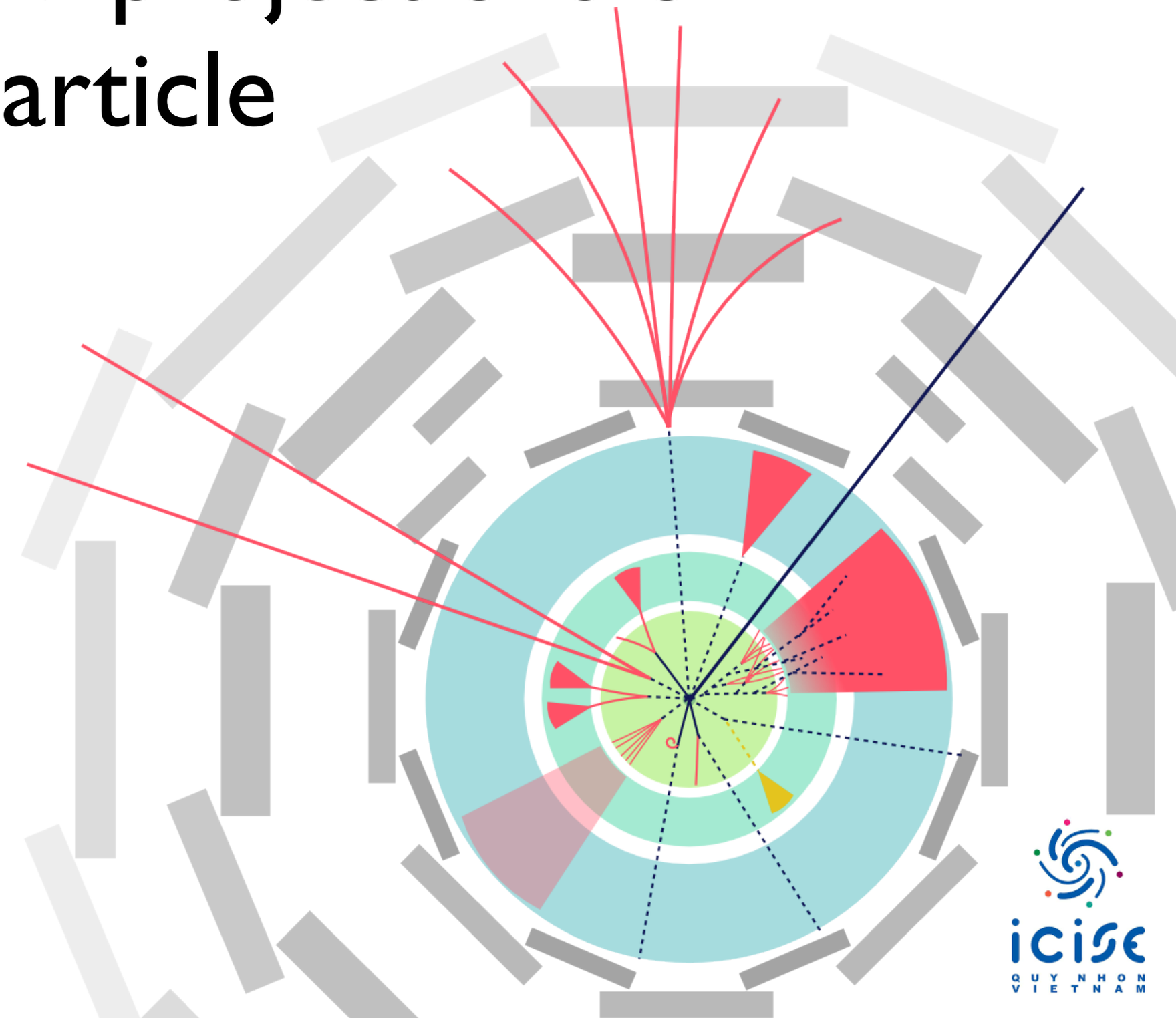
Snapshot and projections of long-lived particle searches



Alice Morris

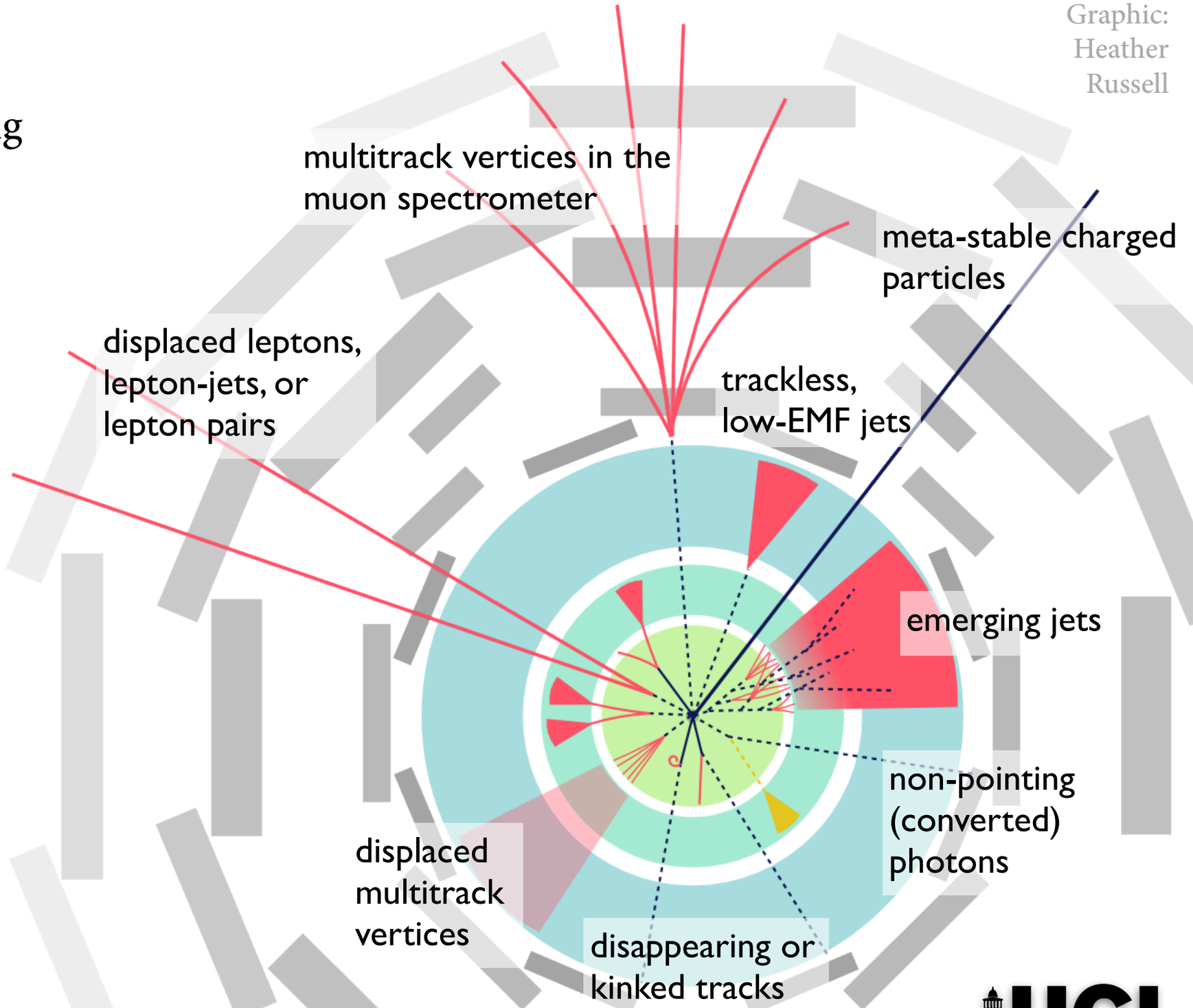
on behalf of the
ATLAS Collaboration

LLP signatures

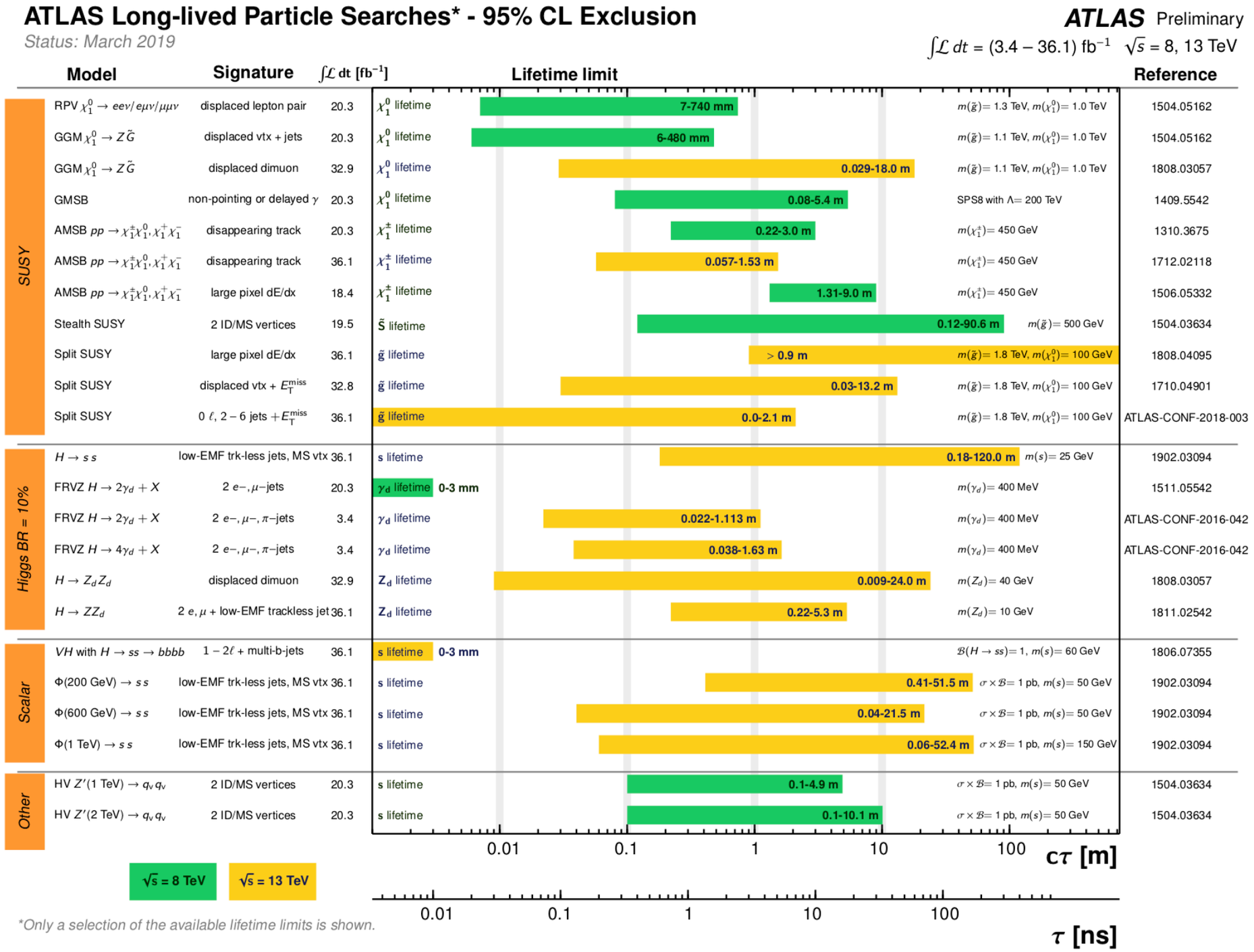
- BSM physics with LLPs can produce many complex topologies

- Experimentally challenging
  - Trigger
  - Reconstruction
  - Time required

- Allows us to cover all available phase space



ATLAS LLP summary



+ more since March 2019!

Snapshot

Run 2 Results

Highly ionising particles / magnetic monopole search	arXiv:1905.10130
Prompt and displaced heavy neutral leptons (Juliette's talk)	arXiv:1905.09787
Displaced hadronic jets in calorimeter	**arXiv:1902.03094**
Heavy charged LLPs	**arXiv:1902.01636**
Displaced vertex + muon	**ATLAS-CONF-2019-006**
Multi charged LLPs	**arXiv:1812.03673**
Displaced hadronic jets in muon spectrometer	arXiv:1811.07370
Z + displaced hadronic jet	**arXiv:1811.02542**
Displaced muon vertex (non-collimated)	**arXiv:1808.03057**
BSM H → 2a → 4b	arXiv:1806.07355
Heavy charged LLPs (SUSY)	arXiv:1808.04095
SUSY search reinterpretations for LLPs	ATLAS-CONF-2018-003

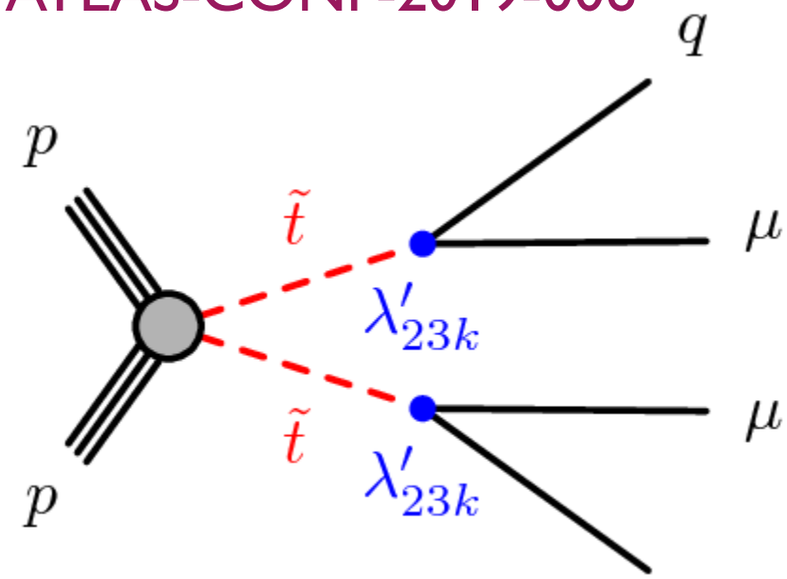
HL-LHC

Lepton-jets at HL-LHC (Juliette's talk)	ATL-PHYS-PUB-2019-002
DV+MET at HL-LHC	**ATL-PHYS-PUB-2018-033**
Disappearing tracks at HL-LHC	**ATL-PHYS-PUB-2018-031**

