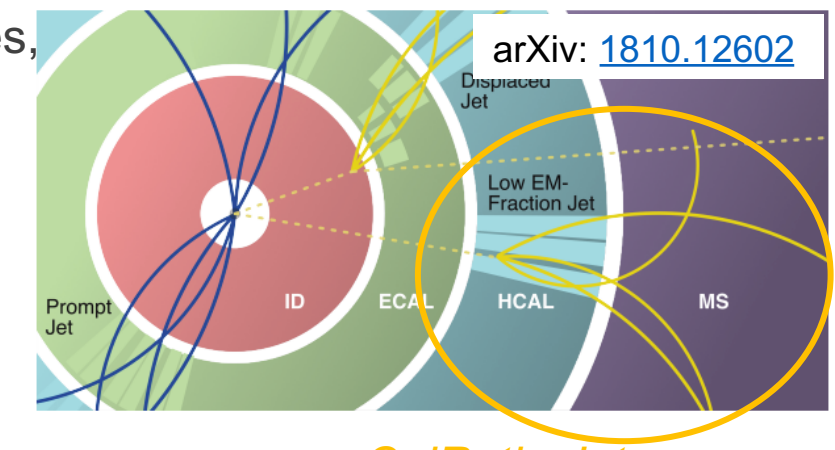


result:

Region	Estimation	Observed
Low-E_T	$5.3^{+2.1}_{-1.6}$	7
High-E_T	$8.5^{+2.3}_{-2.0}$	10

Reinterpretation

- Various BSM models predict long-lived particles, which can be constrained by the previously published analysis
- Difficult to reproduce a physics result exactly due to the unconventional techniques (trigger/reconstruction/machine learning).



CalRatio Jet

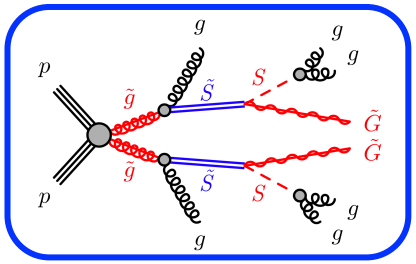
RECAST framework

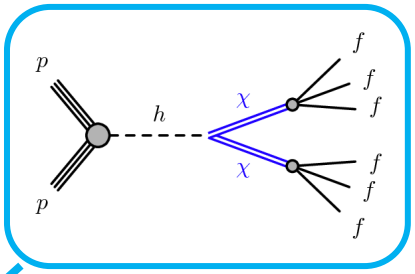
Other RECAST reinterpretation: ATL-PHYS-PUB-2019-032

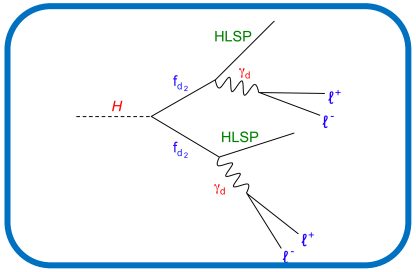
Reinterpretation of Displaced hadronic jets in the calorimeter

