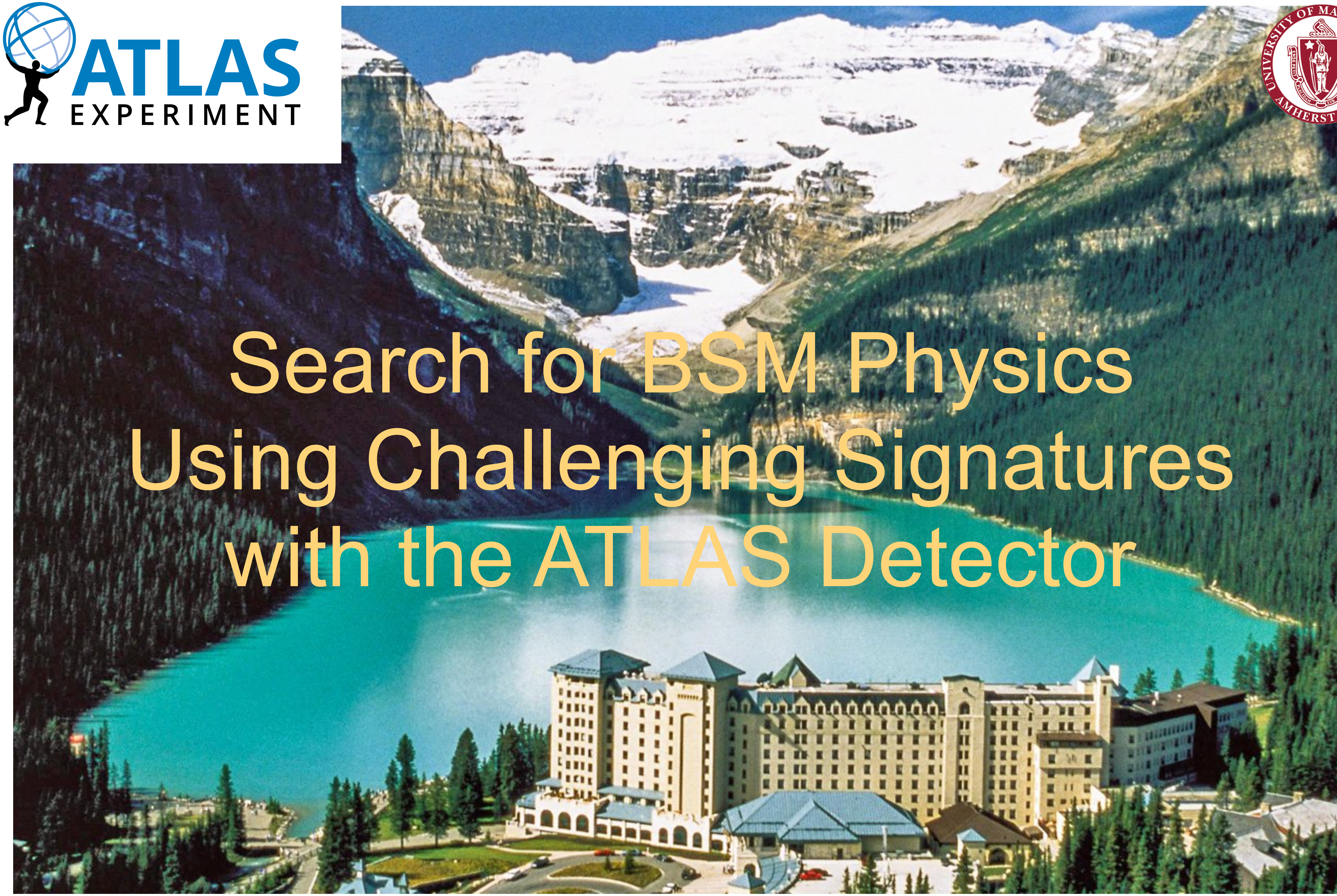
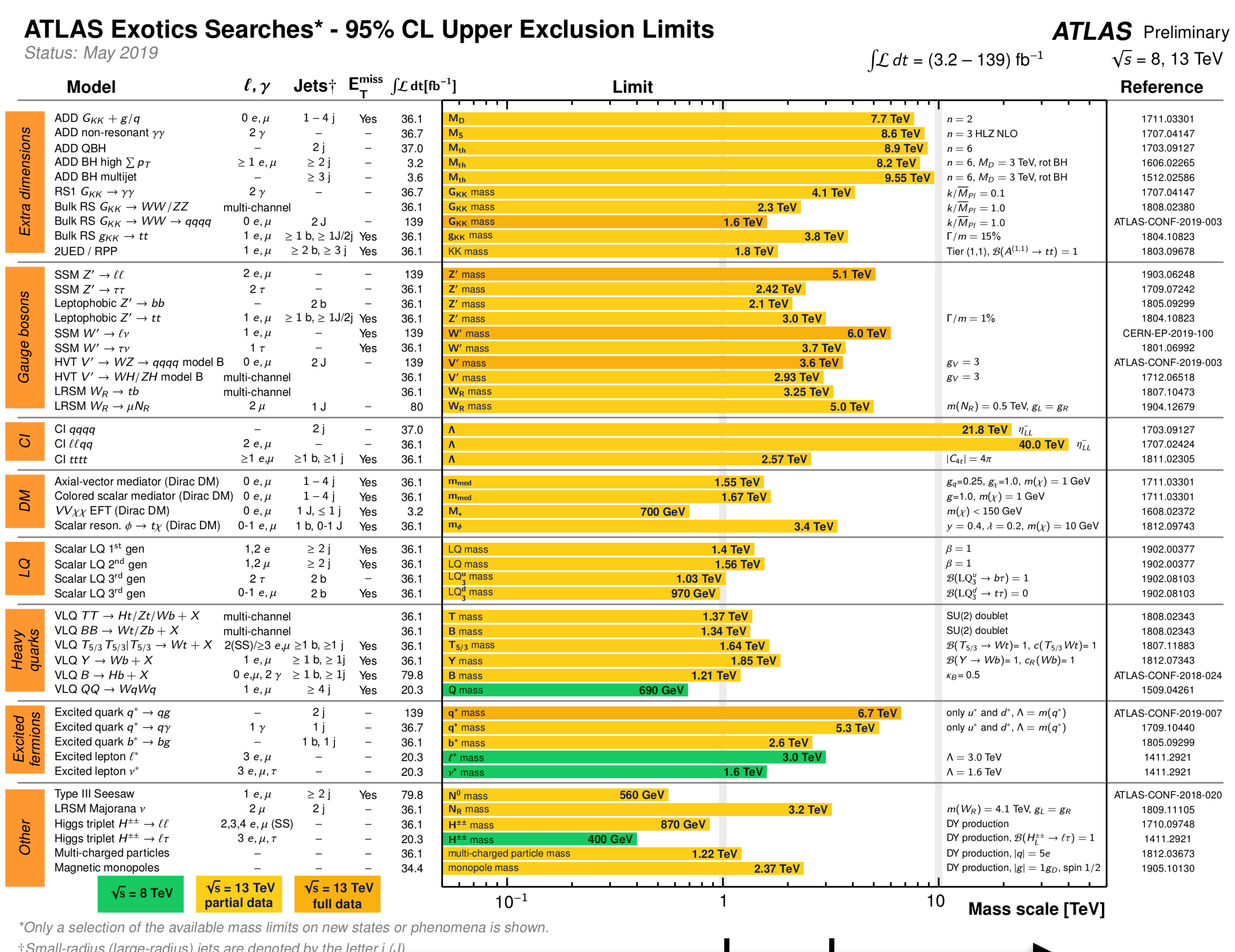
Search for BSM Physics Using Challenging Signatures with the ATLAS Detector