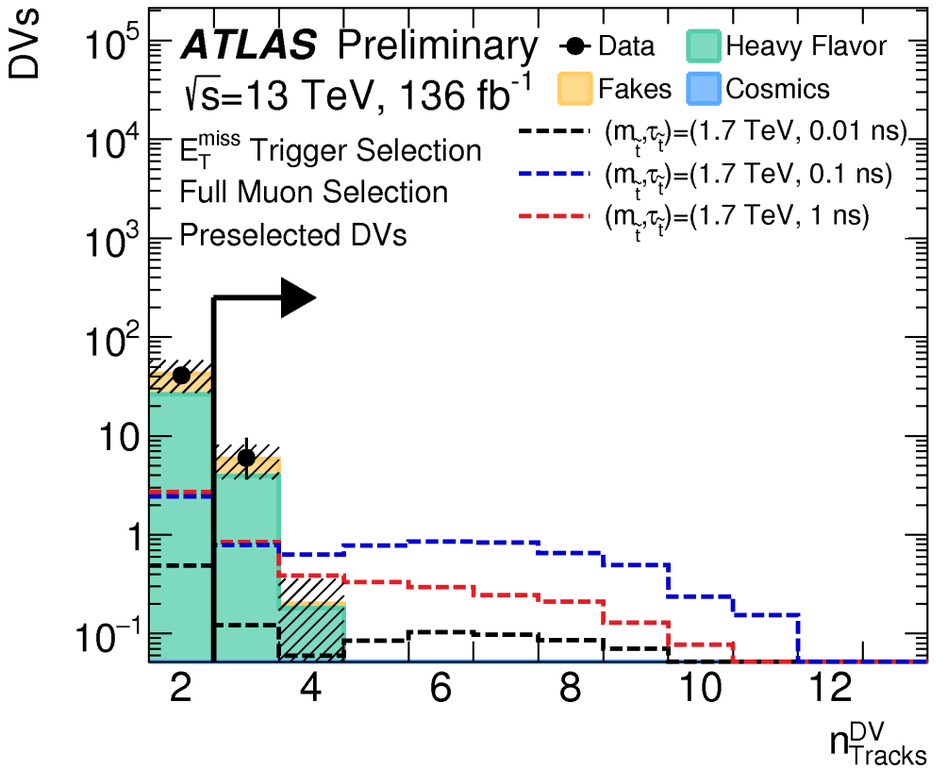
Displaced vertex + muon

- **Signature**: displaced multi-track vertex and displaced muon
- **Model**: RPV SUSY
- Large-radius tracking and displaced vertex reconstruction
- Signal regions from triggers:
  - missing p_T > 180 GeV
  - muon p_T > 60 GeV, $|\eta| < 2.5$ (missing p_T < 180 GeV)
- Muon spectrometer rejects cosmic and fake muons
- Inner detector rejects heavy flavour background
- Backgrounds calculated via transfer factors from CRs (data-driven)

ATLAS-CONF-2019-006



$m_{\tilde{t}} \in [1,2]$ TeV



Displaced vertex + muon

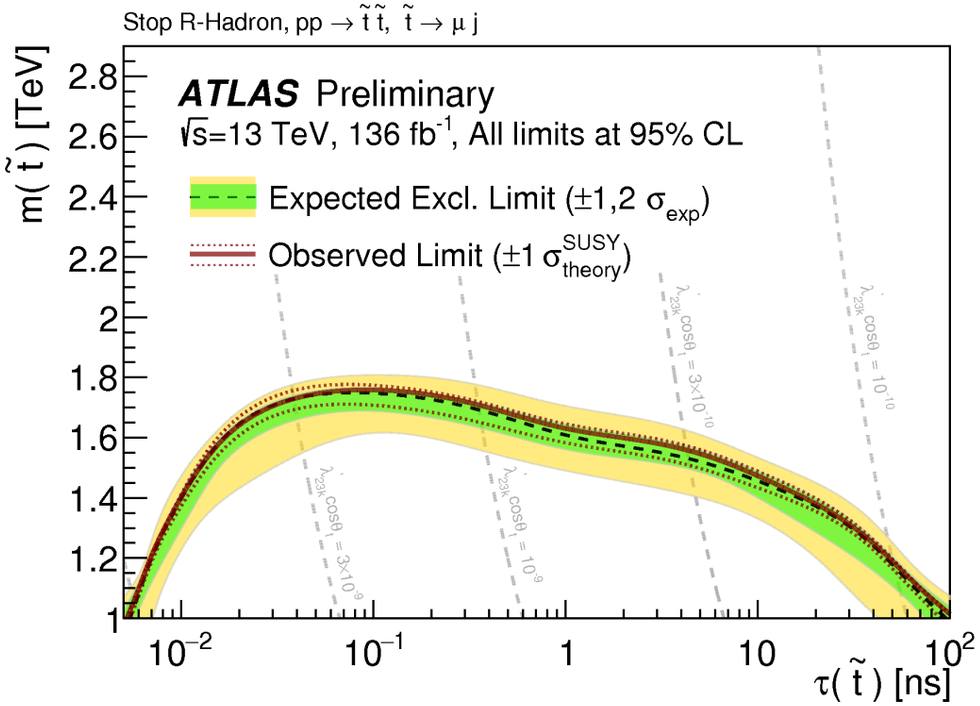
- Full Run 2 data (2016/17/18), 13 TeV, 136 fb^{-1}

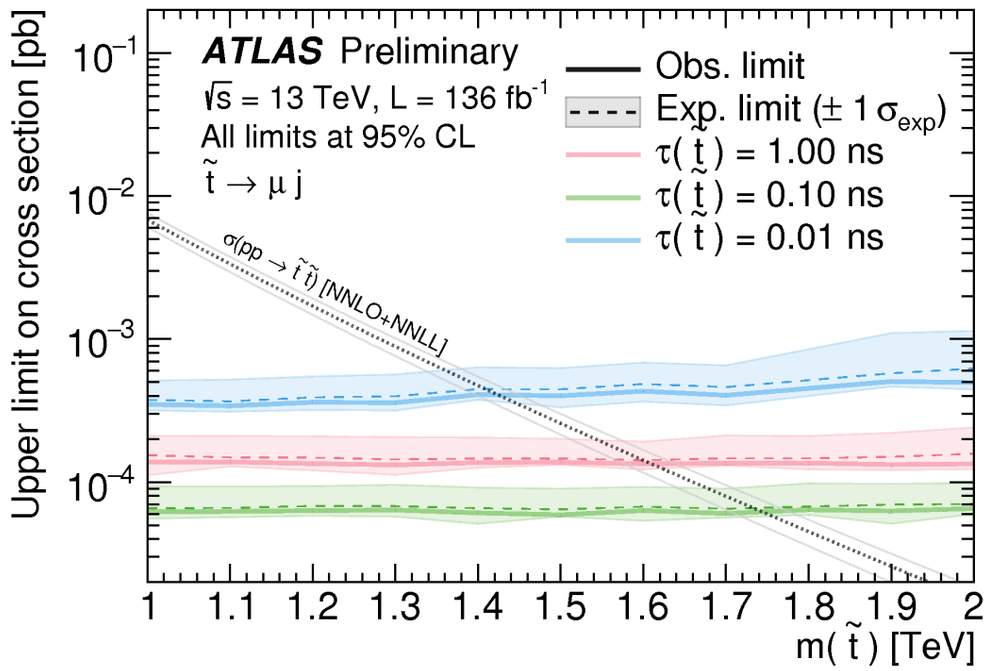
	Predicted	**Obs**
Missing p_T trigger SR	0.43 ± 0.16 ± 0.16	0
Muon trigger SR	1.88 ± 0.20 ± 0.28	1

- $m_{\tilde{t}} < 1.7$ TeV excluded for $\tau_{\tilde{t}} = 0.1$ ns (older limit from CMS was 1.4 TeV)
- $m_{\tilde{t}} < 1.3$ TeV for $\tau_{\tilde{t}} = 0.01$ - 30 ns
- Strictest limits for metastable stop decays via RPV coupling for $0.01 < \tau < 100$ ns
- Model-independent limits on # signal events and σ_{vis} also derived

Signal Region	S^{95}_{obs}	S^{95}_{exp}	$\langle\sigma_{vis}\rangle^{95}_{obs}$[fb]
E_T^{miss} Trigger SR	3.1	$3.1^{+1.1}_{-0.1}$	0.023
Muon Trigger SR	3.7	$4.2^{+1.6}_{-1.0}$	0.027

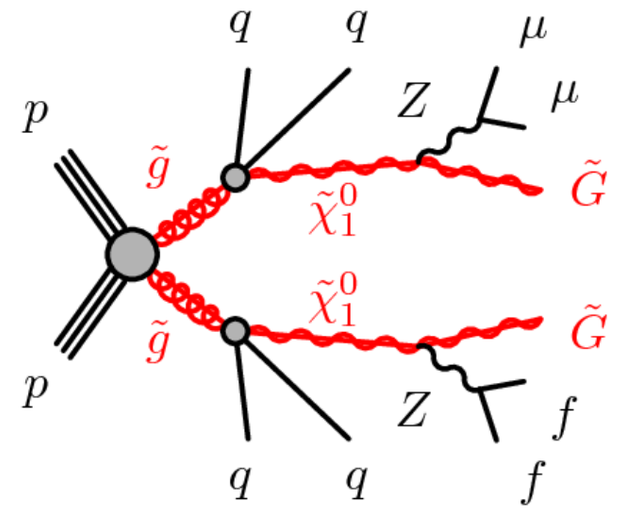
ATLAS-CONF-2019-006



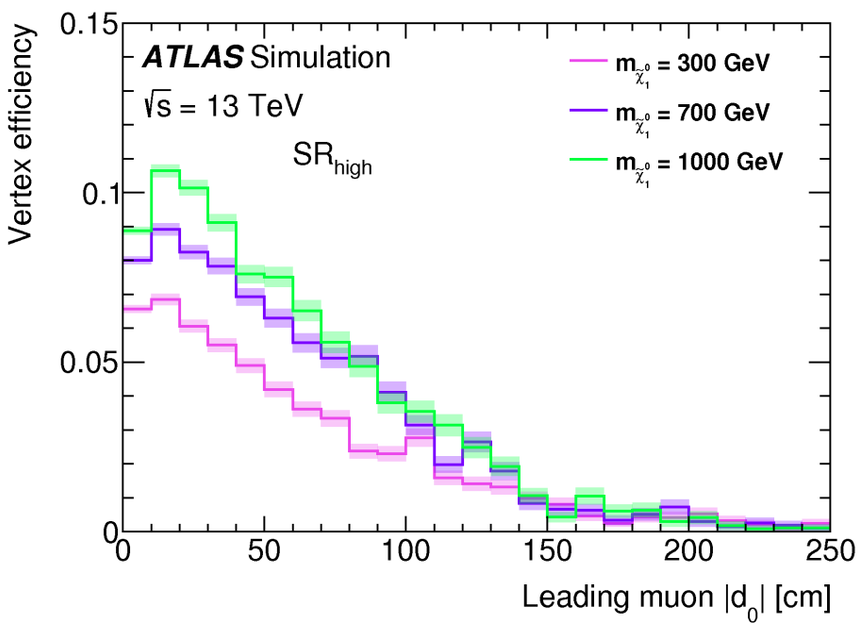


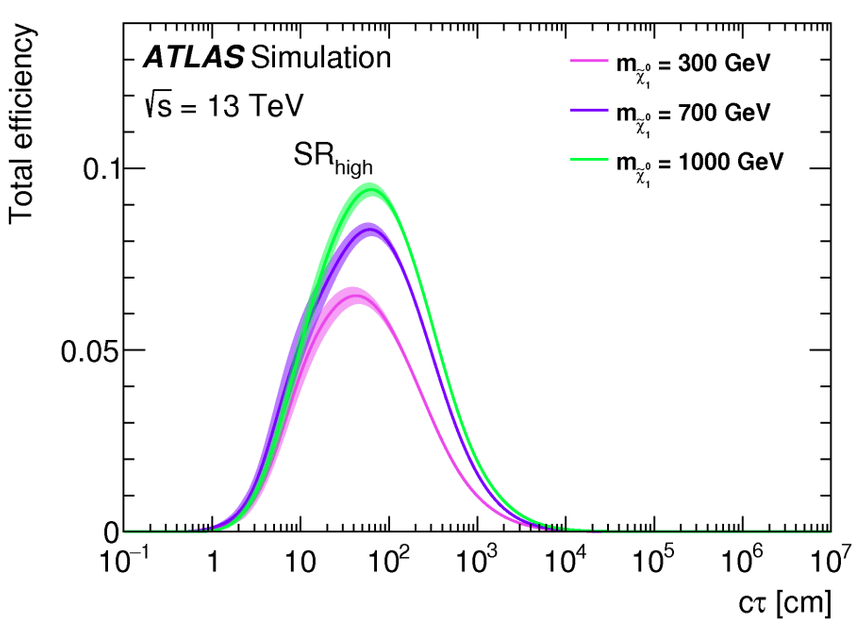
Displaced dimuons

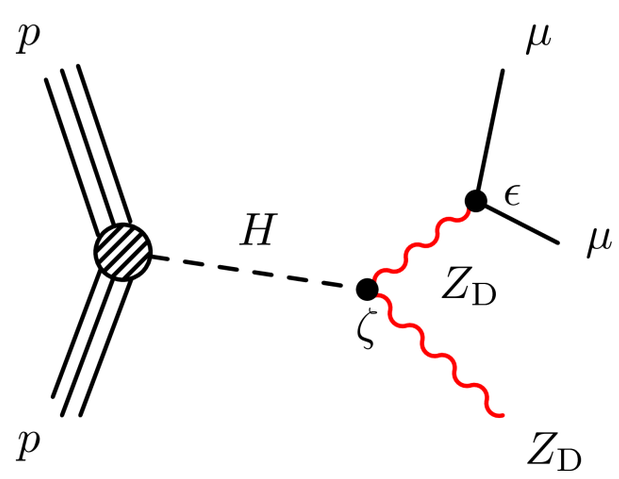
- **Signature**: $\mu^+\mu^-$ from a vertex more than several cm from IP
- **Models**: general gauge-mediated SUSY (GGM) and $H \to Z_D Z_D$ (dark sector)
- Use MS standalone tracks, increases fiducial volume in d_0, extrapolate tracks back to ID
- Pass at least 1 of 4 triggers, two for high masses (GGM), two for low masses (dark sector)
- Two signal regions for high and low masses



