



# Search for BSM Physics Using Challenging Signatures with the ATLAS Detector

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# Searches for BSM Physics at ATLAS

► Lots of BSM ground covered in direct searches

- no evidence using more conventional signatures

## non-SUSY

ATLAS Exotics Searches\* - 95% CL Upper Exclusion Limits  
Status: May 2019

Model	$\ell, \gamma$	Jets†	$E_T^{\text{miss}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0 e, \mu$	$1-4 j$	36.1	$M_D$ <b>7.7 TeV</b>	$n=2$ 1711.03301
	ADD non-resonant $\gamma\gamma$	$2 \gamma$	-	36.7	$M_S$ <b>8.6 TeV</b>	$n=3$ HLZ NLO 1707.04147
	ADD QBH	-	$2 j$	-	$M_h$ <b>8.9 TeV</b>	1703.09127
	ADD BH high $\Sigma p_T$	$\geq 1 e, \mu$	$\geq 2 j$	-	$M_h$ <b>8.2 TeV</b>	1606.02265
	ADD BH multijet	-	$\geq 3 j$	-	$M_h$ <b>9.55 TeV</b>	$n=6, M_D=3 \text{ TeV}, \text{rot BH}$ 1512.02586
	RS1 $G_{KK} \rightarrow \gamma\gamma$	$2 \gamma$	-	-	$G_{KK}$ mass <b>4.1 TeV</b>	$k/M_{Pl}=0.1$ 1707.04147
	Bulk RS $G_{KK} \rightarrow WW/ZZ$	multi-channel	-	-	$G_{KK}$ mass <b>2.3 TeV</b>	1808.02380
Gauge bosons	Bulk RS $G_{KK} \rightarrow WW + qqqq$	$0 e, \mu$	$2 j$	-	$G_{KK}$ mass <b>1.6 TeV</b>	ATLAS-CONF-2019-003
	Bulk RS $G_{KK} \rightarrow \tau\tau$	$1 e, \mu$	$\geq 1 b, \geq 1 J/2$	Yes	$3.8 \text{ TeV}$	1804.10823
	2UED / RPP	$1 e, \mu$	$\geq 2 b, \geq 3 j$	Yes	$3.6 \text{ TeV}$	1803.09678
	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	$Z'$ mass <b>5.1 TeV</b>	1903.06248
	SSM $Z' \rightarrow \tau\tau$	$2 \tau$	-	-	$Z'$ mass <b>2.42 TeV</b>	1709.07242
	Leptophobic $Z' \rightarrow bb$	-	$2 b$	-	$Z'$ mass <b>2.1 TeV</b>	1805.09299
	Leptophobic $Z' \rightarrow tt$	$1 e, \mu$	$\geq 1 b, \geq 1 J/2$	Yes	$Z'$ mass <b>3.0 TeV</b>	1804.10823
CI	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes	$W'$ mass <b>6.0 TeV</b>	CERN-EP-2019-100
	SSM $W' \rightarrow \nu\nu$	$1 \tau$	-	Yes	$W'$ mass <b>3.7 TeV</b>	1801.06992
	HVT $V' \rightarrow WZ$ or $qqqq$ model B	$0 e, \mu$	$2 j$	-	$V'$ mass <b>3.6 TeV</b>	ATLAS-CONF-2019-003
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel	-	-	$V'$ mass <b>2.93 TeV</b>	1712.06518
	LRSM $W_R \rightarrow tb$	multi-channel	-	-	$W_R$ mass <b>3.25 TeV</b>	1807.10473
	LRSM $W_R \rightarrow \mu N_R$	$2 \mu$	$1 j$	-	$W_R$ mass <b>5.0 TeV</b>	1904.12679
	DM	CI $qqqq$	-	$2 j$	-	$A$ <b>21.8 TeV</b>
CI $\ell\ell qq$		$2 e, \mu$	-	-	$A$ <b>40.0 TeV</b>	$\eta_{LL}$ 1707.02424
CI $tttt$		$\geq 1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	$A$ <b>2.57 TeV</b>	$ C_{6\ell}  = 4\pi$ 1811.02305
LQ	Axial-vector mediator (Dirac DM)	$0 e, \mu$	$1-4 j$	Yes	$m_{\text{mediator}}$ <b>1.55 TeV</b>	$g_{\phi}=0.25, g_{\ell}=1.0, m(\chi) = 1 \text{ GeV}$ 1711.03301
	Colored scalar mediator (Dirac DM)	$0 e, \mu$	$1-4 j$	Yes	$m_{\text{mediator}}$ <b>1.67 TeV</b>	$g_{\ell}=1.0, m(\chi) = 1 \text{ GeV}$ 1711.03301
	VV $\chi\chi$ EFT (Dirac DM)	$0 e, \mu$	$1 j, \leq 1 J$	Yes	$M_{\chi}$ <b>700 GeV</b>	$m(\chi) < 150 \text{ GeV}$ 1608.02372
	Scalar reson. $\phi \rightarrow t\bar{t}$ (Dirac DM)	$0-1 e, \mu$	$1 b, 0-1 J$	Yes	$m_{\phi}$ <b>3.4 TeV</b>	$y = 0.4, \lambda = 0.2, m(\chi) = 10 \text{ GeV}$ 1812.09743
Heavy quarks	Scalar LQ $1^{st}$ gen	$1, 2 e$	$\geq 2 j$	Yes	LQ mass <b>1.4 TeV</b>	$\beta = 1$ 1902.00377
	Scalar LQ $2^{nd}$ gen	$1, 2 \mu$	$\geq 2 j$	Yes	LQ mass <b>1.56 TeV</b>	$\beta = 1$ 1902.00377
	Scalar LQ $3^{rd}$ gen	$2 \tau$	$2 b$	-	LQ mass <b>1.03 TeV</b>	$\beta(LQ^{\pm} \rightarrow b\tau) = 1$ 1902.08103
	Scalar LQ $3^{rd}$ gen	$0-1 e, \mu$	$2 b$	Yes	LQ mass <b>970 GeV</b>	$\beta(LQ^{\pm} \rightarrow \tau\tau) = 0$ 1902.08103
Excited fermions	VLQ $TT \rightarrow Ht/Zt/Wb + X$	multi-channel	-	-	T mass <b>1.37 TeV</b>	SU(2) doublet 1808.02343
	VLQ $BB \rightarrow Wt/Zb + X$	multi-channel	-	-	B mass <b>1.34 TeV</b>	SU(2) doublet 1808.02343
	VLQ $T_{5/3} T_{5/3} \rightarrow Wt + X$	$2(SS) \geq 3 e, \mu \geq 1 b, \geq 1 j$	Yes	Yes	$T_{5/3}$ mass <b>1.64 TeV</b>	$\beta(T_{5/3} \rightarrow Wt) = 1, c(T_{5/3} Wt) = 1$ 1807.11883
	VLQ $Y \rightarrow Wb + X$	$1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	Y mass <b>1.85 TeV</b>	$\beta(Y \rightarrow Wb) = 1, c_{\ell}(Wb) = 1$ 1812.07343
	VLQ $B \rightarrow Hb + X$	$0 e, \mu, 2 \gamma$	$\geq 1 b, \geq 1 j$	Yes	B mass <b>1.21 TeV</b>	$k_{\beta} = 0.5$ ATLAS-CONF-2018-024
Excited fermions	Excited quark $q^* \rightarrow qg$	-	$2 j$	-	q* mass <b>6.7 TeV</b>	only $u'$ and $d', \Lambda = m(q')$ 1709.10440
	Excited quark $q^* \rightarrow q\gamma$	$1 \gamma$	$1 j$	-	q* mass <b>5.3 TeV</b>	only $u'$ and $d', \Lambda = m(q')$ 1805.09299
	Excited quark $b^* \rightarrow bg$	-	$1 b, 1 j$	-	b* mass <b>2.6 TeV</b>	$\Lambda = 3.0 \text{ TeV}$ 1411.2921
	Excited lepton $\ell^*$	$3 e, \mu$	-	-	$\ell^*$ mass <b>3.0 TeV</b>	$\Lambda = 1.6 \text{ TeV}$ 1411.2921
	Excited lepton $\nu^*$	$3 e, \mu, \tau$	-	-	$\nu^*$ mass <b>1.6 TeV</b>	
Other	Type III Seesaw	$1 e, \mu$	$\geq 2 j$	Yes	$N^{\pm}$ mass <b>560 GeV</b>	$m(W_R) = 4.1 \text{ TeV}, g_{\ell} = g_{\nu}$ 1809.11105
	LRSM Majorana $\nu$	$2 \mu$	$2 j$	-	$N^{\pm}$ mass <b>3.2 TeV</b>	DY production 1710.09748
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2, 3, 4 e, \mu$ (SS)	-	-	$H^{\pm\pm}$ mass <b>870 GeV</b>	DY production, $\beta(H^{\pm\pm} \rightarrow \ell\tau) = 1$ 1411.2921
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3 e, \mu, \tau$	-	-	$H^{\pm\pm}$ mass <b>400 GeV</b>	DY production, $ q  = 5e$ 1812.03673
Multi-charged particles	-	-	-	multi-charged particle mass <b>1.22 TeV</b>	DY production, $ q  = 1g_D, \text{spin } 1/2$ 1905.10130	
Magnetic monopoles	-	-	-	monopole mass <b>2.37 TeV</b>		

\*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter  $j$  ( $J$ ).