Reinterpreted signal models

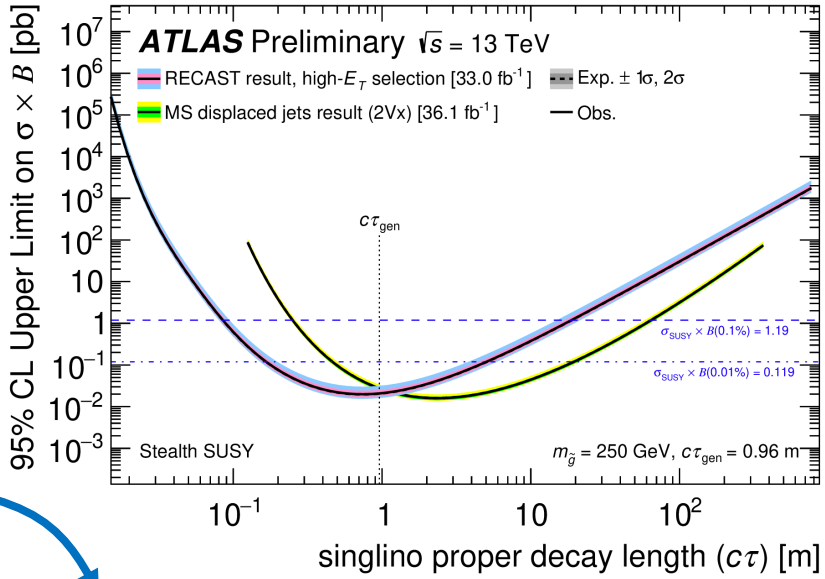
& Exclusion limits



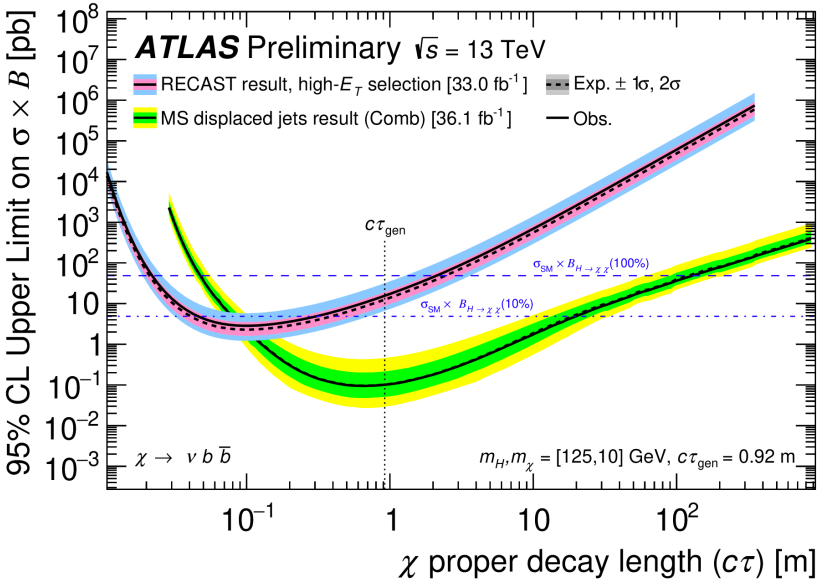




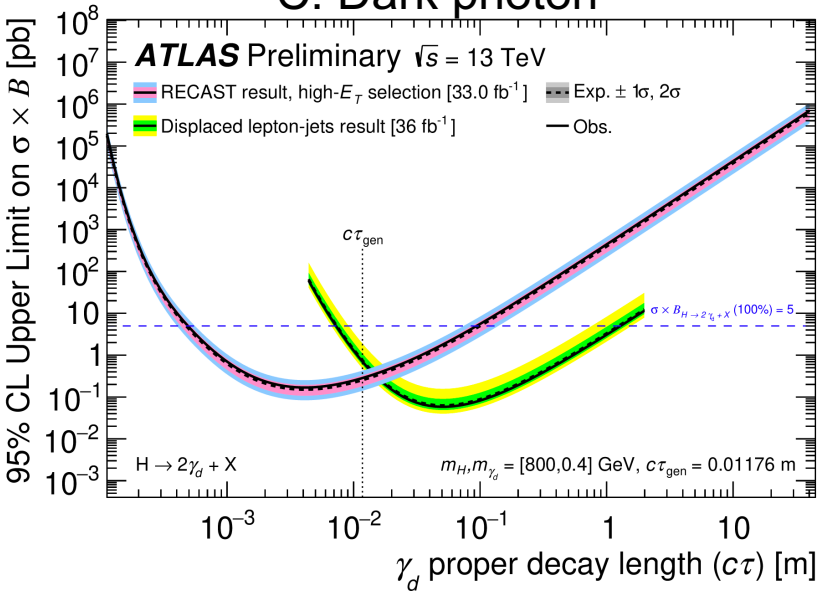
A. Stealth SUSY



B. Higgs Portal baryogenesis



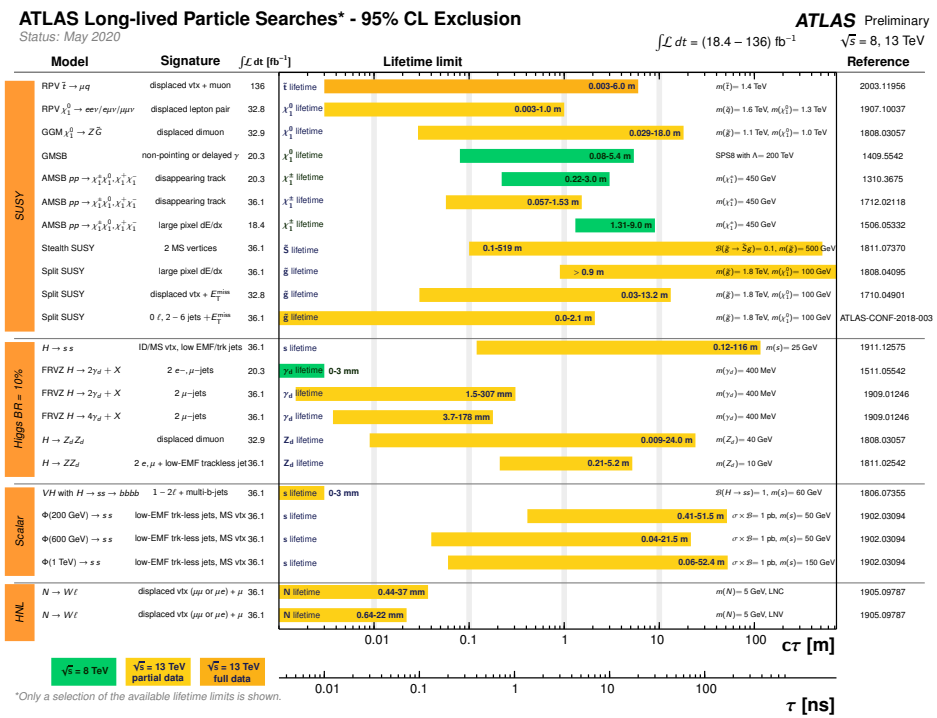
C. Dark photon



Summary

- Long-lived particles appear in various BSM models
  - Characteristic / challenging signature

ATL-PHYS-PUB-2020-011



- No deviation from the SM yet
  - but we continue to develop new techniques to extend the uncovered discovery reach

- We show a part of Run-2 full data. New results with Run-2 full data are being analysed carefully. Stay tuned!