$m_{\tilde{\chi}_1^0} \in [300,1000]$ GeV







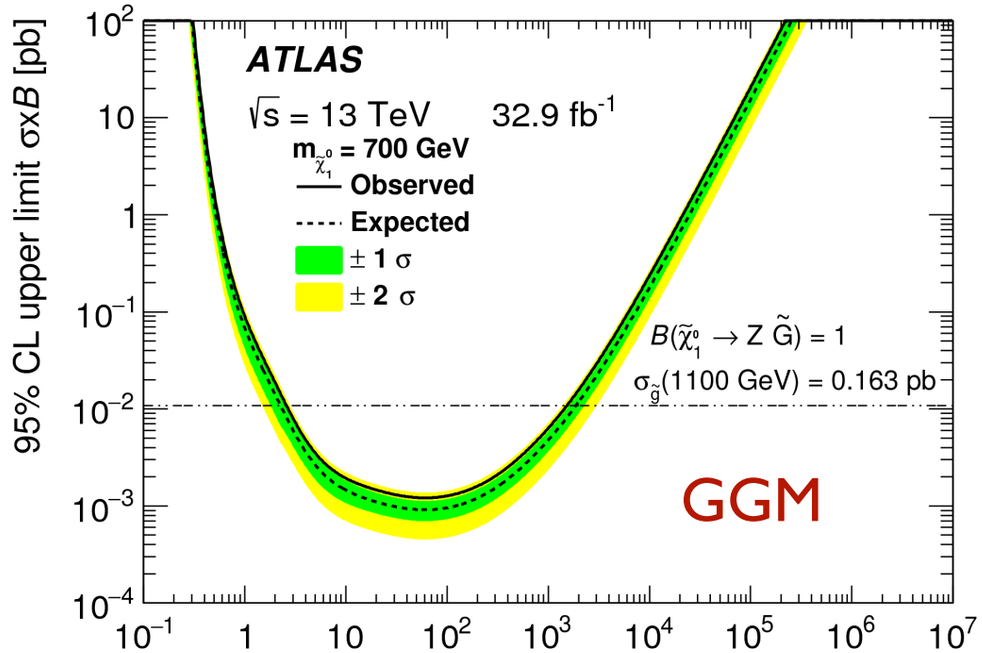
$m_{Z_D} \in [20,60]$ GeV

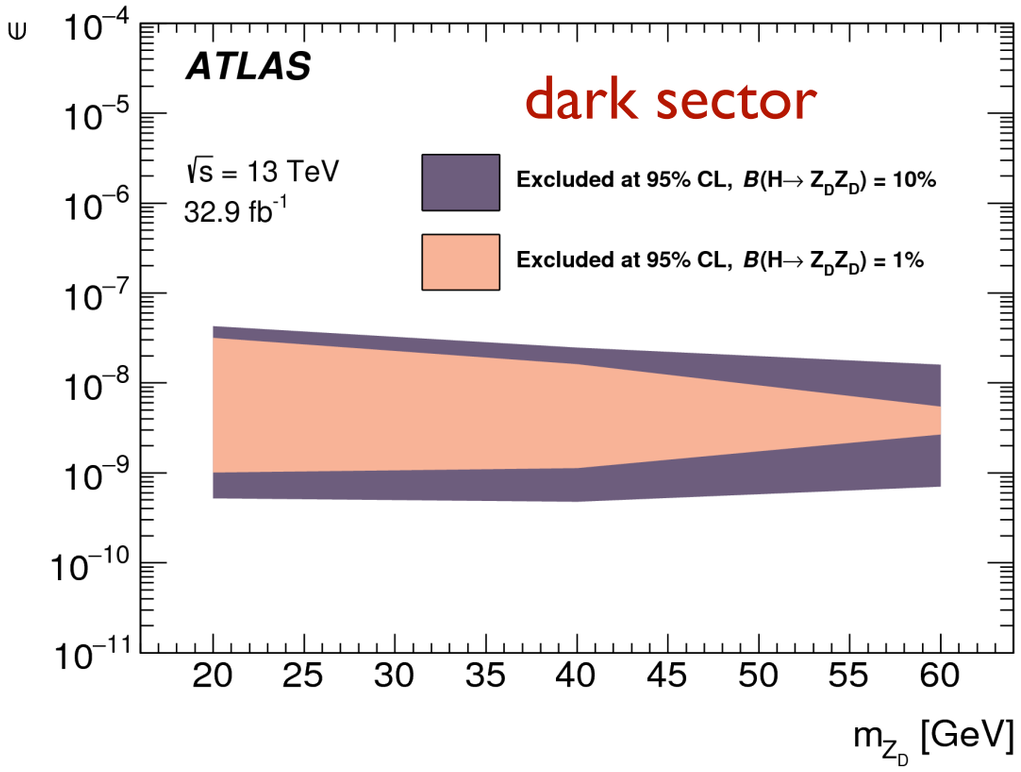
arXiv:1808.03057

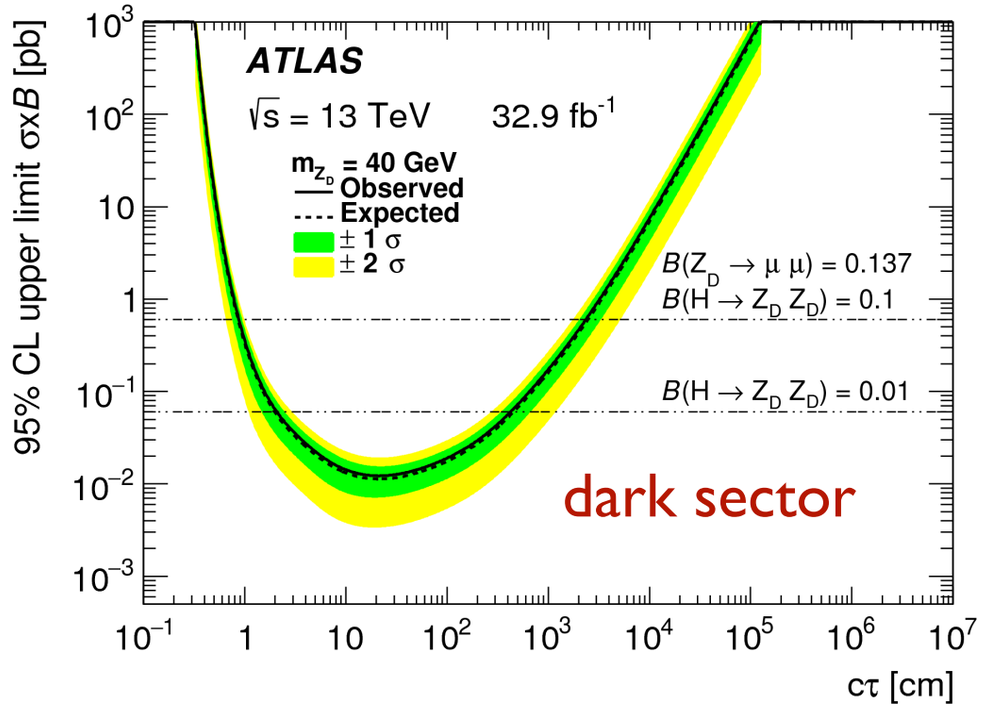
Displaced dimuons

- Loose selections and trigger strategy leads to high efficiency for range of topologies and kinematics
- Limits set with 32.9 fb^{-1} of 2016 data
- Lifetime ranges excluded for each mass point in GGM and dark sector models
- Values of coupling parameter $\varepsilon \sim 10^{-8}$ excluded for $20 < m_{Z_D} < 60$ GeV

arXiv:1808.03057

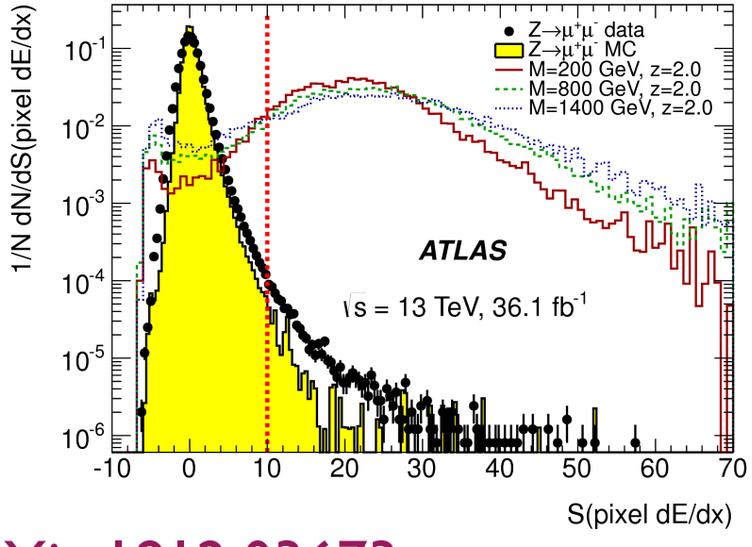




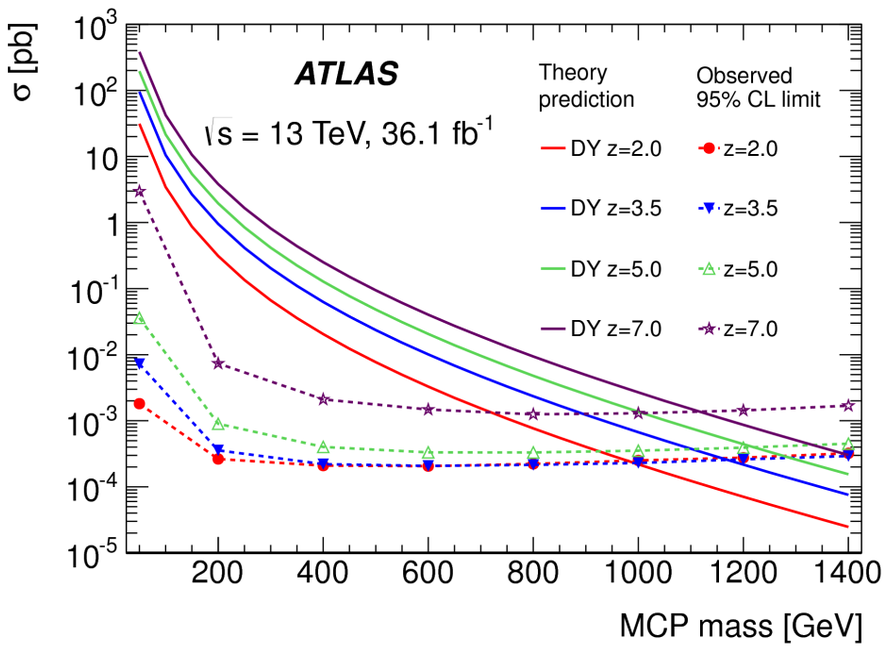


Multi charged LLPs

- **Signature**: muon-like particles with high ionisation losses along track in several subdetectors, traversing whole detector
- **Model**: long-lived multi-charged particles (MCPs)
  - m_{MCP} = 50–1400 GeV, $|q|$ = 2e, 2.5e, 3e, … 7e
  - "Blue-sky" search, but some models predict multi-charged new particles
- Single muon trigger
  - Limited by timing window ($\beta > 0.6$)
  - Addition of MET trigger to accept slow, high-mass MCPs (~20% of signal)
- **Background**: high pT muons (data-driven estimate), instrumental (removed with material veto)
- 2015+2016 data, 36.1 fb^{-1}
  - 0 events observed for z = 2 and z > 2



arXiv:1812.03673



	z										
	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Lower mass limit [TeV]	0.98	1.06	1.13	1.17	1.20	1.22	1.22	1.21	1.19	1.16	1.12

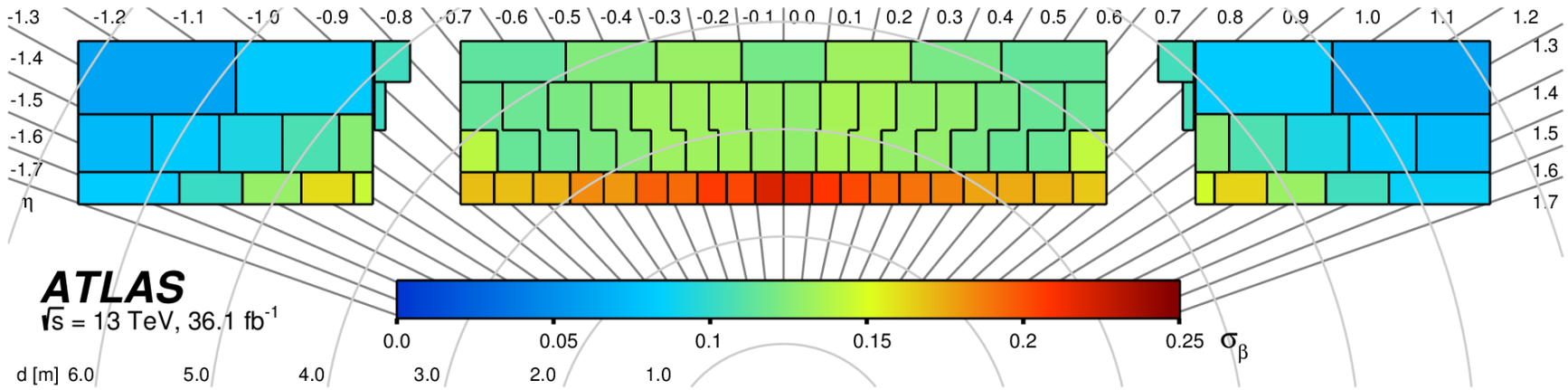
$|q| = ze$

Heavy charged LLPs

- **Signature**: heavy charged particles with large ionisation energy loss and time-of-flight, reaching at least the ATLAS hadronic calorimeter

arXiv:1902.01636

- **Models**:
  - R-hadrons: **gluinos** or **stops** (full-detector or MS-agnostic)
  - EW SUSY: **staus** or **charginos** (use ID & MS)
- Trigger on single muon or MET
- Candidate velocity (β) calculated from time of flight (ToF) and dE/dx, combined with momentum to estimate mass
  - Accurate ToF measurements need custom calibrations (position within Tile cell of particle impact, or run-to-run timing measurement fluctuations)
  - dE/dx measurements come from Pixel detector