excluded masses 1 3 TeV

ATLAS SUSY Searches\* - 95% CL Lower Limits  
July 2019

## SUSY

ATLAS Preliminary  
 $\sqrt{s} = 13 \text{ TeV}$

Model	Signature	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference
Inclusive Searches	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{q}^0$	$0 e, \mu$ mono-jet	$E_T^{\text{miss}}$ 36.1	$\tilde{q}$ [2x, 8x Degen] $m(\tilde{q}^0) < 100 \text{ GeV}$ $\tilde{q}$ [1x, 8x Degen] $m(\tilde{q}^0) - m(\tilde{q}^{\pm}) = 5 \text{ GeV}$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^0$	$0 e, \mu$ 2-6 jets	$E_T^{\text{miss}}$ 36.1	$\tilde{g}$ $m(\tilde{g}^0) < 200 \text{ GeV}$ $\tilde{g}$ $m(\tilde{g}^0) = 900 \text{ GeV}$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^0(\ell\tilde{\ell})^0$	$3 e, \mu$ 4 jets $ee, \mu\mu$ 2 jets	$E_T^{\text{miss}}$ 36.1	$\tilde{g}$ $m(\tilde{g}^0) < 800 \text{ GeV}$ $\tilde{g}$ $m(\tilde{g}^0) - m(\tilde{q}^0) = 50 \text{ GeV}$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^0 WZ\tilde{\chi}_1^0$	$0 e, \mu$ 7-11 jets SS $e, \mu$ 6 jets	$E_T^{\text{miss}}$ 36.1 $E_T^{\text{miss}}$ 139	$\tilde{g}$ $m(\tilde{g}^0) < 400 \text{ GeV}$ $\tilde{g}$ $m(\tilde{g}^0) - m(\tilde{q}^0) = 200 \text{ GeV}$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow n\tilde{\chi}_1^0$	$0-1 e, \mu$ 3 b SS $e, \mu$ 6 jets	$E_T^{\text{miss}}$ 79.8 $E_T^{\text{miss}}$ 139	$\tilde{g}$ $m(\tilde{g}^0) < 200 \text{ GeV}$ $\tilde{g}$ $m(\tilde{g}^0) - m(\tilde{q}^0) = 300 \text{ GeV}$
3 <sup>rd</sup> gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{b}_1^0/\tilde{b}_1^{\pm}$	Multiple Multiple	$E_T^{\text{miss}}$ 36.1 $E_T^{\text{miss}}$ 139	$\tilde{b}_1$ $m(\tilde{b}_1^0) = 300 \text{ GeV}, BR(\tilde{b}_1^{\pm}) = 1$ $m(\tilde{b}_1^0) = 300 \text{ GeV}, BR(\tilde{b}_1^{\pm}) = BR(\tilde{t}_1^{\pm}) = 0.5$ $m(\tilde{b}_1^0) = 200 \text{ GeV}, m(\tilde{t}_1^0) = 300 \text{ GeV}, BR(\tilde{b}_1^{\pm}) = 1$
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{b}_2^0 \rightarrow b\tilde{h}\tilde{\chi}_1^0$	$0 e, \mu$ 6 b	$E_T^{\text{miss}}$ 139	$\tilde{b}_1$ $\Delta m(\tilde{b}_2^0, \tilde{t}_1^0) = 130 \text{ GeV}, m(\tilde{b}_1^0) = 100 \text{ GeV}$ $\Delta m(\tilde{b}_2^0, \tilde{t}_1^0) = 130 \text{ GeV}, m(\tilde{b}_1^0) = 1 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{b}_1^0$ or $\tilde{t}_1^0$	$0-2 e, \mu$ 0-2 jets/1-2 b	$E_T^{\text{miss}}$ 36.1	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 400 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{t}_1^0$	$1 e, \mu$ 3 jets/1 b	$E_T^{\text{miss}}$ 139	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 800 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 b\nu, \tilde{t}_1 \rightarrow \tilde{t}_1 G$	$1 \tau + 1 e, \mu, \tau$ 2 jets/1 b	$E_T^{\text{miss}}$ 36.1	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 0 \text{ GeV}$ $m(\tilde{t}_1^0) = 50 \text{ GeV}$ $m(\tilde{t}_1^0) - m(\tilde{b}_1^0) = 5 \text{ GeV}$
EW direct	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{c}^0/\tilde{c}\tilde{c}, c \rightarrow c\tilde{\chi}_1^0$	$0 e, \mu$ mono-jet	$E_T^{\text{miss}}$ 36.1	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 0 \text{ GeV}$ $m(\tilde{t}_1^0) = 50 \text{ GeV}$ $m(\tilde{t}_1^0) - m(\tilde{b}_1^0) = 5 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t_1 + h$	$1-2 e, \mu$ 4 b	$E_T^{\text{miss}}$ 36.1	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 0 \text{ GeV}, m(\tilde{t}_1^0) - m(\tilde{b}_1^0) = 180 \text{ GeV}$ $m(\tilde{t}_1^0) = 360 \text{ GeV}, m(\tilde{t}_1^0) - m(\tilde{b}_1^0) = 40 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t_1 + Z$	$3 e, \mu$ 1 b	$E_T^{\text{miss}}$ 139	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 0 \text{ GeV}, m(\tilde{t}_1^0) - m(\tilde{b}_1^0) = 40 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t_1 + h, \tilde{t}_1 \rightarrow t_1 + Z$	$0 e, \mu$ 3 b $4 e, \mu$ 0 jets	$E_T^{\text{miss}}$ 36.1 $E_T^{\text{miss}}$ 36.1	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 0 \text{ GeV}$ $m(\tilde{t}_1^0) = 0 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t_1 + h, \tilde{t}_1 \rightarrow t_1 + Z$	$0 e, \mu$ 3 b $4 e, \mu$ 0 jets	$E_T^{\text{miss}}$ 36.1 $E_T^{\text{miss}}$ 36.1	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 0 \text{ GeV}$ $m(\tilde{t}_1^0) = 0 \text{ GeV}$
Long-lived particles	Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet $E_T^{\text{miss}}$ 36.1	$\tilde{\chi}_1^{\pm}$ $m(\tilde{\chi}_1^{\pm}) = 0 \text{ GeV}$ $\tilde{\chi}_1^{\pm}$ $m(\tilde{\chi}_1^{\pm}) = 5 \text{ GeV}$
	Stable $\tilde{g}$ R-hadron	Multiple	$E_T^{\text{miss}}$ 36.1	$\tilde{g}$ $m(\tilde{g}^0) = 100 \text{ GeV}$
	Metastable $\tilde{g}$ R-hadron, $\tilde{g} \rightarrow q\tilde{q}^0$	Multiple	$E_T^{\text{miss}}$ 36.1	$\tilde{g}$ $m(\tilde{g}^0) = 100 \text{ GeV}$
	LFV $p\bar{p} \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow q\ell\tau/\mu\tau$	$4 e, \mu$ 0 jets	$E_T^{\text{miss}}$ 36.1	$\tilde{\nu}_\tau$ $m(\tilde{\nu}_\tau^0) = 100 \text{ GeV}$
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}/\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow WWZZ\ell\ell\nu\nu$	4-5 large-R jets	$E_T^{\text{miss}}$ 36.1	$\tilde{\chi}_1^{\pm}$ $m(\tilde{\chi}_1^{\pm}) = 70 \text{ GeV}$
RPV	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^0, \tilde{q}^0 \rightarrow q\tilde{q}^0$	Multiple	$E_T^{\text{miss}}$ 36.1	$\tilde{g}$ $m(\tilde{g}^0) = 200 \text{ GeV}, \text{bino-like}$
	$\tilde{u}_L\tilde{u}_L \rightarrow \tilde{u}_L^0, \tilde{u}_L^0 \rightarrow b\tilde{s}$	Multiple	$E_T^{\text{miss}}$ 36.1	$\tilde{u}_L$ $m(\tilde{u}_L^0) = 200 \text{ GeV}, \text{bino-like}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\tilde{t}_1^0$	2 jets + 2 b	$E_T^{\text{miss}}$ 36.7	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 100 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\tilde{t}_1^0$	$2 e, \mu$ 2 b $1 \mu$ DV	$E_T^{\text{miss}}$ 36.1 $E_T^{\text{miss}}$ 136	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 100 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\tilde{t}_1^0$	$2 e, \mu$ 2 b $1 \mu$ DV	$E_T^{\text{miss}}$ 36.1 $E_T^{\text{miss}}$ 136	$\tilde{t}_1$ $m(\tilde{t}_1^0) = 100 \text{ GeV}$

\*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

excluded masses 1 2 TeV

► what are conventional signatures?

- jets and leptons (usually high  $p_T$ ) from IP
- large missing  $E_T$  (e.g. non-interacting stable particles)

# BSM Physics with Non-Conventional Signatures

▶ Stable or meta-stable, interacting (charged) particles

- Dirac monopoles
- sleptons
- $R$ -hadrons

▶ Meta-stable non-interacting particles

- neutralinos
- heavy neutrinos
- hidden/dark-sector particles (scalar or vector)

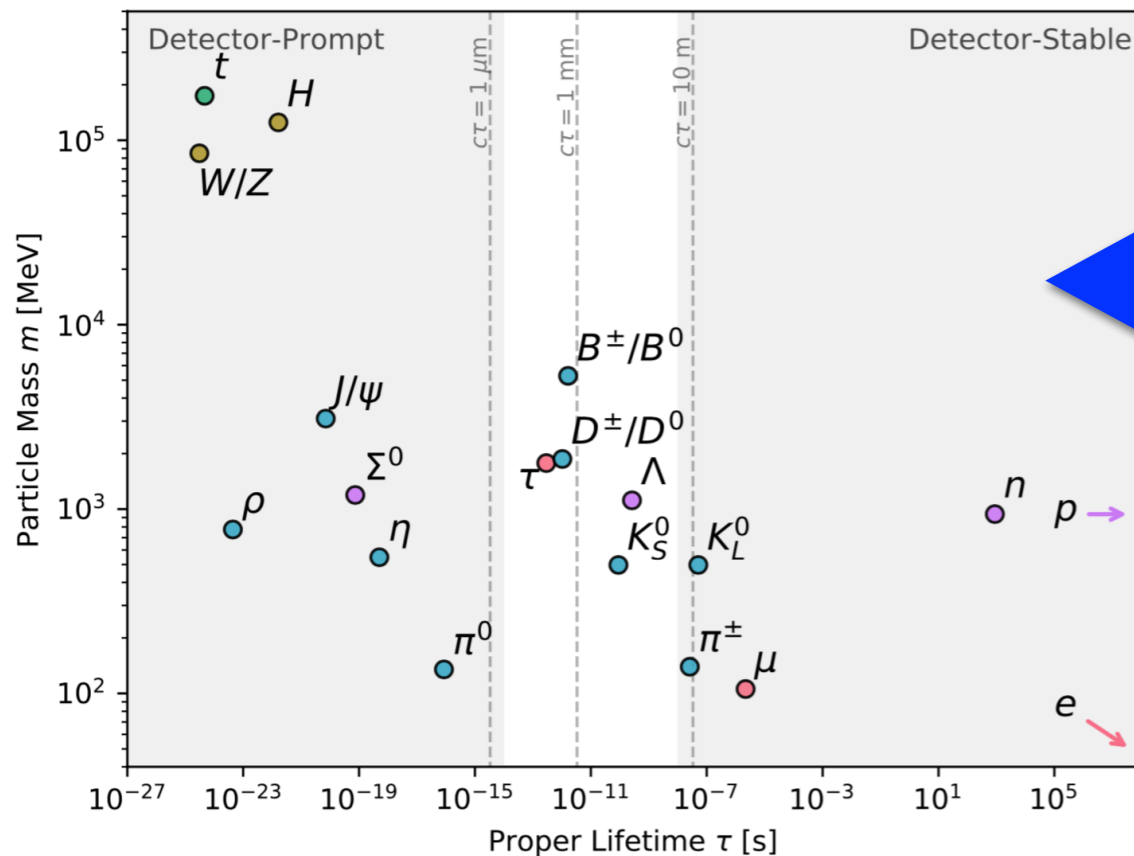


		Small coupling	Small phase space	Scale suppression
SUSY	GMSB			✓
	AMSB		✓	
	Split-SUSY			✓
	RPV	✓		
NN	Twin Higgs	✓		
	Quirky Little Higgs	✓		
	Folded SUSY		✓	
DM	Freeze-in	✓		
	Asymmetric			✓
	Co-annihilation		✓	
Portals	Singlet Scalars	✓		
	ALPs			✓
	Dark Photons	✓		
	Heavy Neutrinos			✓

<https://arxiv.org/abs/1810.12602>

▶ Not crazy... SM itself displays wide range of lifetimes

- near degeneracy in mass spectra
- small couplings
- highly virtual intermediate states