Carlo Dallapiccola
University of Massachusetts - Amherst
on behalf of the ATLAS Collaboration

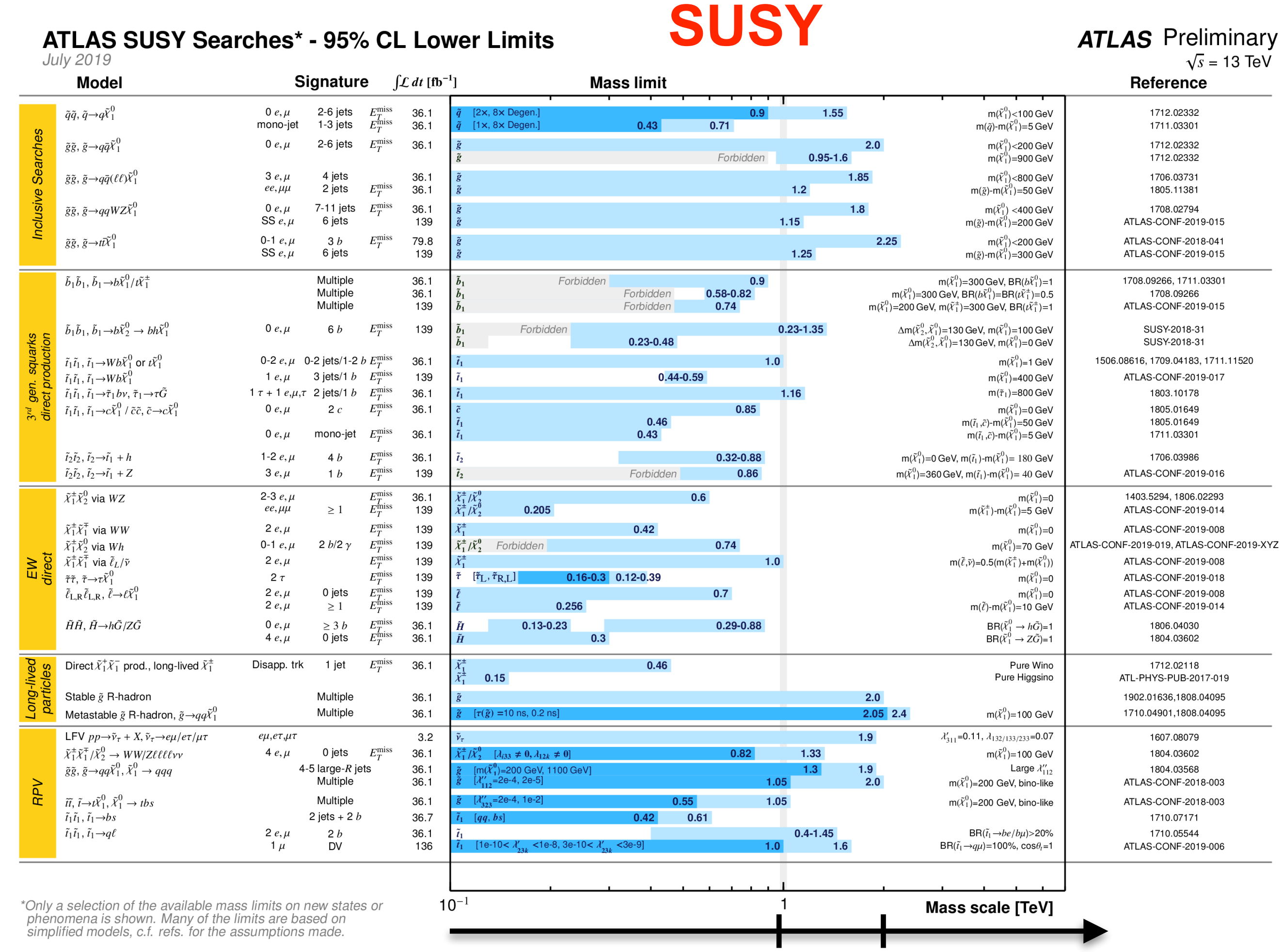
- Lots of BSM ground covered in direct searches
  - no evidence using more conventional signatures

non-SUSY



excluded masses 1 3 TeV

SUSY



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)