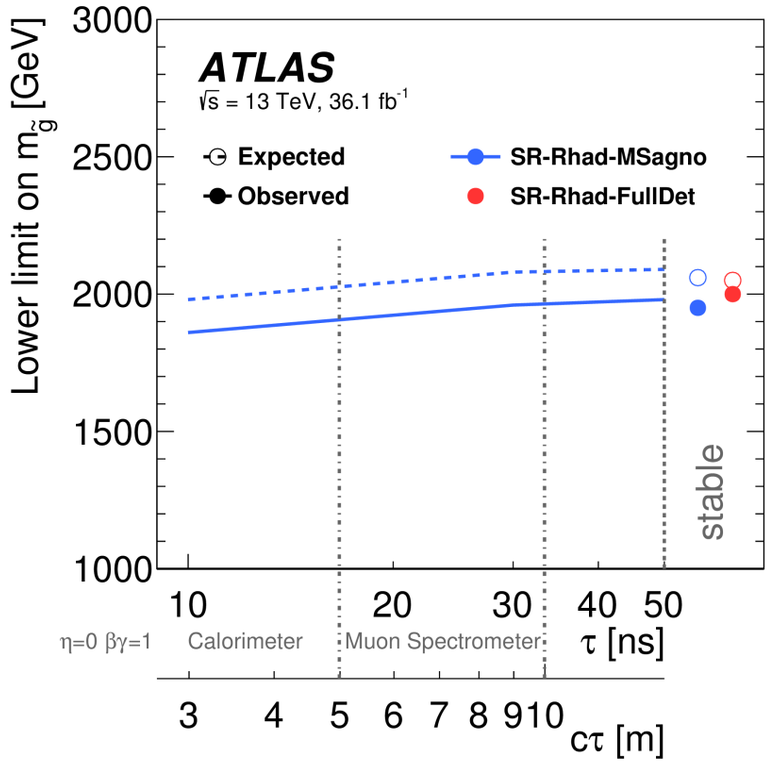


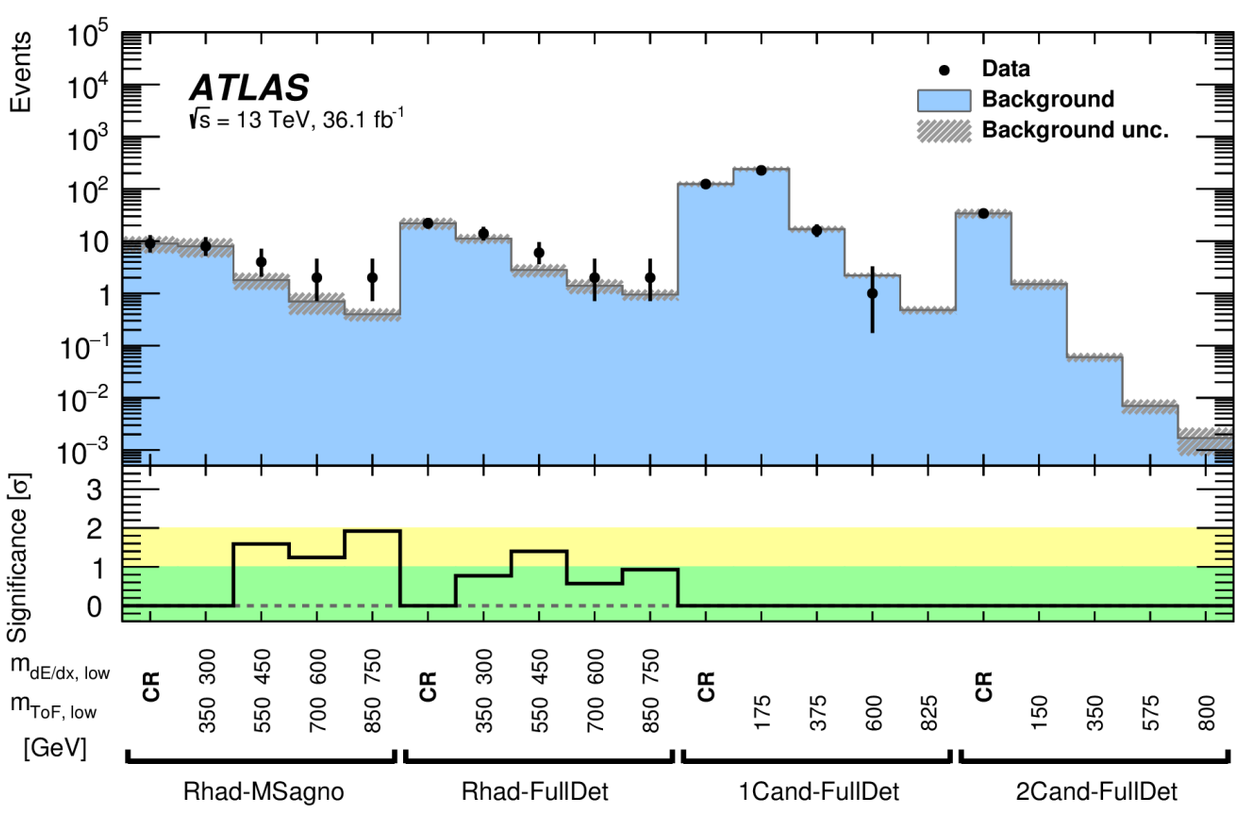
Heavy charged LLPs

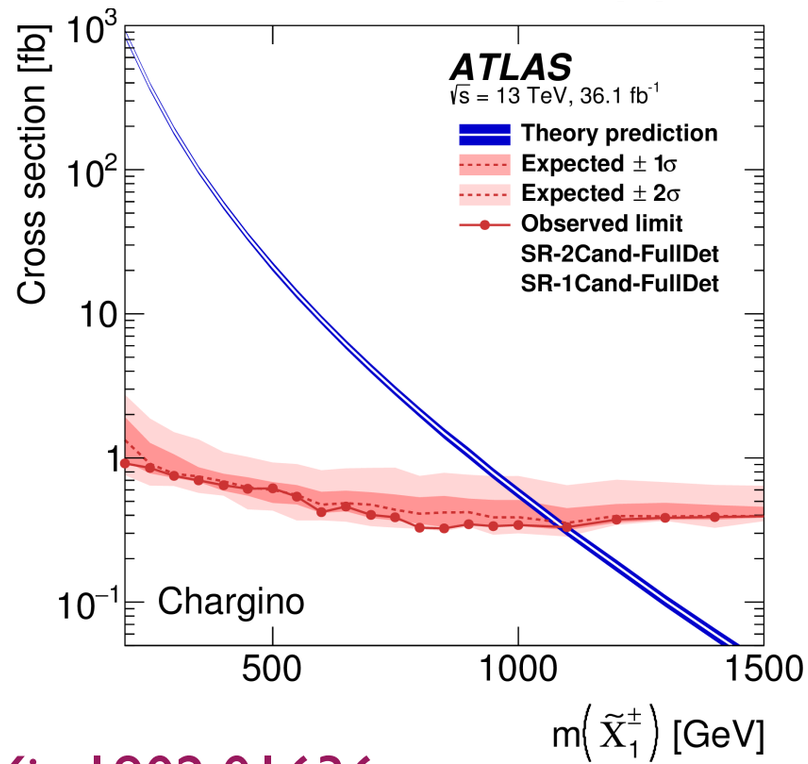
- **Background estimate**: data-driven, randomly sample mass values from probability density functions derived from distributions of p, β_{ToF}, $(\beta\gamma)_{dE/dx}$

- Analysis on 2015+2016 data (36.1 fb^{-1}) with no significant excess in 16 search regions

- Lower limits set on particles mass for R-hadrons, staus and charginos



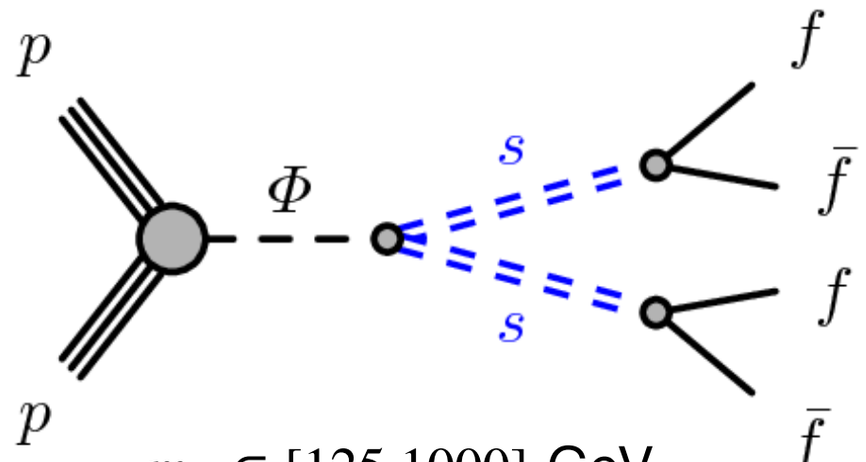




arXiv:1902.01636

Displaced hadronic jets

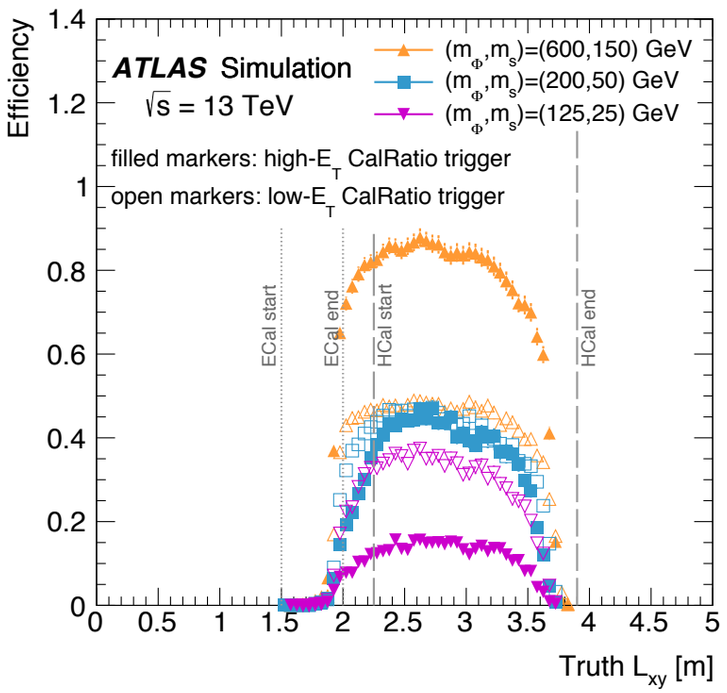
- **Signature**: two narrow, trackless, displaced hadronic jets with high E_{HAD}/E_{EM} (CalRatio jets)
- **Model**: hidden sector $H/\Phi \rightarrow s\ s \rightarrow f\ f\ f\ f$
- Custom trigger relies on CalRatio and trackless feature of jets
  - Two triggers for low- and high-E_T regions