<https://arxiv.org/abs/1810.12602>

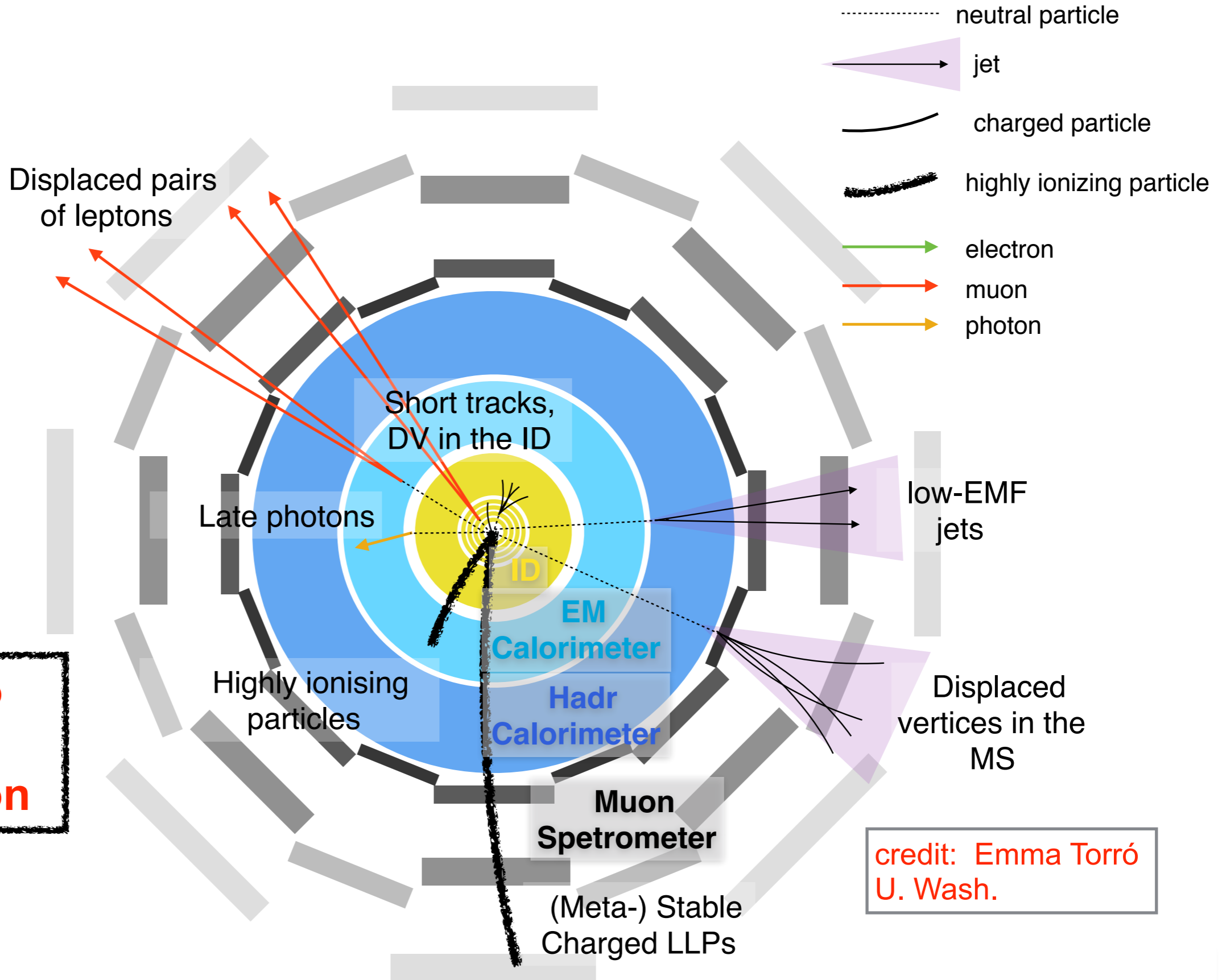
# Detector Signatures: Long-Lived Particles (LLP)

## ▶ Cross-Section of ATLAS detector

### Keywords:

- displaced
- delayed
- disappearing
- emergent
- late
- highly-ionizing

**challenges to offline object reconstruction**



credit: Emma Torró  
U. Wash.



# Trigger Challenges

- ▶ Special triggers dedicated to unusual signatures
  - bandwidth concerns → suppress combinatorics, SM bkgds, etc.
  - signal efficiency → detector limitations (e.g. only barrel, only part of tracking volume, detector elements “point” to IP, etc.)
  - implications for background estimation → MC sometimes not reliable
- ▶ Trigger on something in event not directly associated with the unusual signature...associated production
  - ex. prompt high  $p_T$  lepton/jet/ $\gamma$ , MET...
  - introduces model dependence



# Background Estimation Challenges

- ▶ Often the MC simulation is not reliable enough for some/all bkgd
  - Detector features or measurements not used by many other analyses
  - Backgrounds not simulated at all, or rather poorly → cosmics, beam-related backgrounds, instrumental effects, etc.
- ✓ Use only/mostly data itself to provide the estimates...
  - Ex. special triggers applied to empty bunch crossings
  - “ABCD method” utilizing two independent quantities



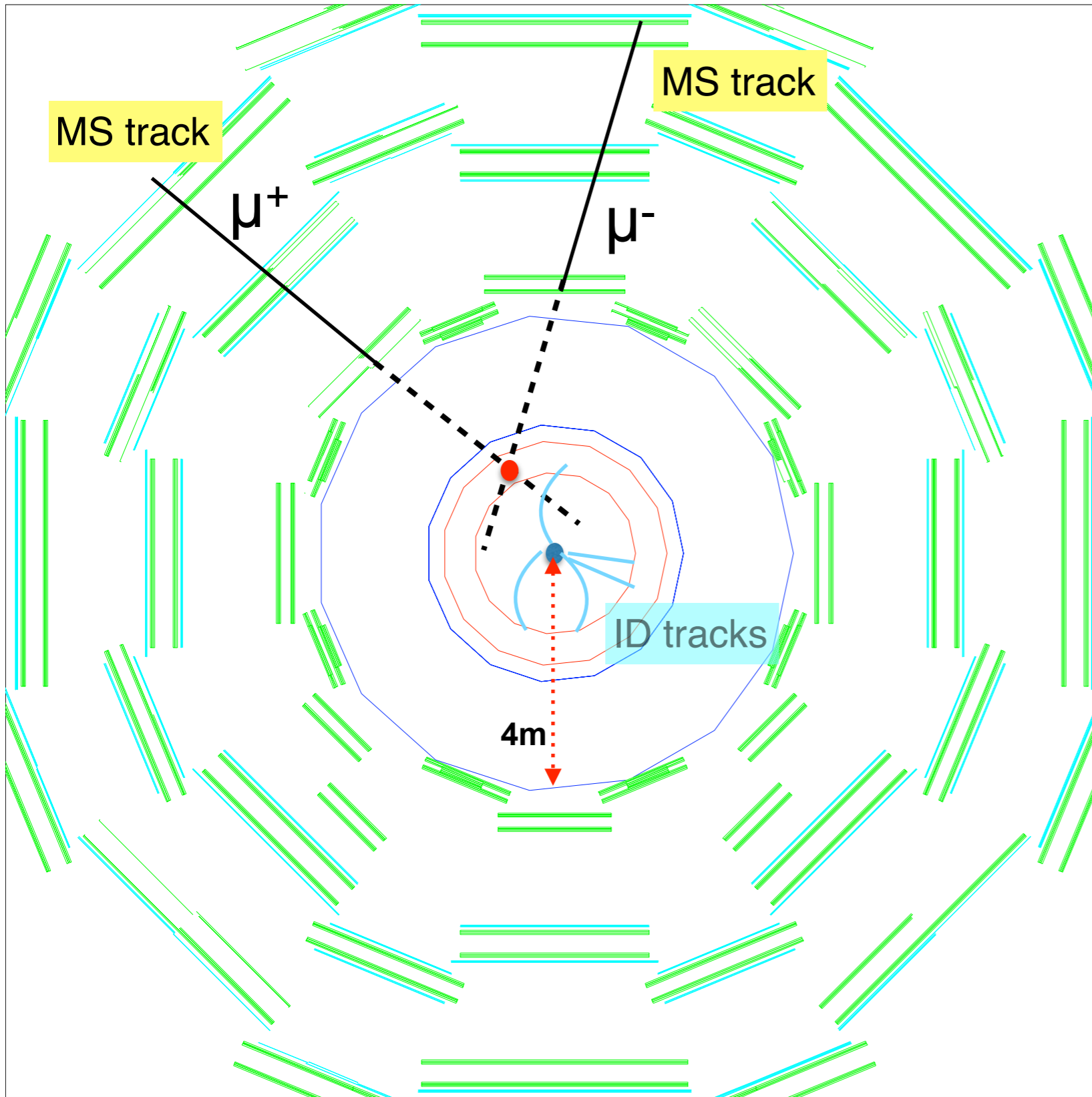
Selection of results that are

- relatively current
- representative of variety of techniques

Selection criteria chosen to be as model-independent as possible  $\Rightarrow$  interpretations in terms of specific baseline signal models



## Displaced dimuon vertices using solely MS tracks



- ▶ Simple approach using what ATLAS measures well/cleanly  $\Rightarrow$  muon tracks!
- ▶ Use only muon tracks not matched to an ID track
- ▶ MS tracks make a vertex

**Sensitivity:**  
Decay lengths of 0.01 - 4m

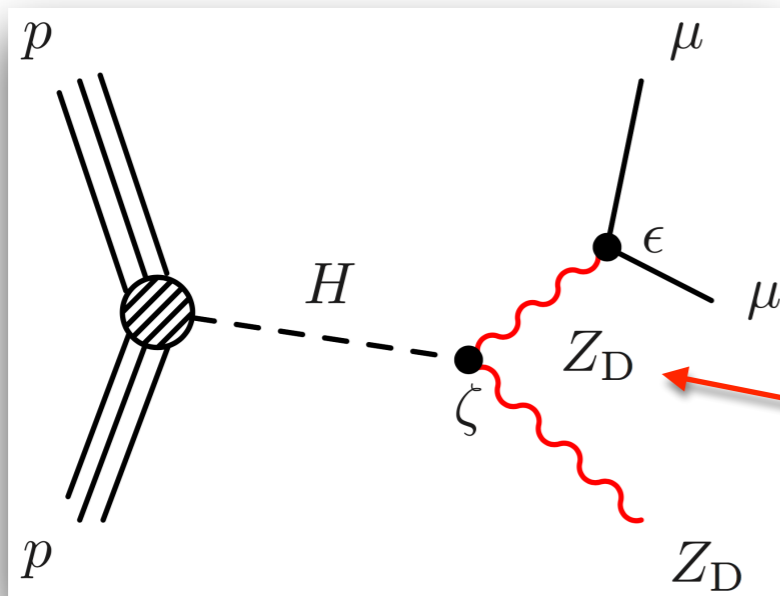
## Interpretations: Signal Models

### Low $p_T$ muons / low mass signal

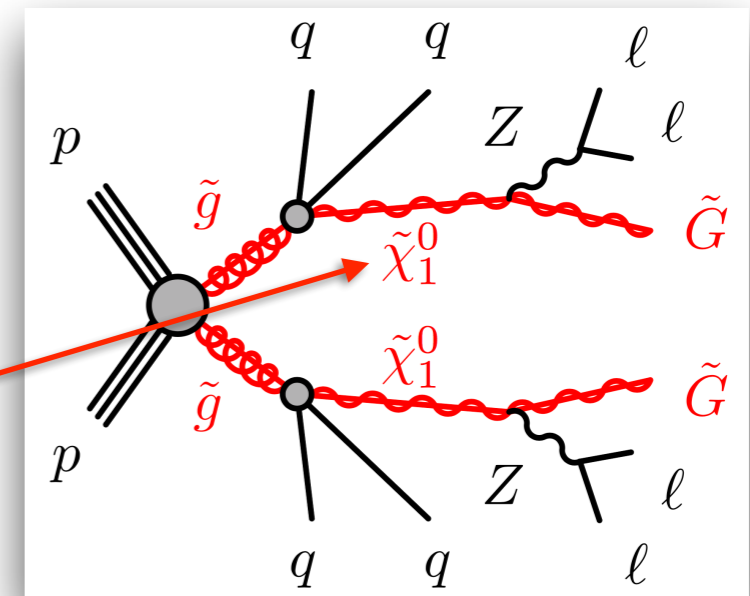
- ▶  $15 < m_{\mu\mu} < 60$  GeV
- ▶ special dimuon trigger
- ▶ backgrounds mostly processes with muons produced far from IP (cosmics, beam, pi/K decay)