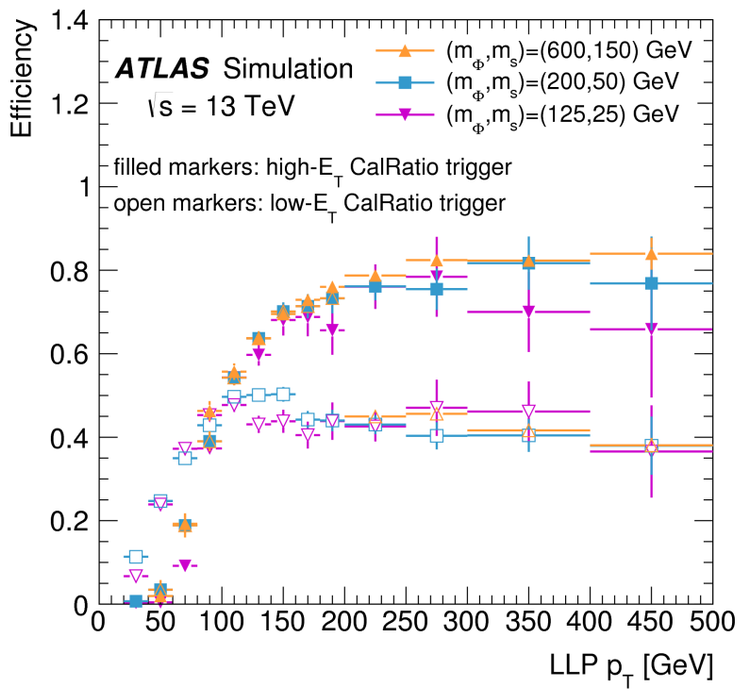


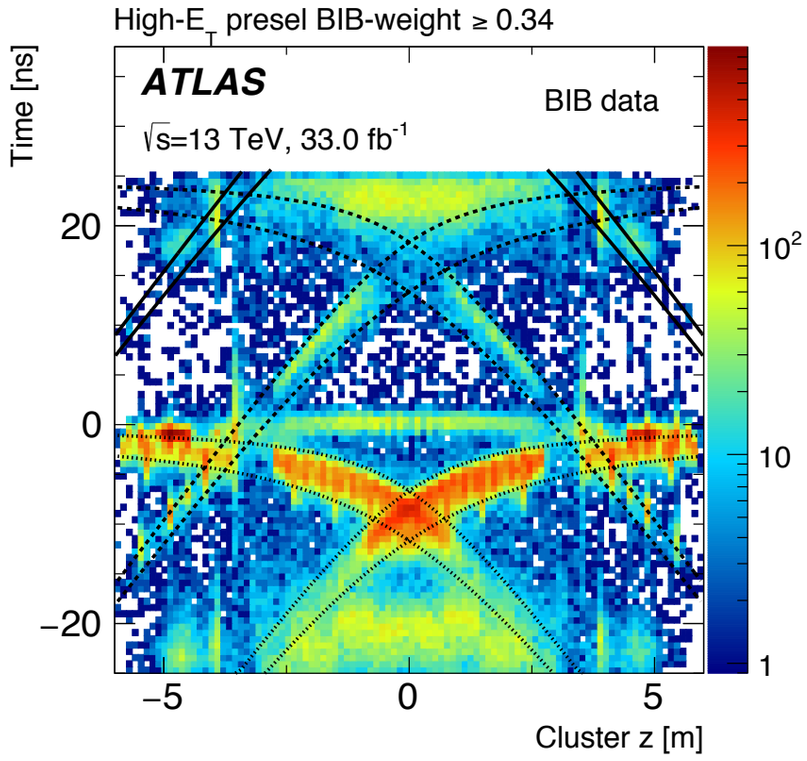
$m_\Phi \in [125,1000]$ GeV

$m_s \in [5,400]$ GeV

- **Backgrounds**: SM QCD multijets, beam induced background (BIB), cosmics



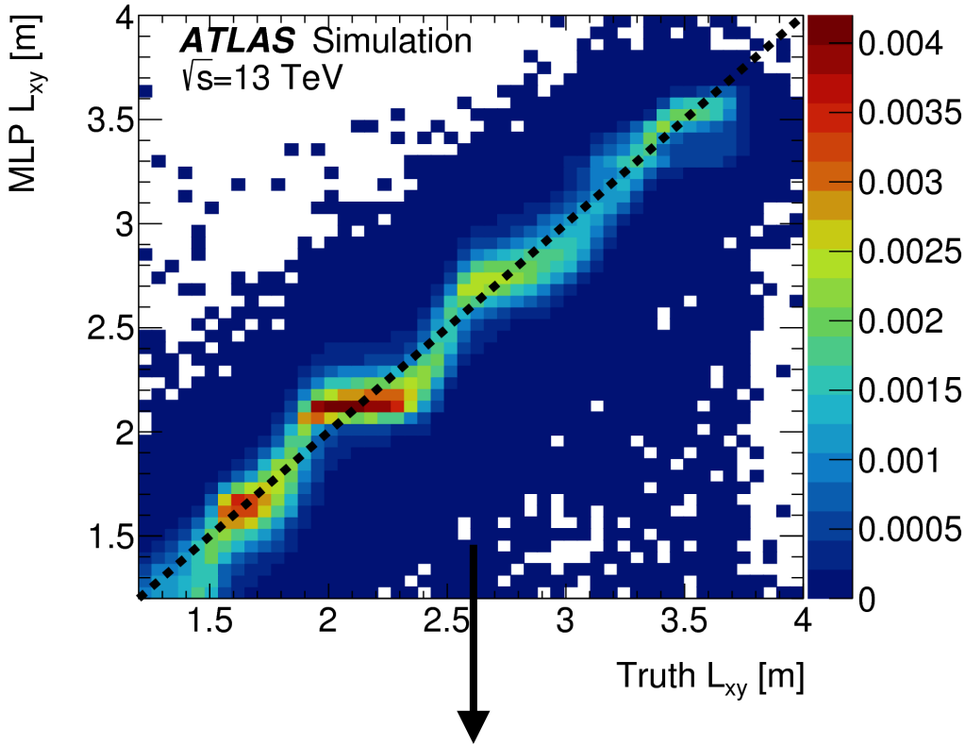


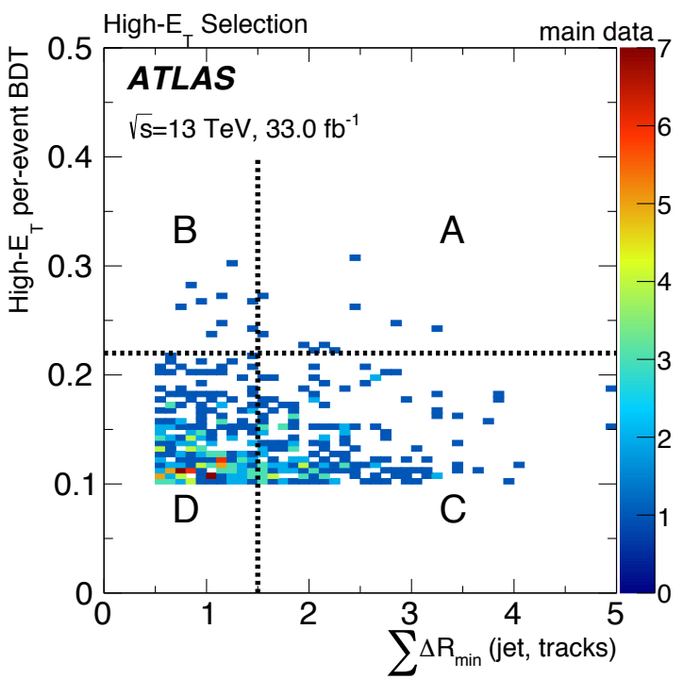


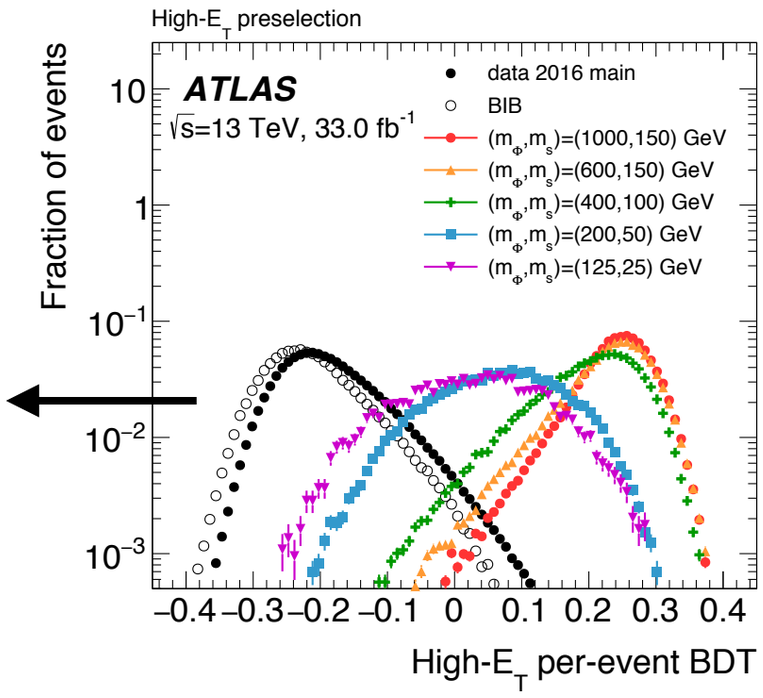
arXiv:1902.03094

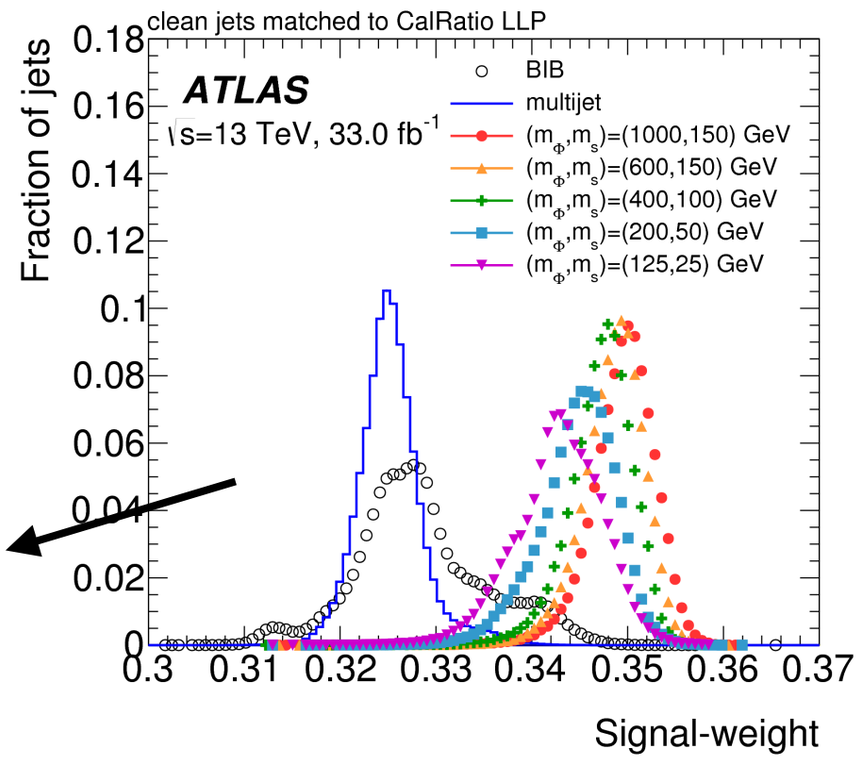
Displaced hadronic jets

- Multilayer perceptron trained on signal MC samples to predict displaced jet decay position
- Per-jet BDT to classify **jets** as signal, multijet or BIB
- Per-event BDTs to distinguish signal and background **events**
- Data-driven background estimate using ABCD method (two ABCD planes/signal regions)





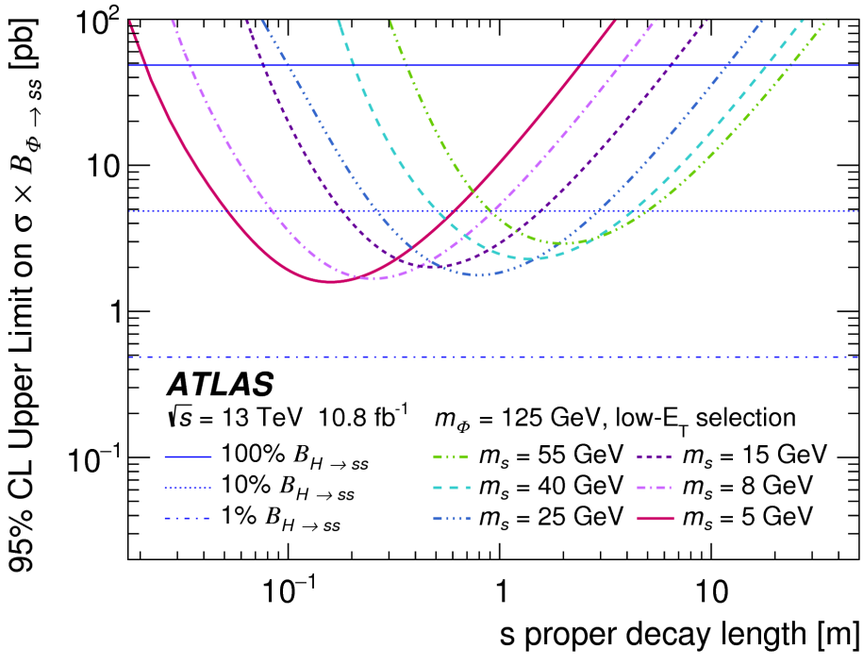


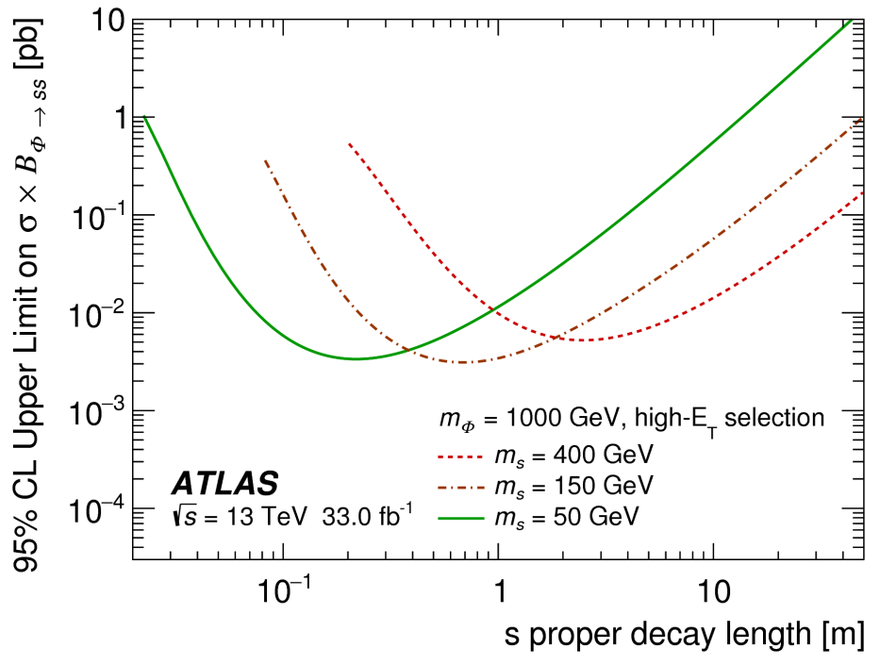


arXiv:1902.03094

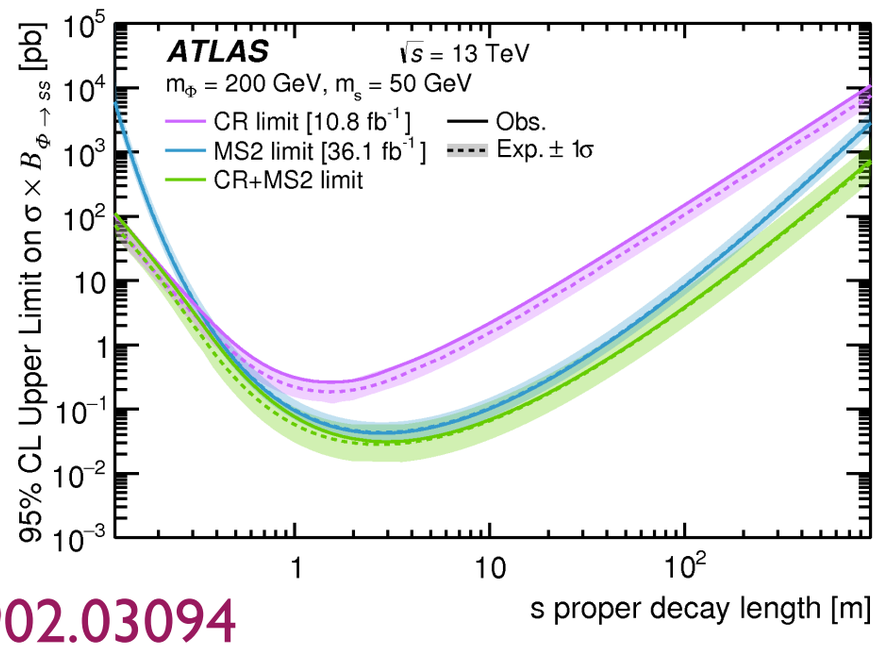
Displaced hadronic jets

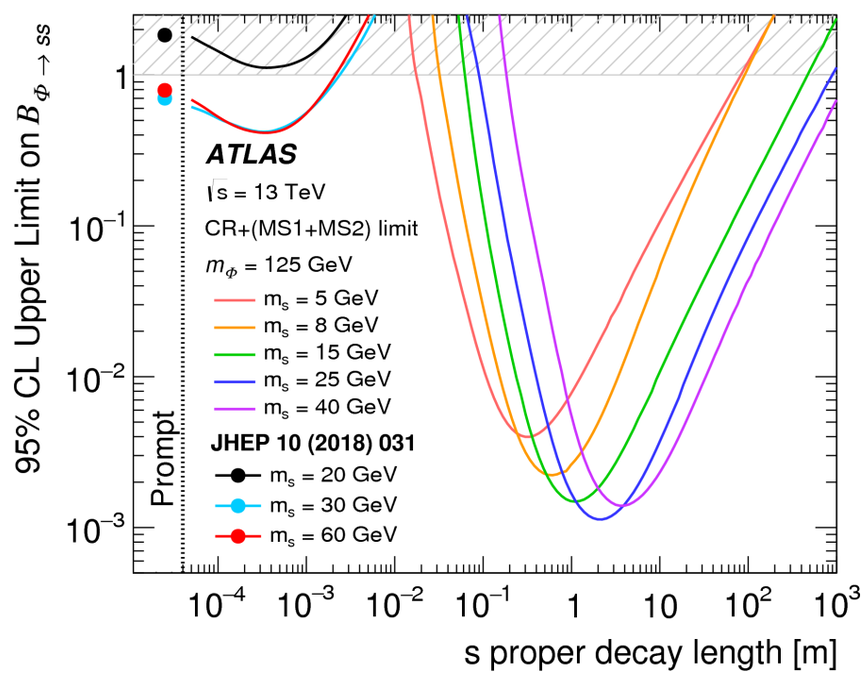
- Limits set using 10.8 fb^{-1} of 2016 data for low-E_T and 33.0 fb^{-1} for high-E_T





- Combined limits with results from MS jets search (arXiv:1811.07370)



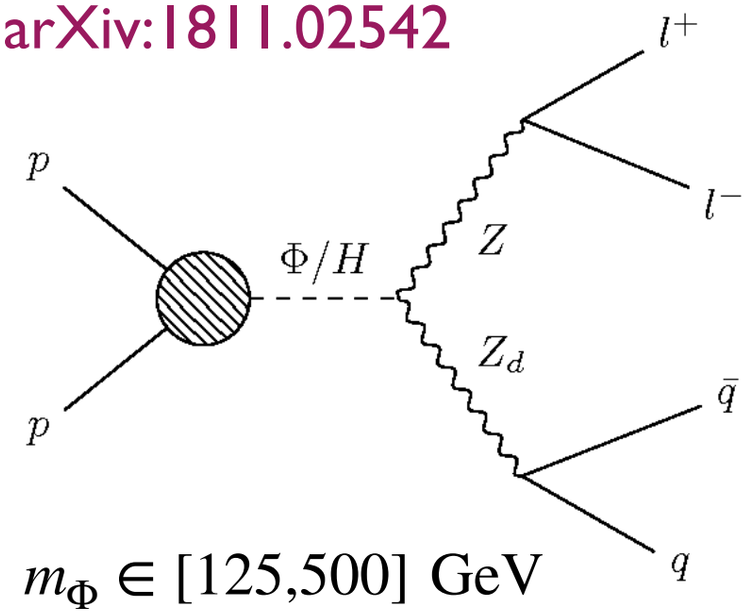


arXiv:1902.03094

Displaced hadronic jet + Z

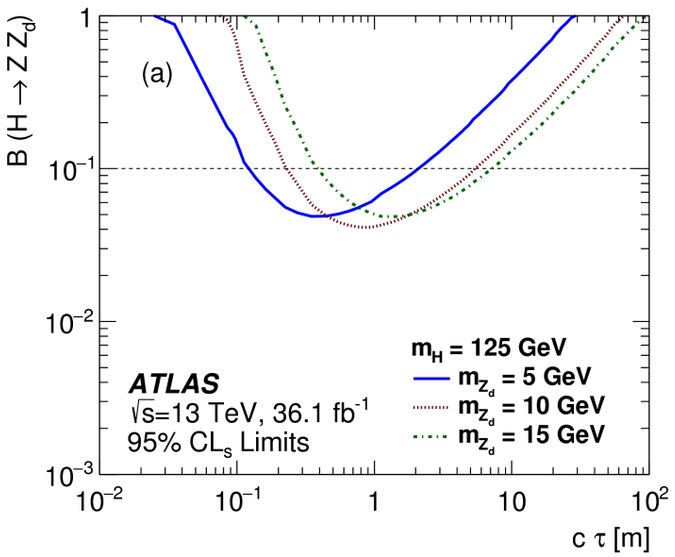
- **Signature**: prompt leptons and one displaced CalRatio jet
- **Model**: $H/\Phi \rightarrow Z(\rightarrow l\,l)\ Z_D(\rightarrow qq)$
- Trigger on prompt lepton
- Cuts on tracks per jet and CalRatio to remove SM backgrounds
- Cuts on jet timing to remove BIB and out-of-time pileup
- **Background estimation**: using SM W+jets data
- Limits set using 36.1 fb^{-1} of 2015/16 data
  - Expands previous search with addition of higher m_Φ models