### High $p_T$ muons / high mass signal

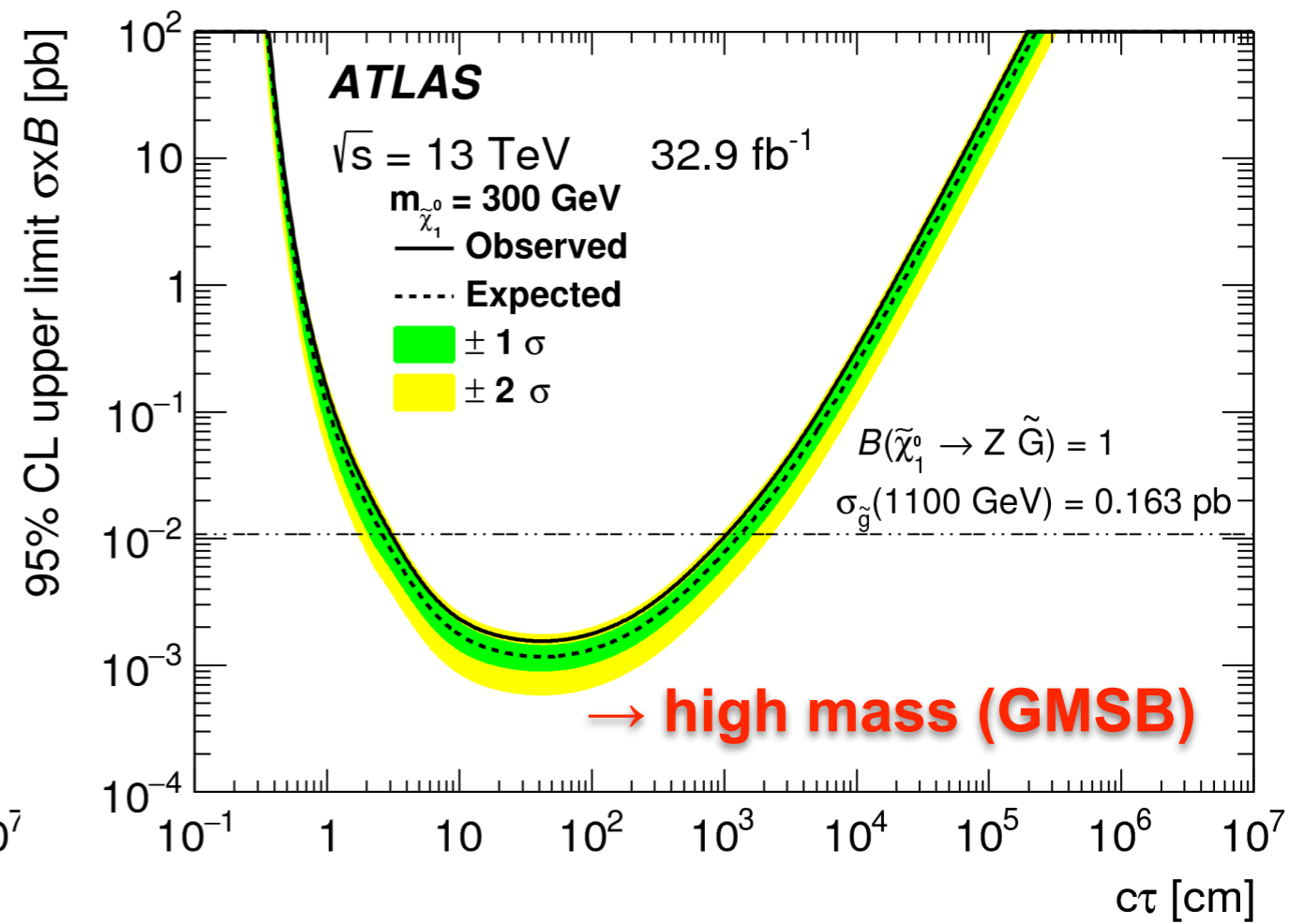
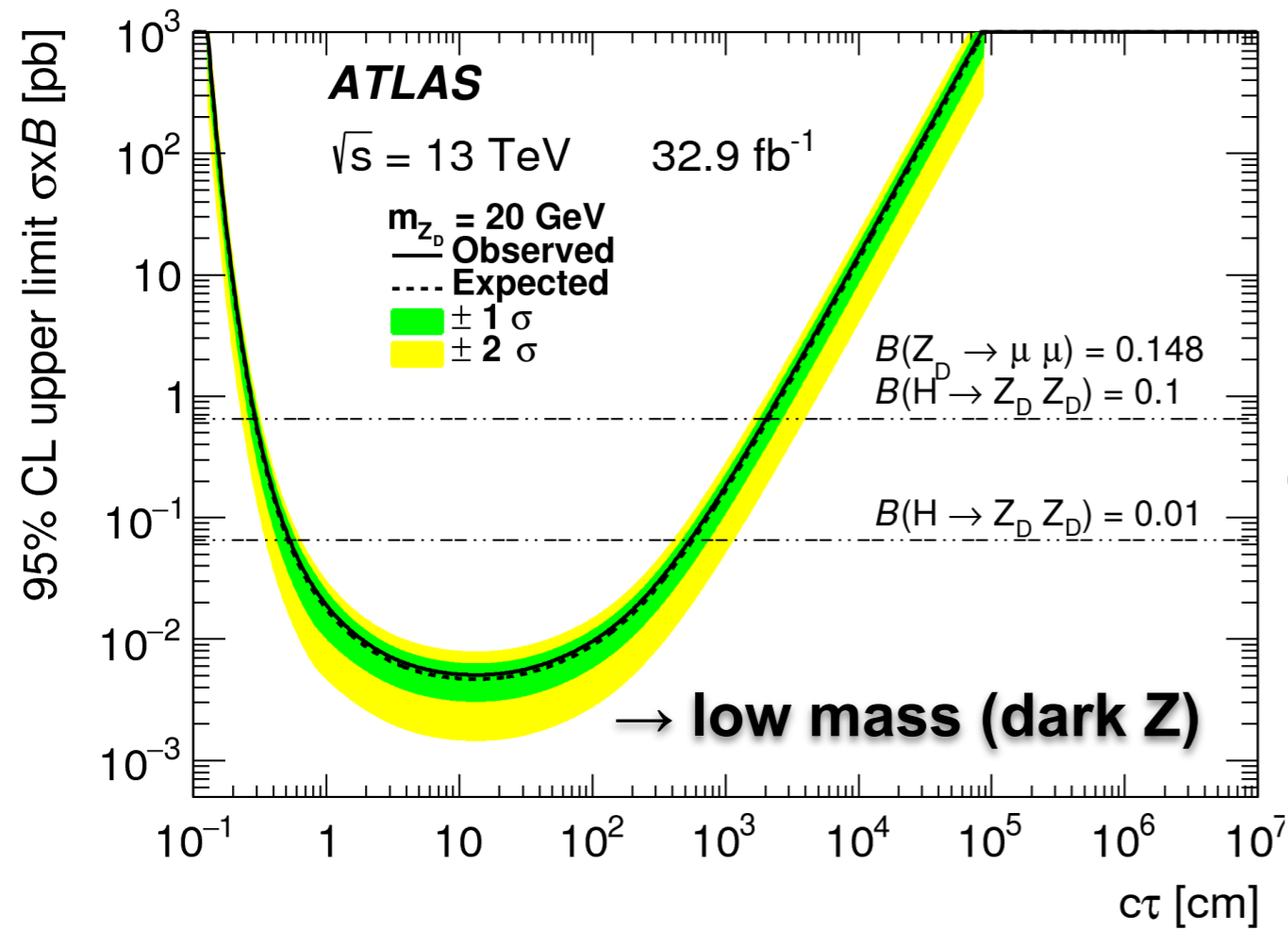
- ▶  $m_{\mu\mu} > 60$  GeV
- ▶ MET and single MS trigger
- ▶ backgrounds mostly processes with muons produced near IP (Drell-Yan/Z boson)



**LLP**

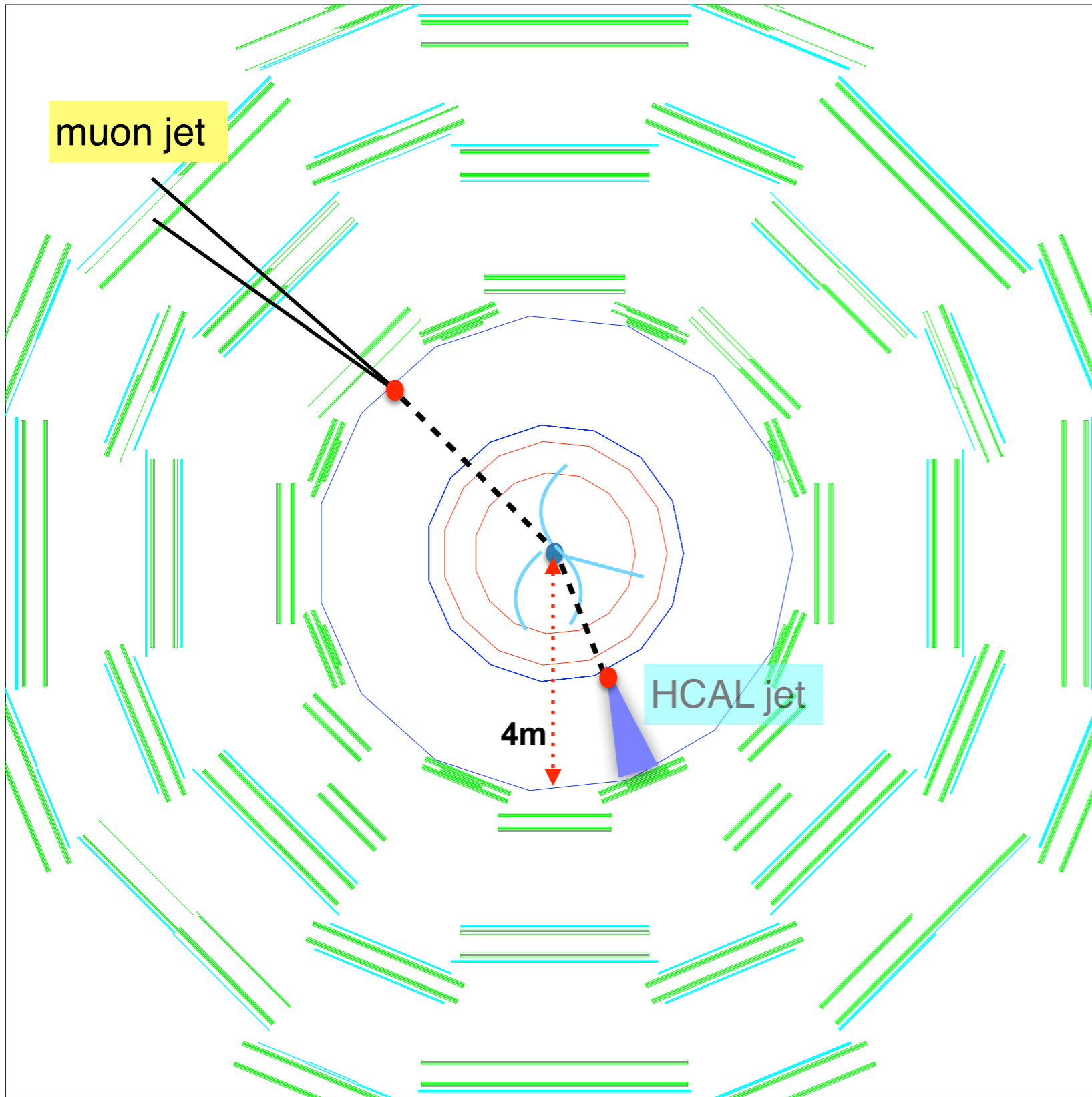






**Exclude  $1 < c\tau < 1000 \text{ cm}$  (approx)**  
 **$20 < m(Z_D) < 60 \text{ GeV}$      $400 < m(\chi) < 1000 \text{ GeV}$**