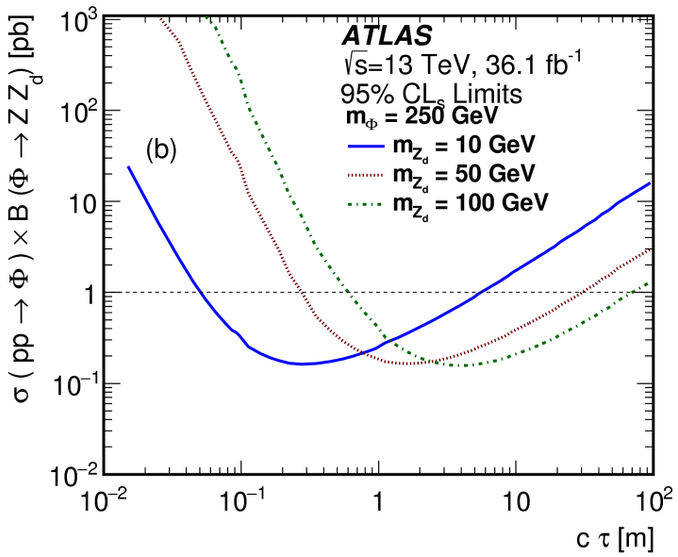
arXiv:1811.02542

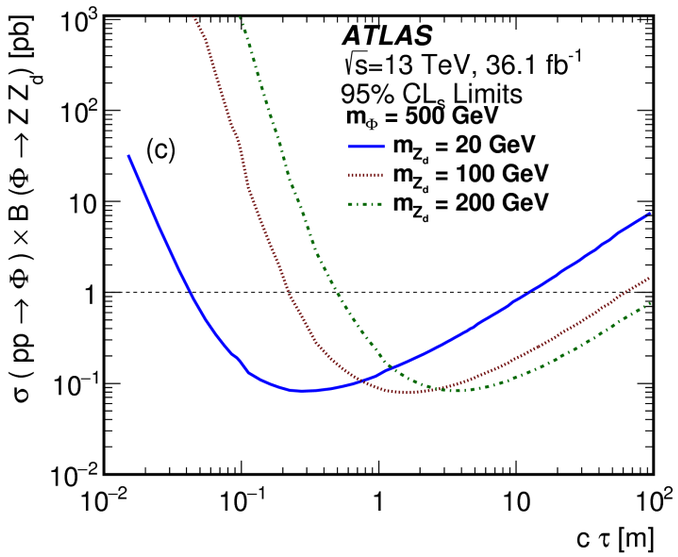


$m_\Phi \in [125,500]$ GeV

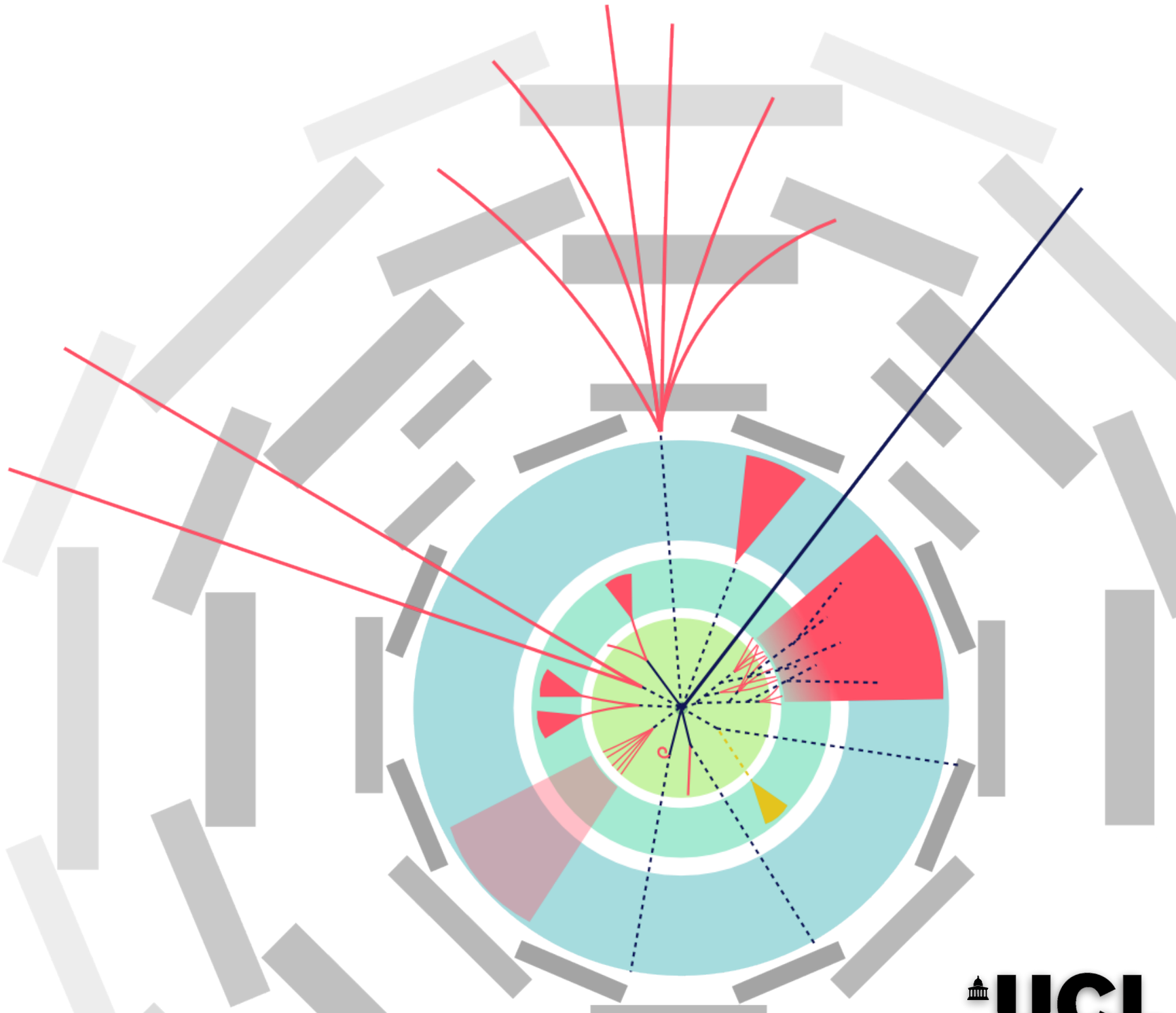
$m_{Z_D} \in [5,200]$ GeV





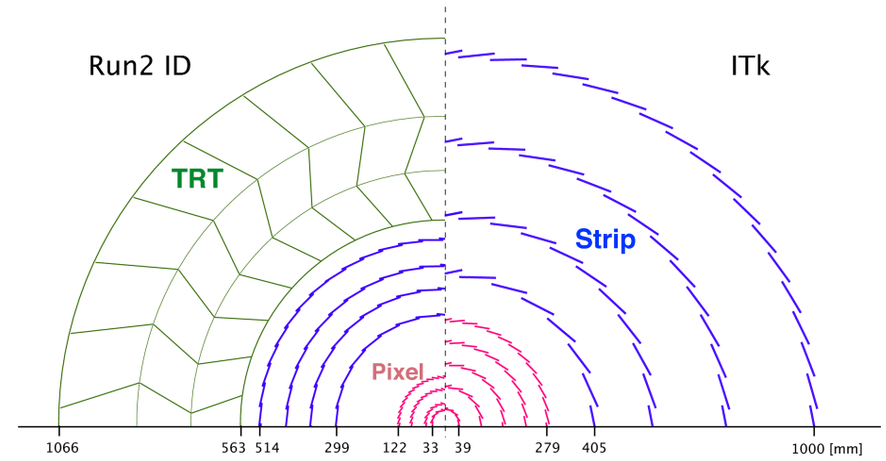


Projections for HL-LHC

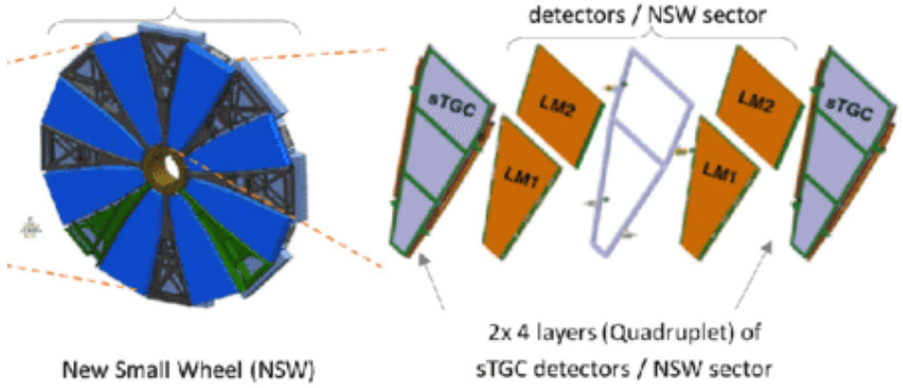


HL-LHC ATLAS upgrade

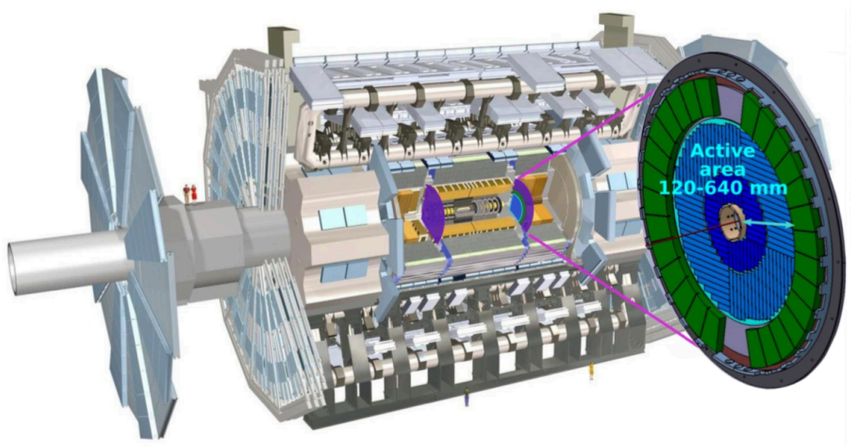
- **Inner Tracker (ITk)**
  - Greatly enlarged silicon tracker - 2x radius and 4x length of current silicon array, 3x area
  - Improved tracking capability



- **Tile and LAr:** electronics improvements
- **Muon system:**
  - Readout improvement to face higher trigger rates
  - New small wheels (also for Run 3)
  - More advanced and flexible muon reconstruction algorithms will be possible

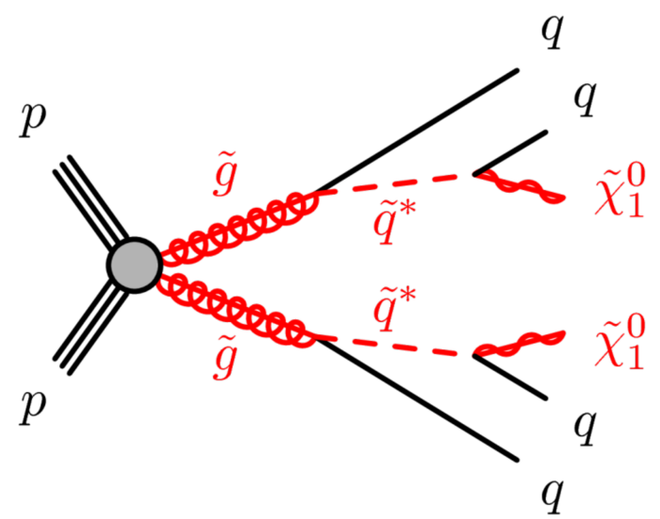


- **Timing detector:**
  - Improve track-to-vertex association in forward region



DV+MET at HL-LHC

- **Signature**: at least 1 displaced vertex + missing E_T
- **Model**: gluino R-hadron pair production, decaying to SM quarks + stable neutralino
- Efficiency estimated using simple particle-level selection and run 2 reinterpretation material
- Improvements to tracking and vertexing performance from ITk



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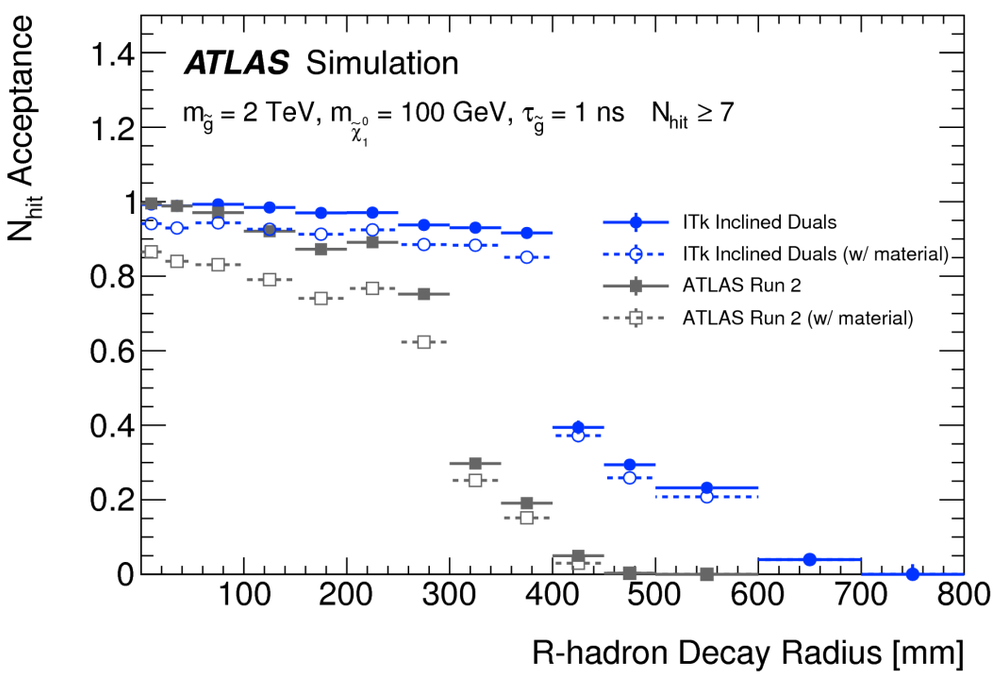
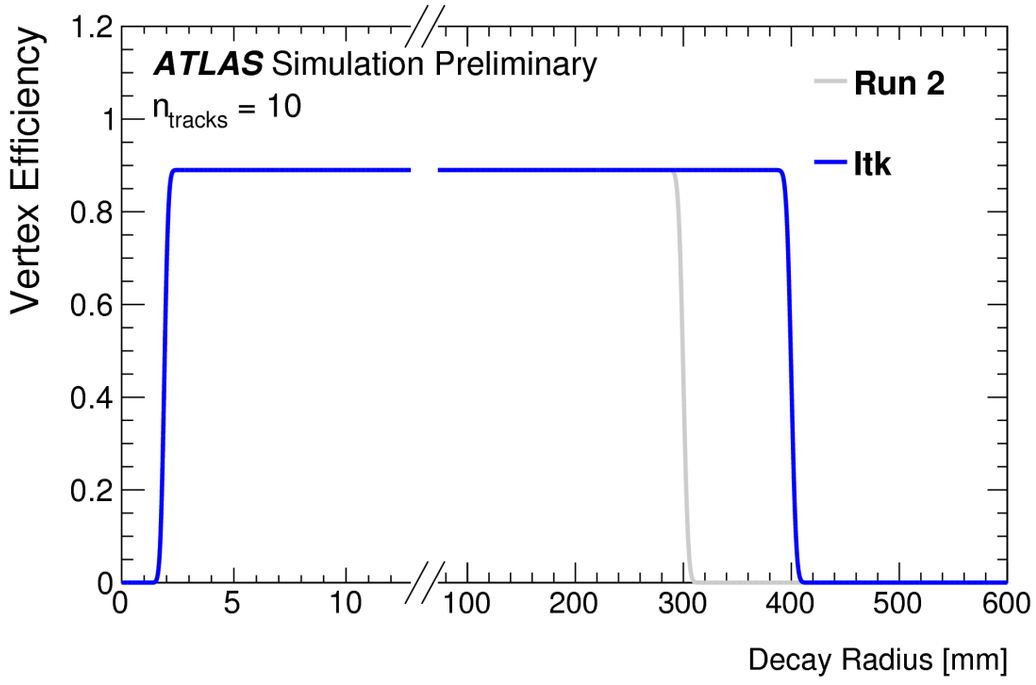


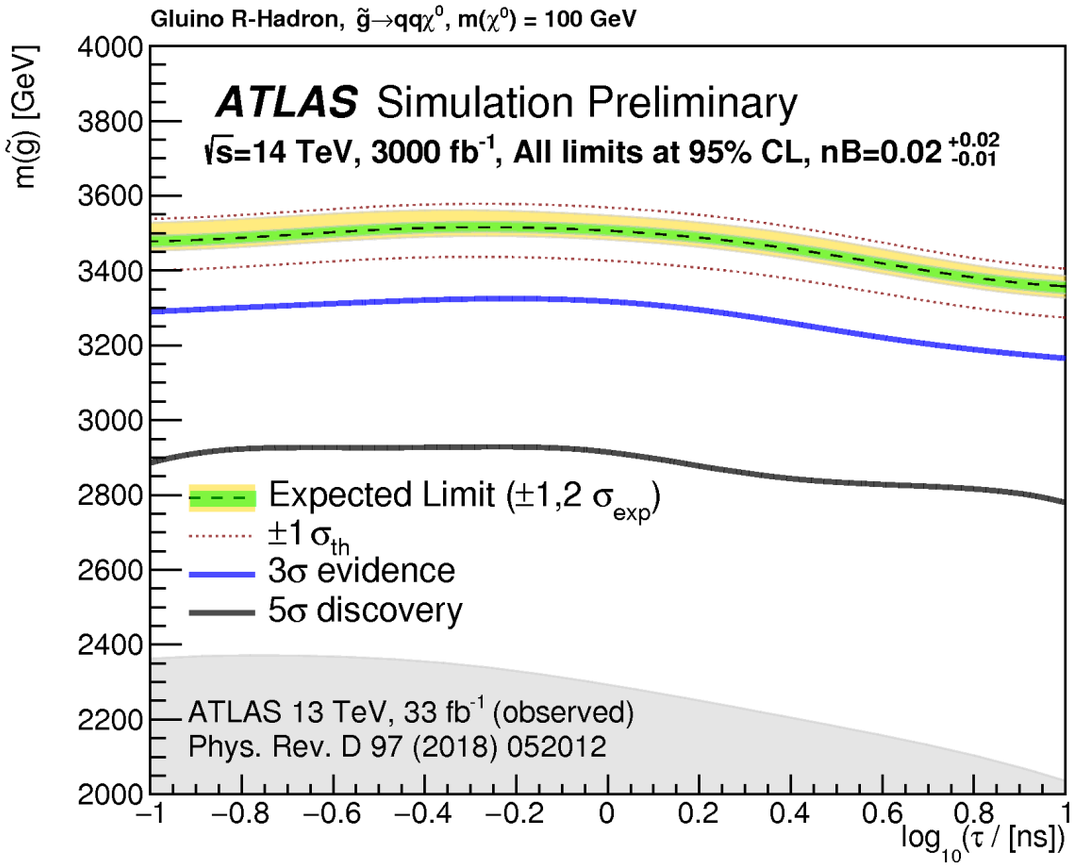


DV+MET at HL-LHC

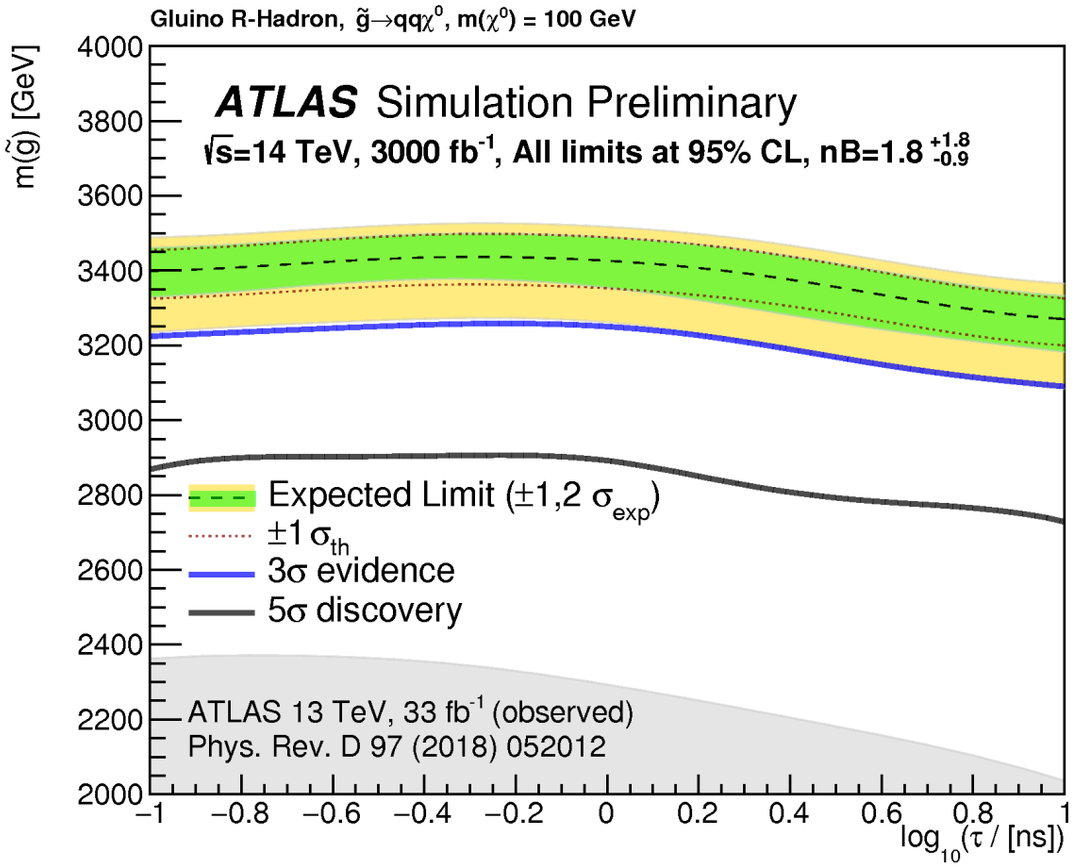
- 5σ discovery potential for gluino masses up to 2.8 TeV for a 100 GeV neutralino, within sensitive lifetime range of $0.1 < \tau < 10$ ns