Displaced collimated muons or hadronic jets: **trackless (ID) and isolated**



► Pair-produced LLP

$\mu\mu - \mu\mu$

$\mu\mu - \text{narrow HCAL jet}$

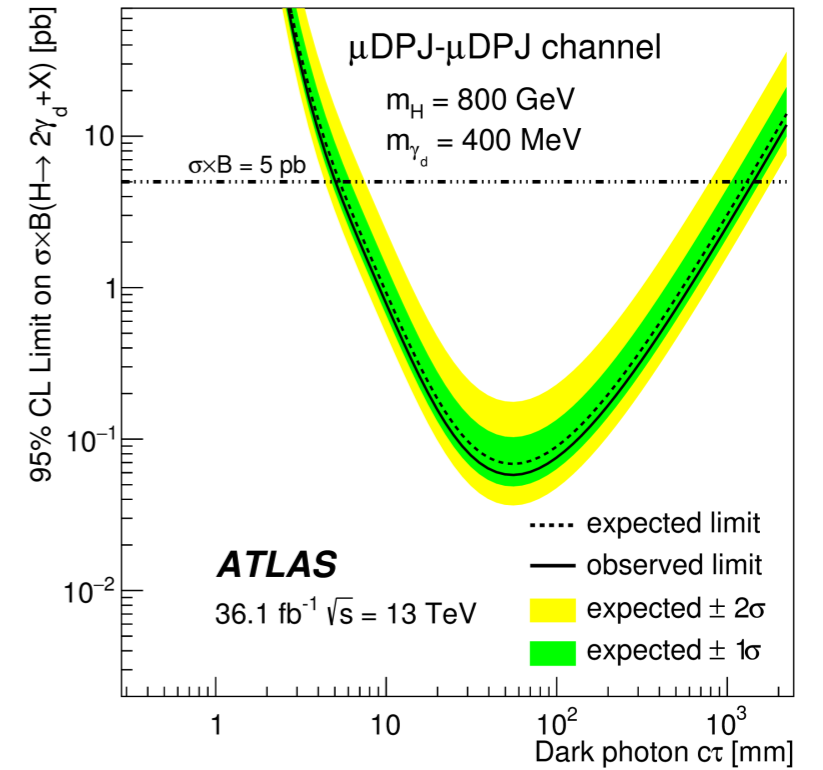
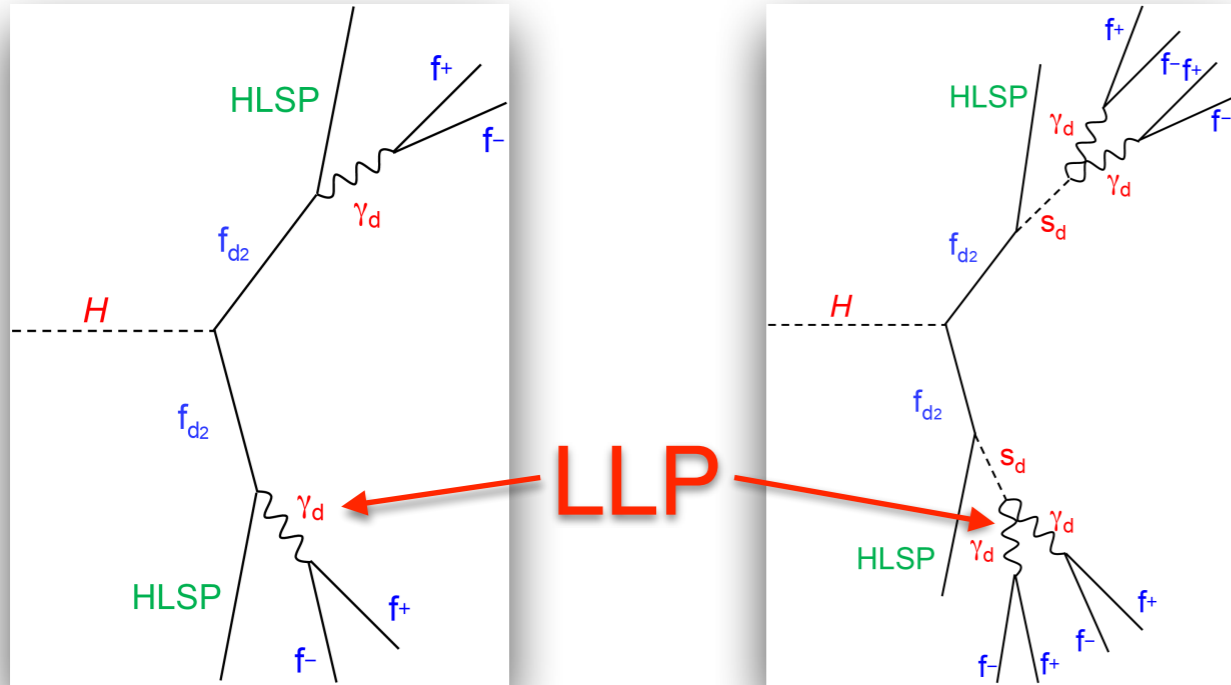
HCAL jet - HCAL jet

**Sensitivity:**

**Decay lengths of 0.01 - 4m ( $\mu\text{jet}$ )**

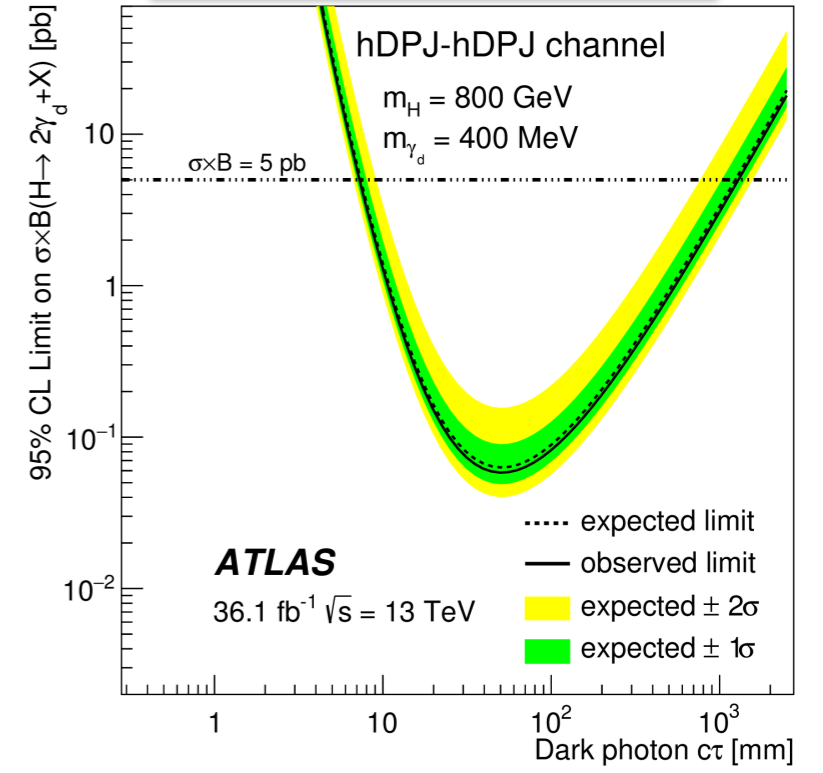
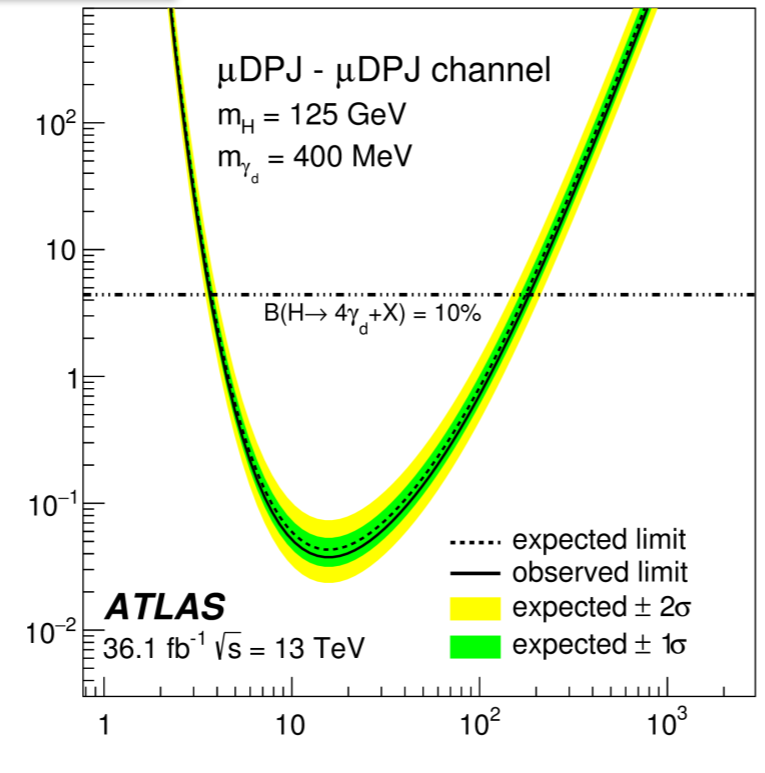
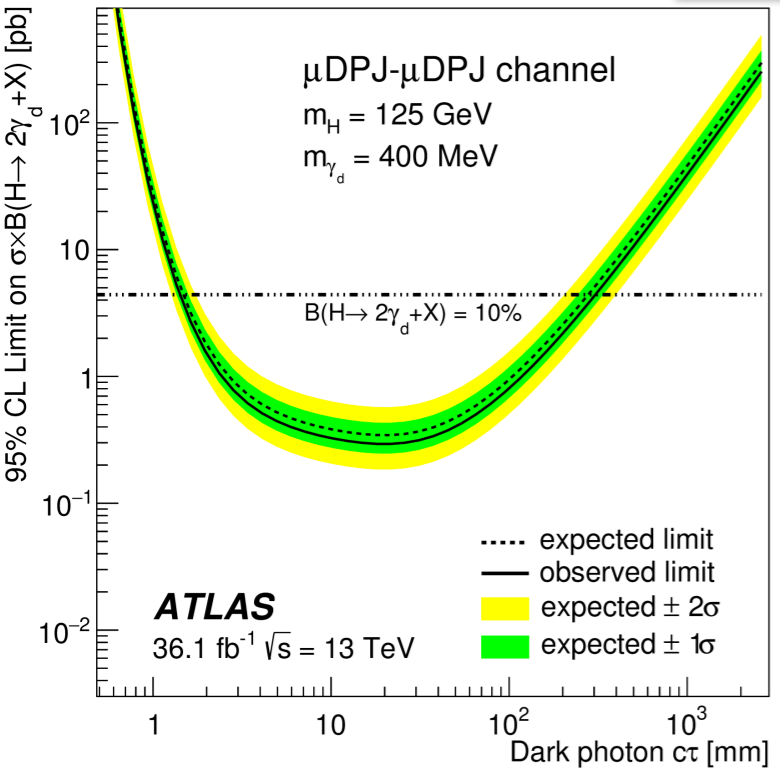
**Decay lengths of 2 - 4m ( $\text{hadjet}$ )**



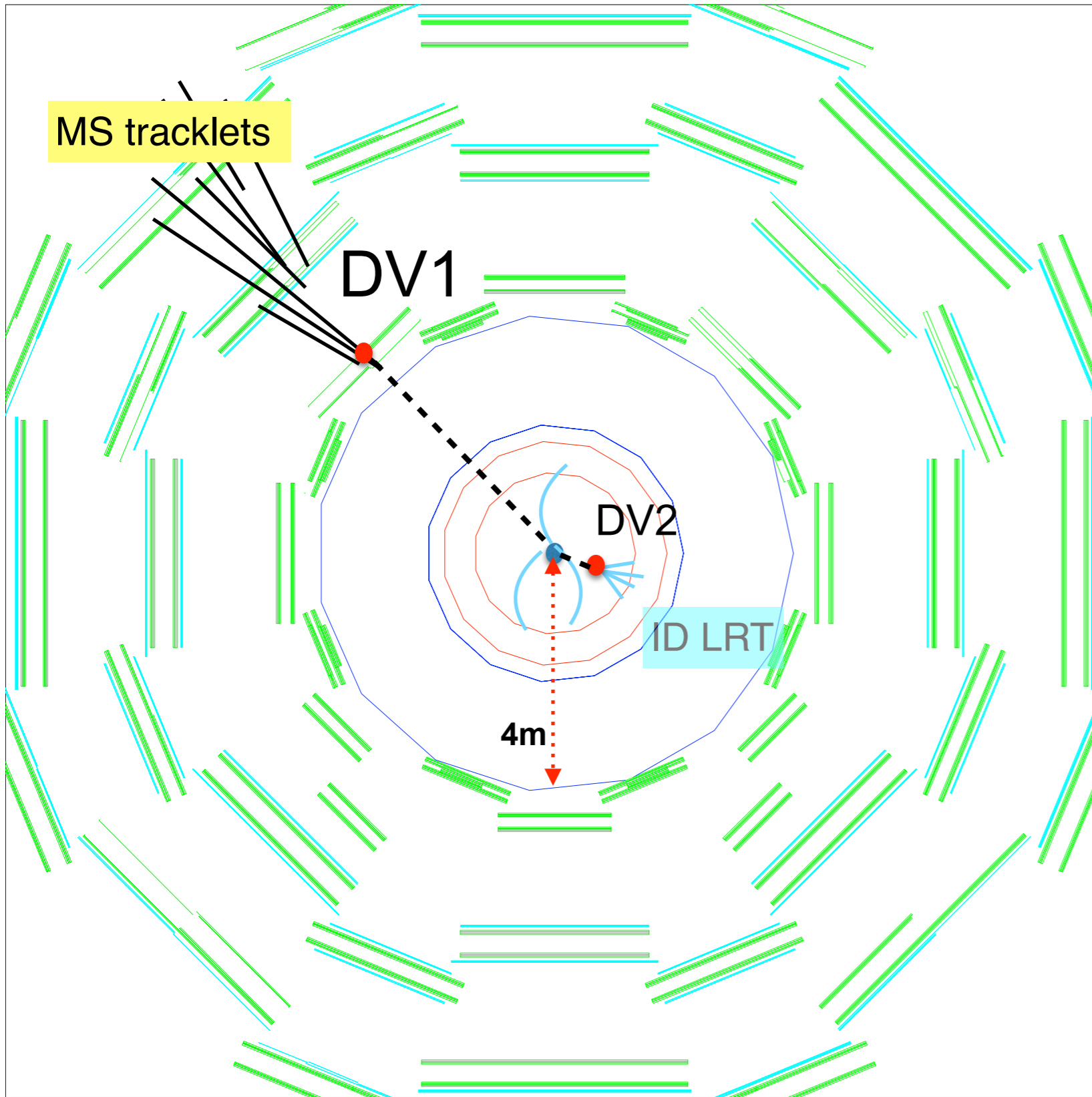


**H (125 GeV)**

**BSM scalar (800 GeV)**



Displaced hadronic vertices reconstructed in ID and within the MS (MS tracklets)



- ▶ Pair-produced LLP (2 DV)
- DV1 ⇒ MS tracklets (trigger)
- DV2 ⇒ ID large-radius trks

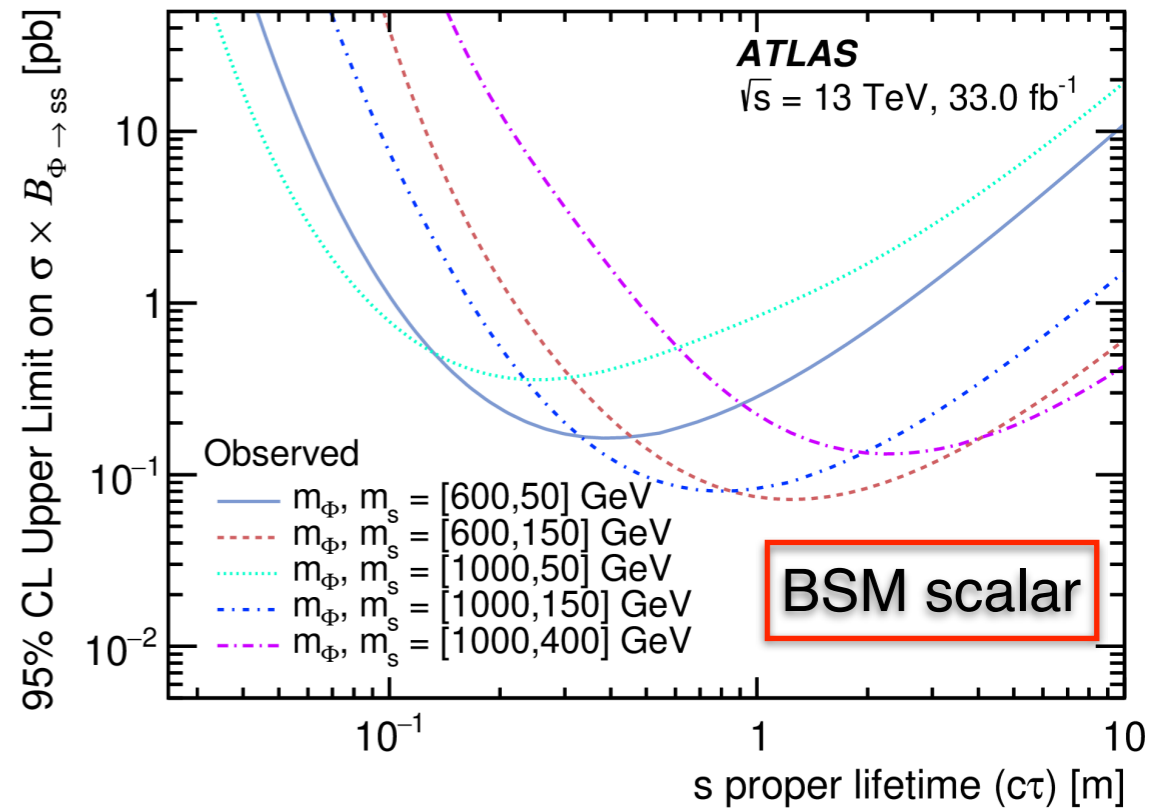
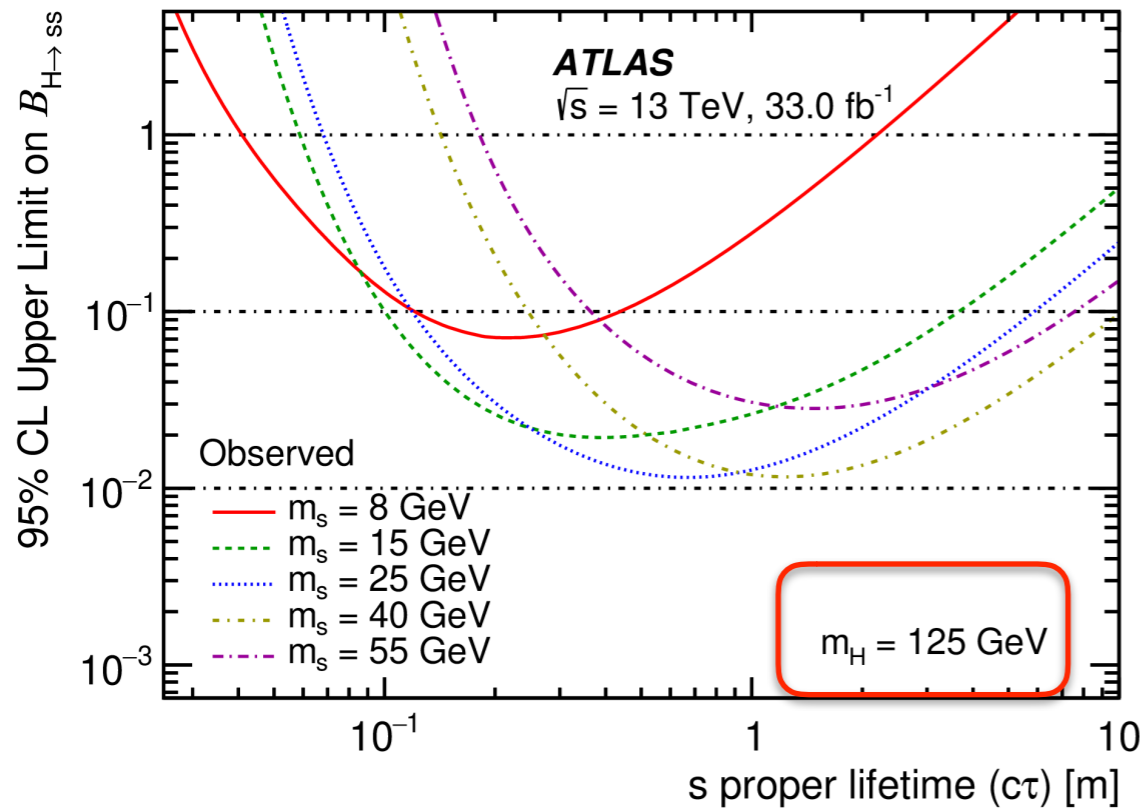
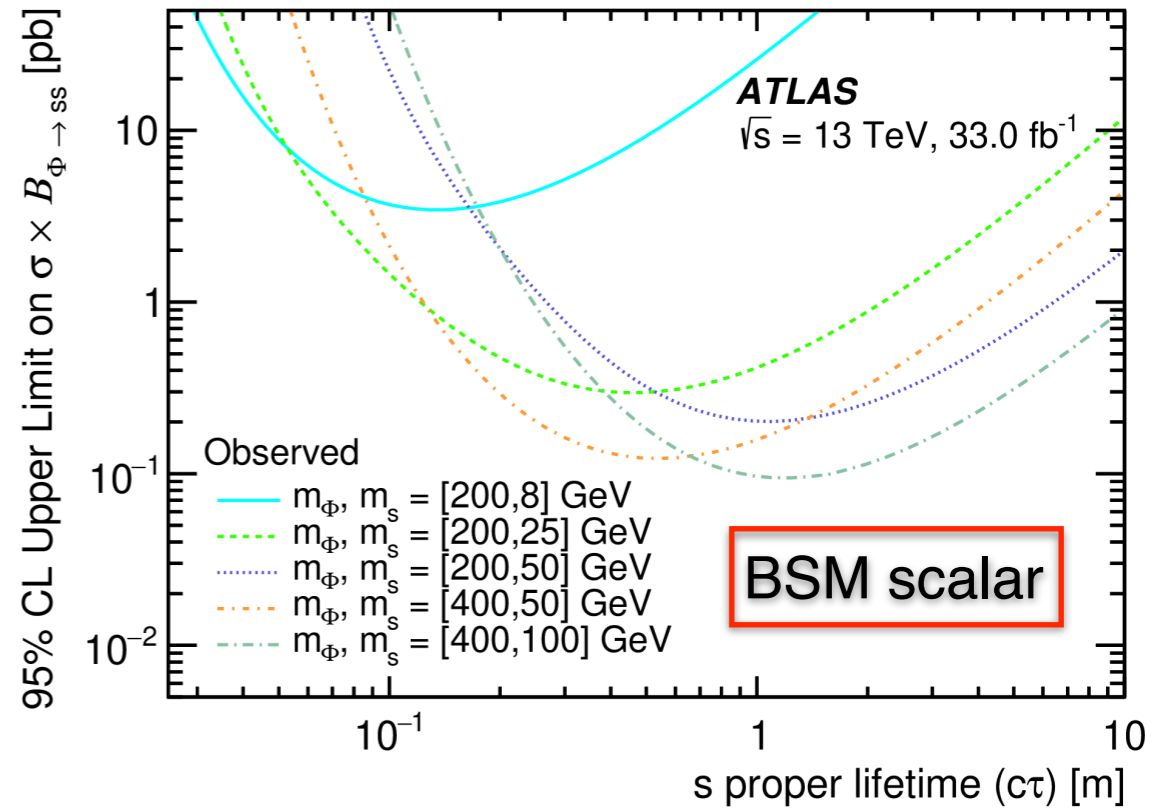
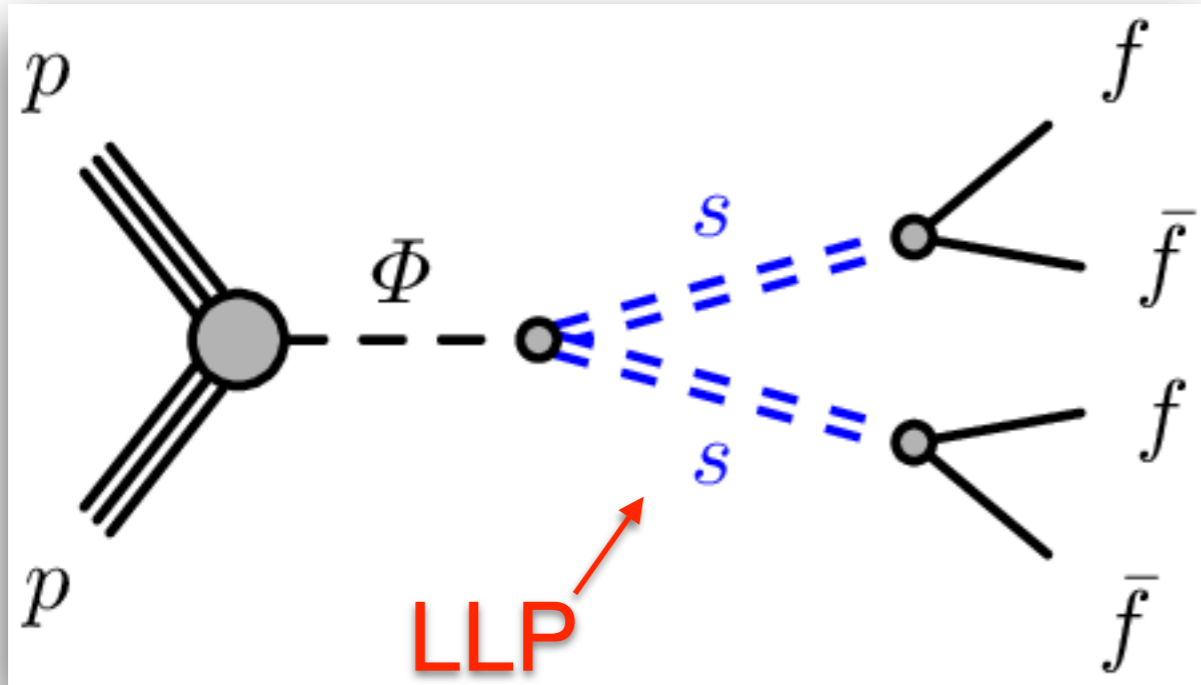
## Sensitivity:

Decay lengths of 3 - 8m (DV1)

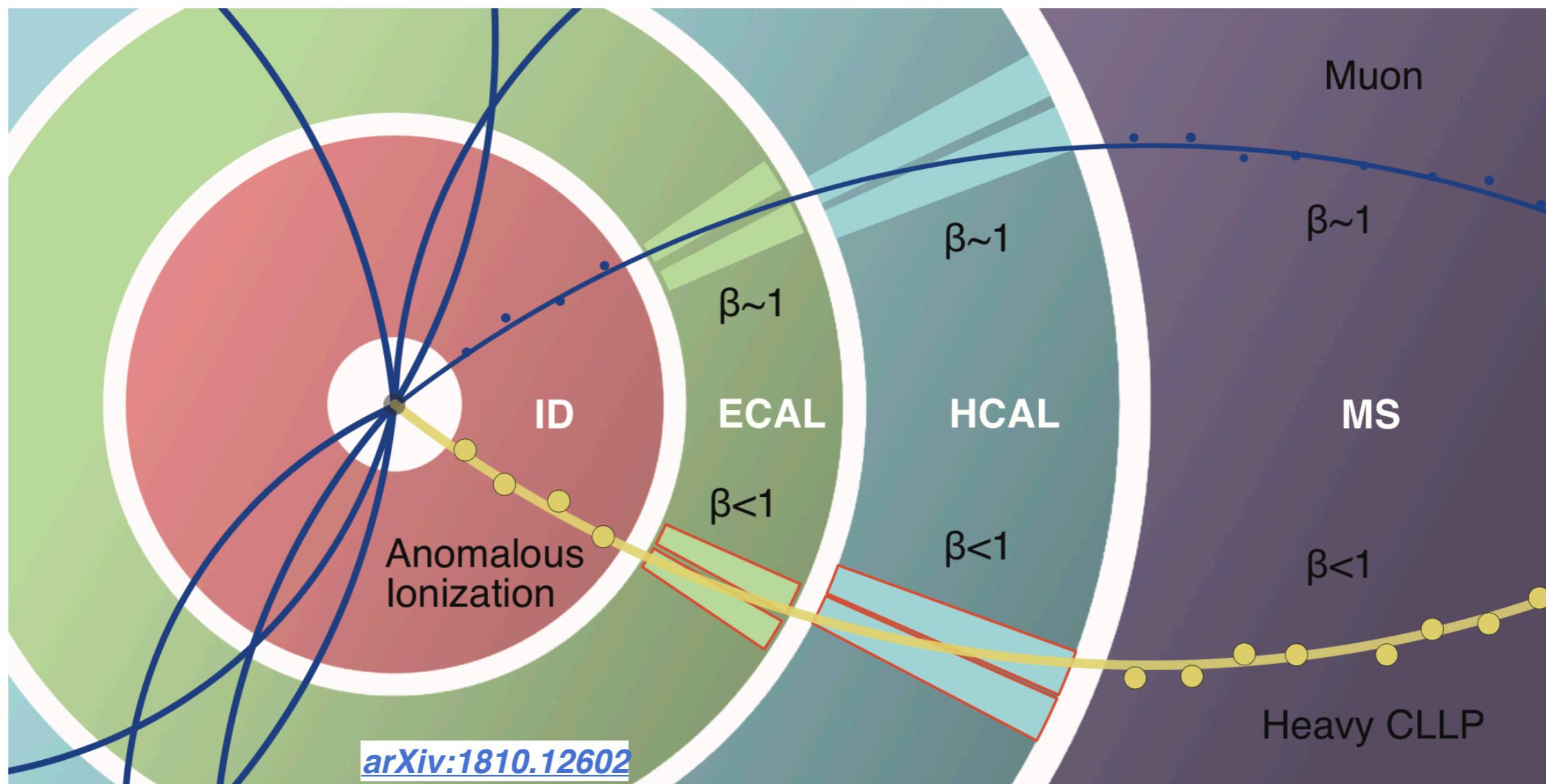
Decay lengths of 0.01 - 0.33m (DV2)

- ▶ MS tracklet DV used in other LLP analyses:
  - MS - MS
  - MS - Jet
  - MS - MET



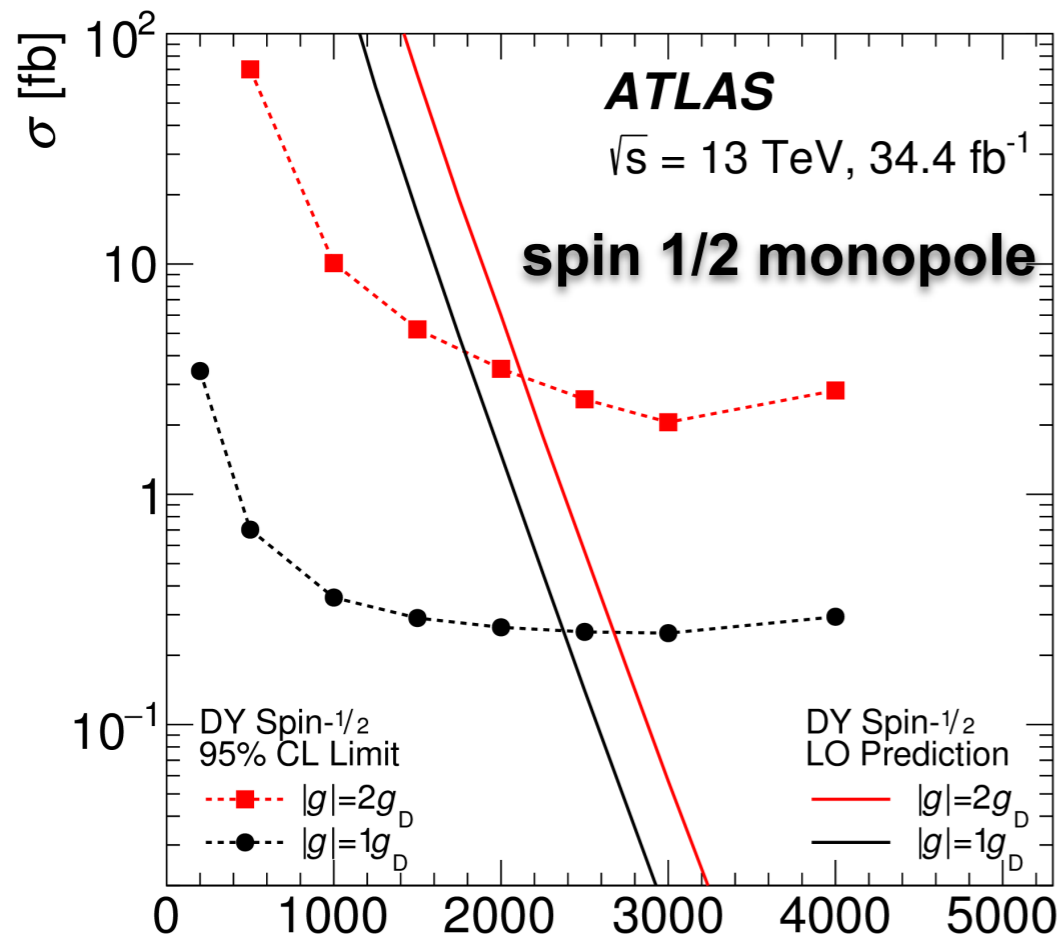


- ▶ Signature of very high energy loss in tracking detectors and electromagnetic calorimeter
  - HECOs → High-Electric-Charge-Objects (s-quark matter, Q balls, micro black hole remnants)
  - Dirac Magnetic Monopoles → TeV-scale masses and large magnetic charge





- ▶ Drell-Yan production assumed
- ▶  $200 < m < 4000$  GeV and  $60 < |q_{e,m}| < 100e$
- ▶ High ionization in Transition Radiation Detector and “pencil-like” deposit of energy in the ECAL