ATL-PHYS-PUB-2018-033

- In absence of gluino pair production, masses up to 3.4 TeV could be excluded

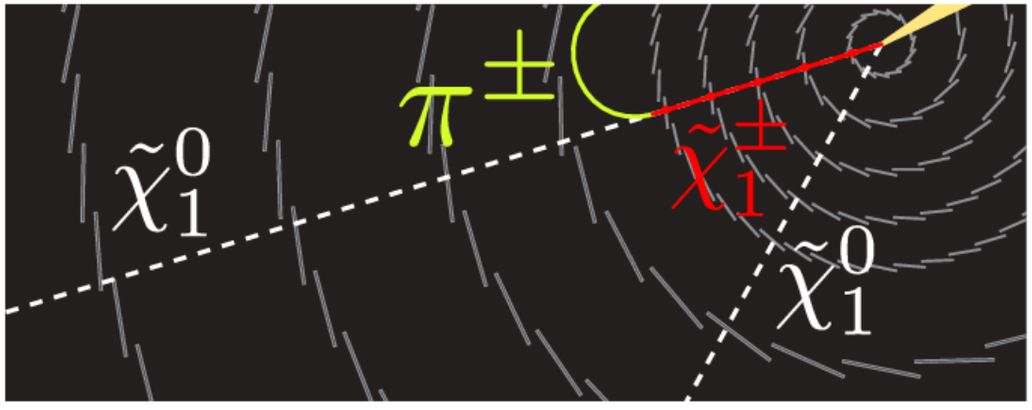


Conservative bkg estimate



Optimistic bkg estimate

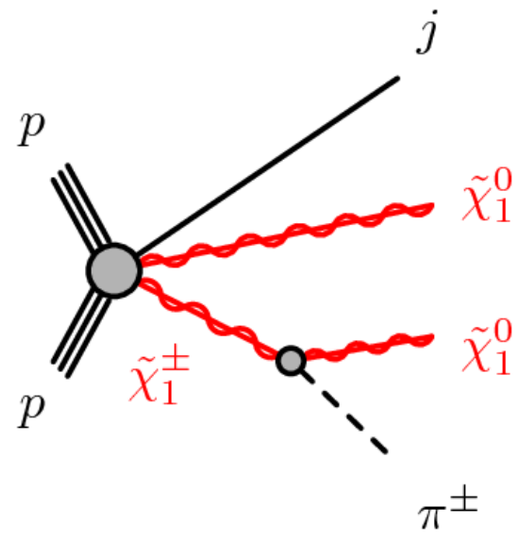
Disappearing tracks at HL-LHC



- **Signature**: disappearing track in inner detector
- **Model**: chargino decay via neutralino and very soft pion
  - If mass of chargino and neutralino are ~degenerate the chargino can be long-lived
- Latest ATLAS results using the 2015–2016 dataset excluded wino masses below 430 GeV with chargino lifetime 0.2 ns
- Truth level analysis with parameterised detector response
- Select events with short tracks, no leptons, large MET

Variable	SR Selection
Lepton veto p_T [GeV]	>20
$\min\{\Delta\phi(\text{jet}_{1-4}, E_T^{\text{miss}})\}$	> 1
E_T^{miss} [GeV]	> 300
Leading jet p_T [GeV]	> 300
Leading tracklet p_T [GeV]	> 150
$\Delta\phi(E_T^{\text{miss}}, \text{trk})$	< 0.5

ATL-PHYS-PUB-2018-031



Disappearing tracks at HL-LHC

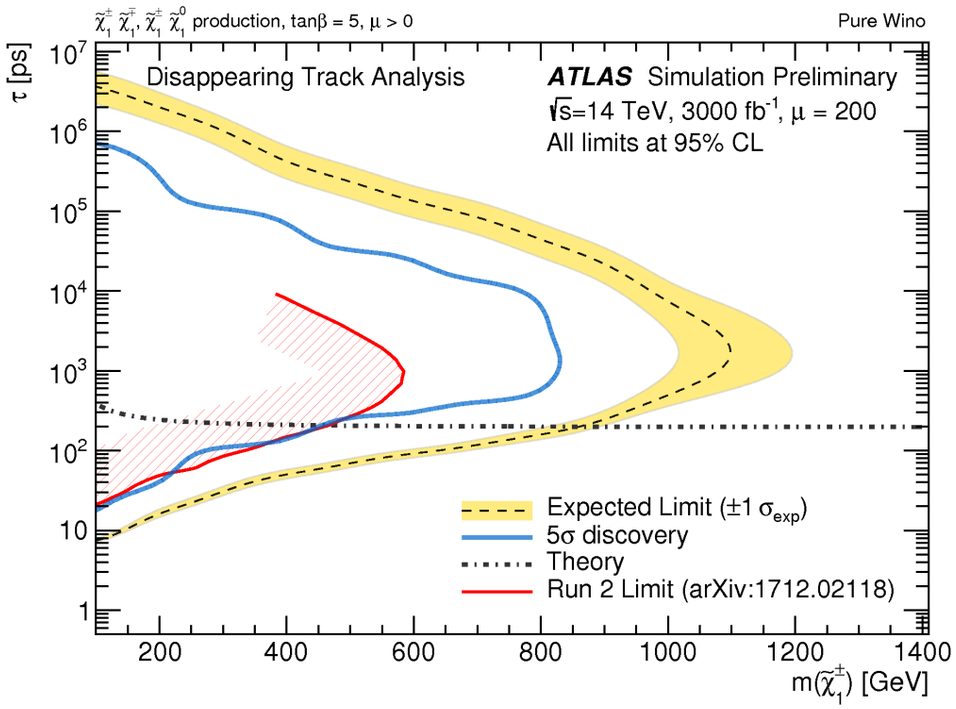
- Large gain in disappearing track sensitivity at HL-LHC

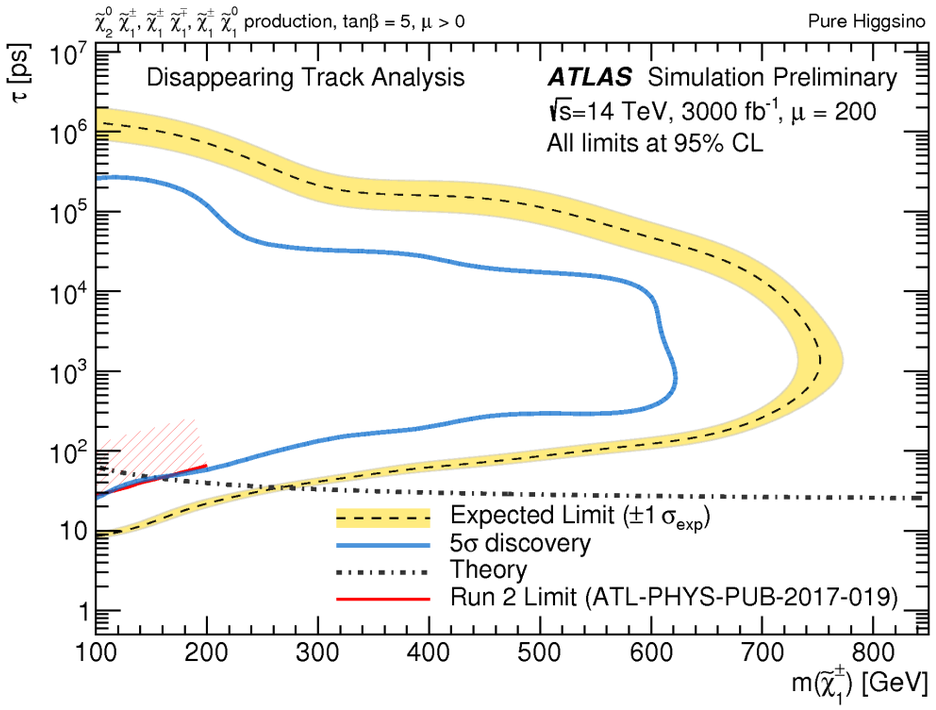
  ATL-PHYS-PUB-2018-031

- Discovery potential:
  - Pure wino: mass < 450 GeV
  - Pure higgsino: mass < 150 GeV

- Exclusion potential:
  - Pure wino: mass < 850 GeV
  - Pure higgsino: mass < 250 GeV

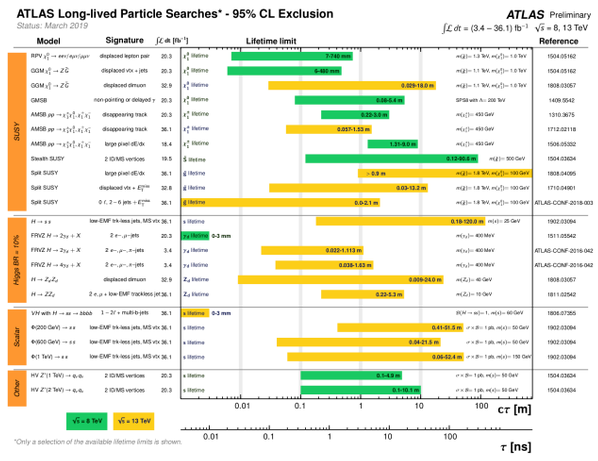
- More tracking and vertexing improvements:
  - ATL-PHYS-PUB-2019-011





Summary

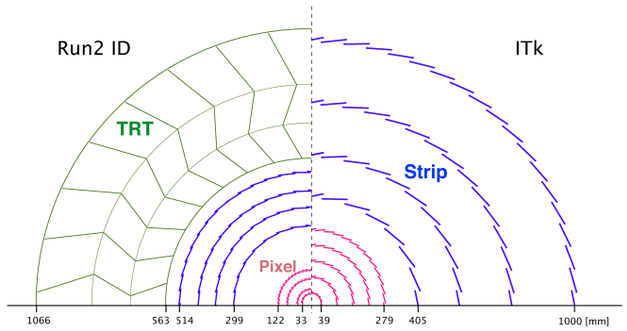
- Many interesting searches happening at the ATLAS experiment, more than I have described here

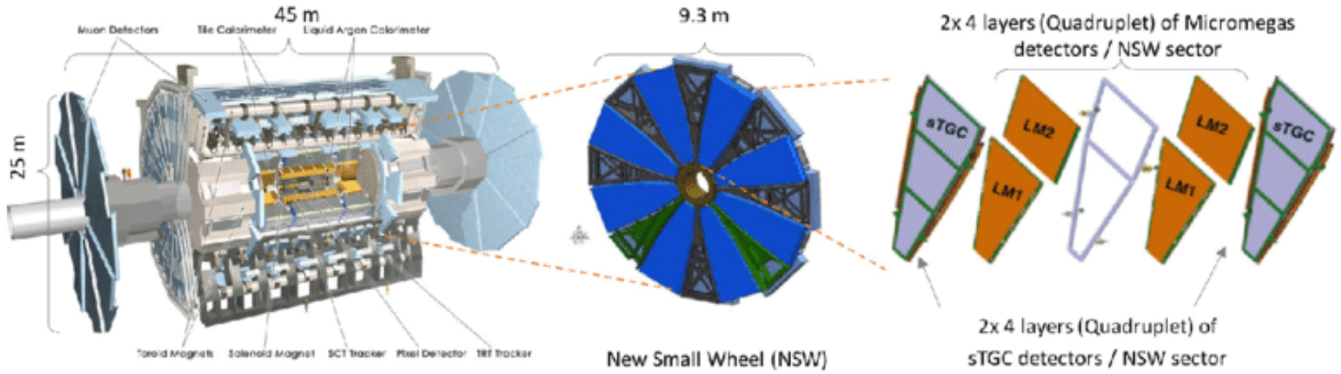


Run 2 Results	
	Highly ionising particles / magnetic monopole search
	Prompt and displaced heavy neutral leptons (Juliette's talk)
	Displaced hadronic jets in calorimeter
	Heavy charged LLPs
	Displaced vertex + muon
	Multi charged LLPs
	Displaced hadronic jets in muon spectrometer
	Z + displaced hadronic jet
	Displaced muon vertex (non-collimated)
	BSM H → 2a → 4b
	Heavy charged LLPs (SUSY)
	SUSY search reinterpretations for LLPs

HL-LHC	
	Lepton-jets at HL-LHC (Juliette's talk)
	DV+MET at HL-LHC
	Disappearing tracks at HL-LHC

- Upgrades to ATLAS experiment will bring improved sensitivity to LLP searches





- Many more analyses in the works…