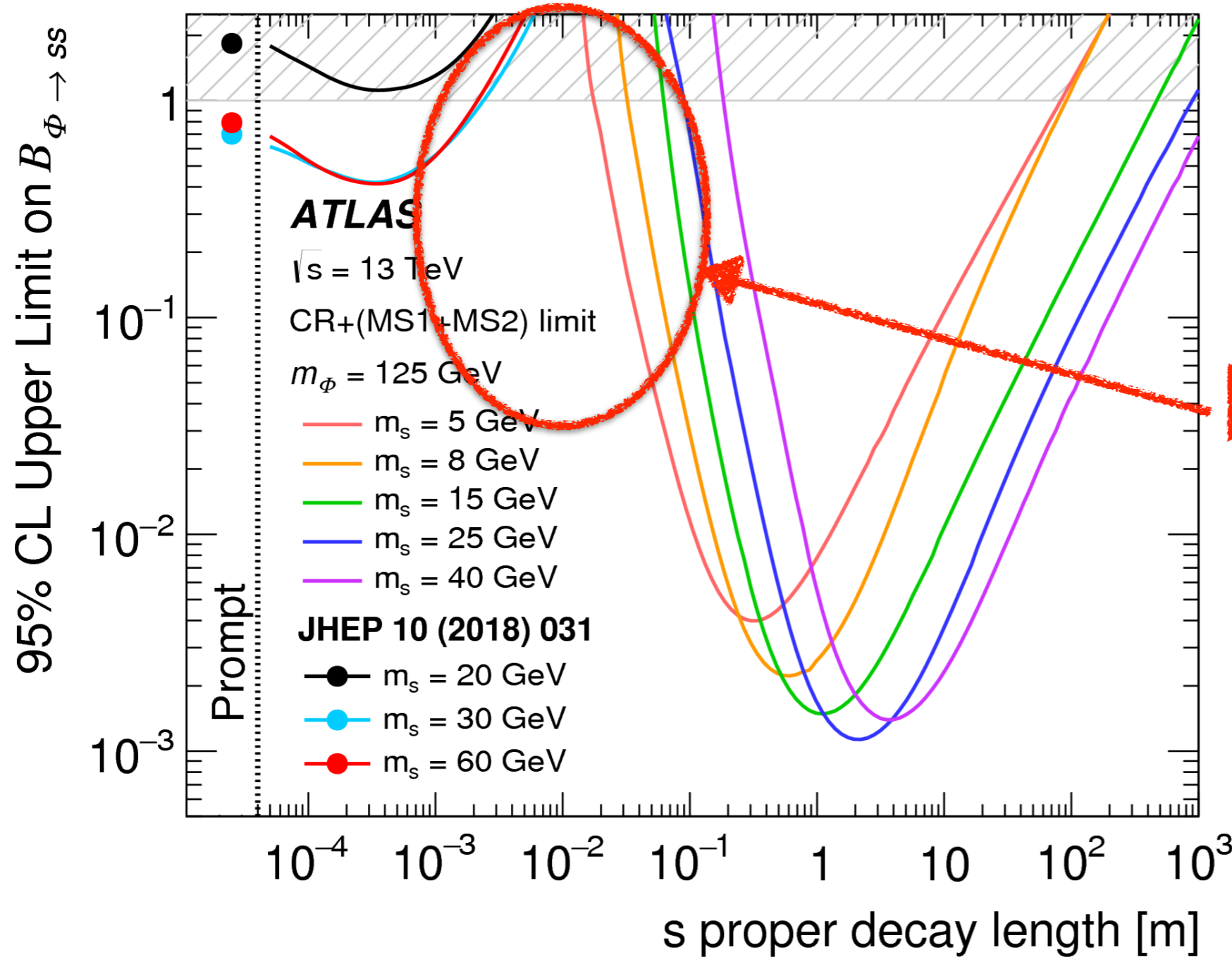
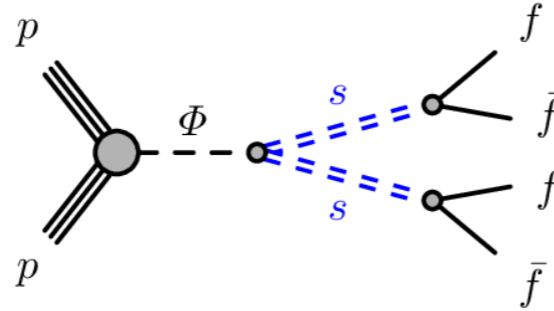


- ▶ Background estimate:  $0.2 \pm 0.4$
- ▶ No events observed in signal region

Lower limits on the mass of Drell–Yan magnetic monopoles and HECOs [GeV]

	$ g  = 1g_D$	$ g  = 2g_D$	$ z  = 20$	$ z  = 40$	$ z  = 60$	$ z  = 80$	$ z  = 100$
Spin-0	1850	1725	1355	1615	1625	1495	1390
Spin-1/2	2370	2125	1830	2050	2000	1860	1650

- ▶ ATLAS increasingly clever in utilizing detector information to search for non-SM phenomena
  - SUSY RPV, SUSY GMSB, dark sectors, monopoles...
- ▶ LHC Run 3 begins in 2022 → will double the Run 2 sample
  - New triggers → increase sensitivity to these exotic signatures
  - Better job of performing analyses in a way that allows for re-interpretation in terms of other models
  - Harmonize signal models amongst analyses
  - Combining limits (including interpretation of “prompt” analyses in terms of LLP scenarios)

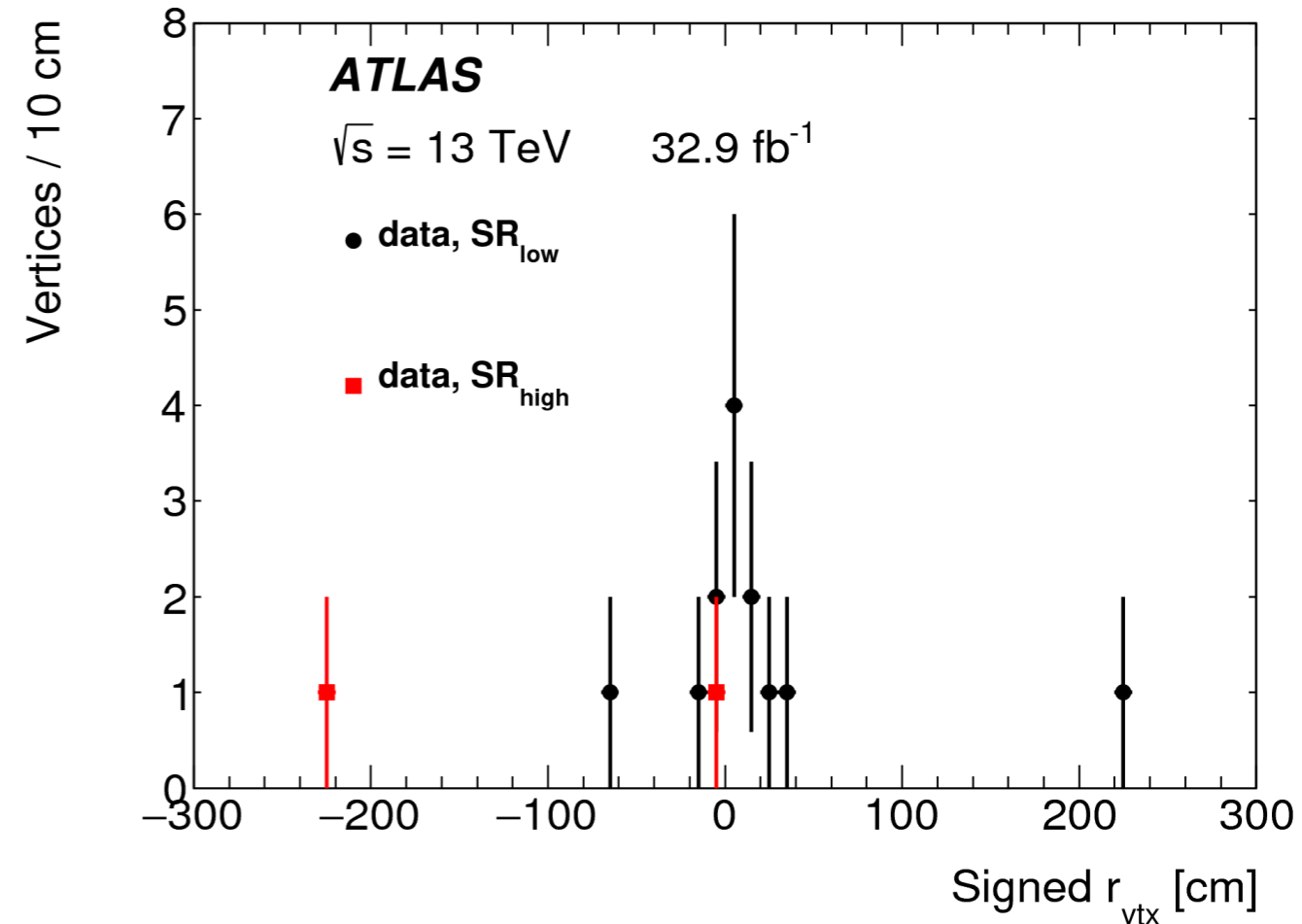
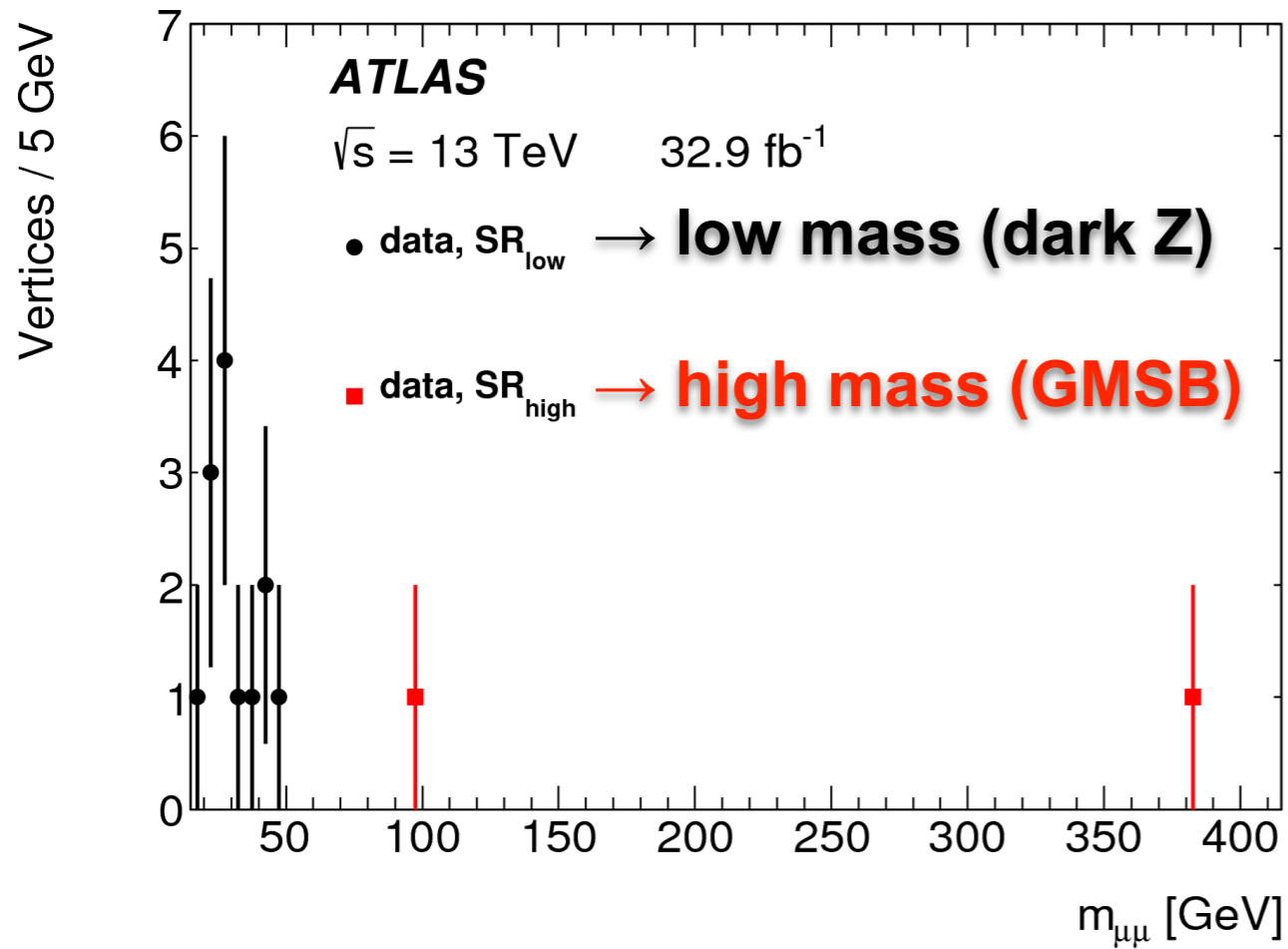


- ▶ MS-MS/MET
  - ▶ MS tracklets
- ▶ CR-CR
  - ▶ Trackless jets with large  $E_{\text{HCAL}}/E_{\text{ECAL}}$
- ▶ JHEP 10 (2018) 031
  - ▶ Standard tracking and b-jets + prompt lepton (VH)

▶ Gap: cover with new analyses



work in progress...



Yield	$\text{SR}_{\text{low}}$	$\text{SR}_{\text{high}}$
$N^{\text{fake}}$	$14.9 \pm 5.2$	$0.0^{+1.4}_{-0.0}$
$N^{\text{prompt}}$	$0.1^{+1.3}_{-0.1}$	$0.5^{+4.7}_{-0.1}$
$N^{\text{bkgd}}$	$15.0 \pm 5.4$	$0.5^{+4.9}_{-0.1}$
$N^{\text{obs}}$	23	4

Observed number of vertices and vertex positions consistent with background prediction