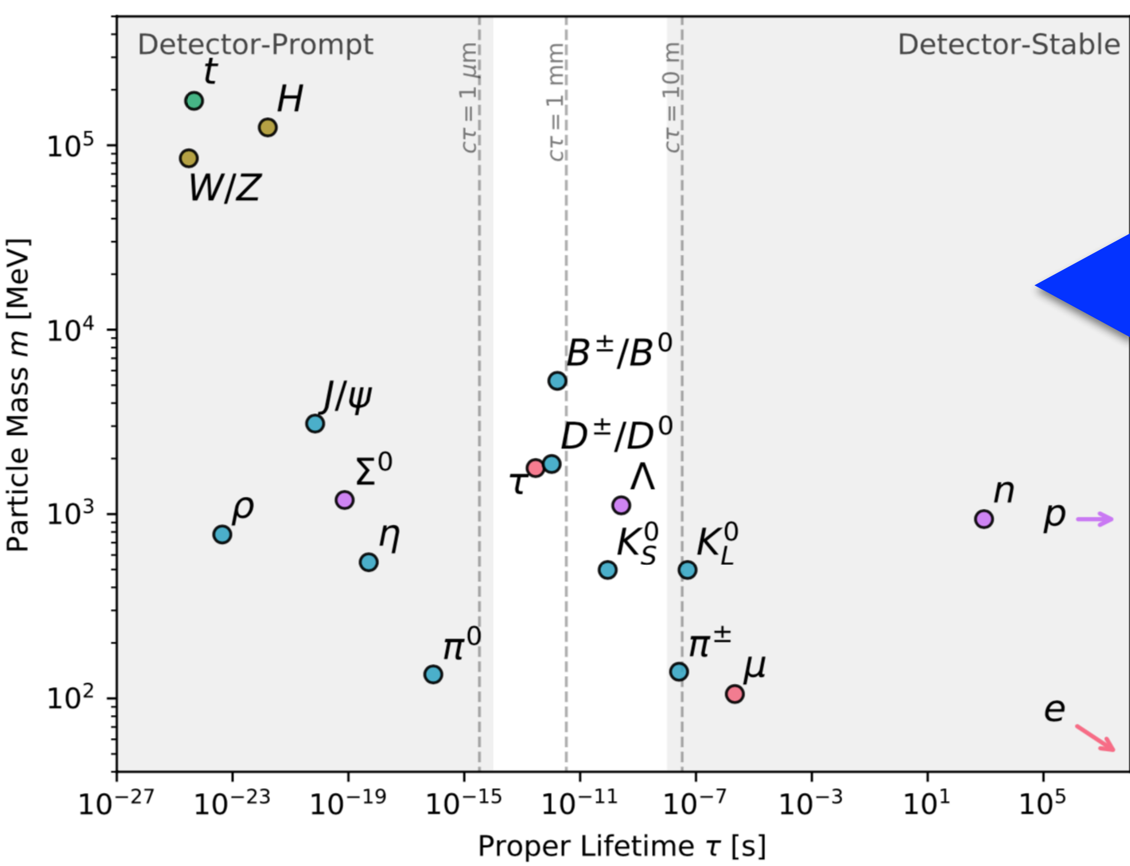
BSM Physics with Non-Conventional Signatures

- Stable or meta-stable, <u>interacting</u> (<u>charged</u>) particles
  - Dirac monopoles
  - sleptons
  - *R*-hadrons
- Meta-stable <u>non-interacting</u> 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



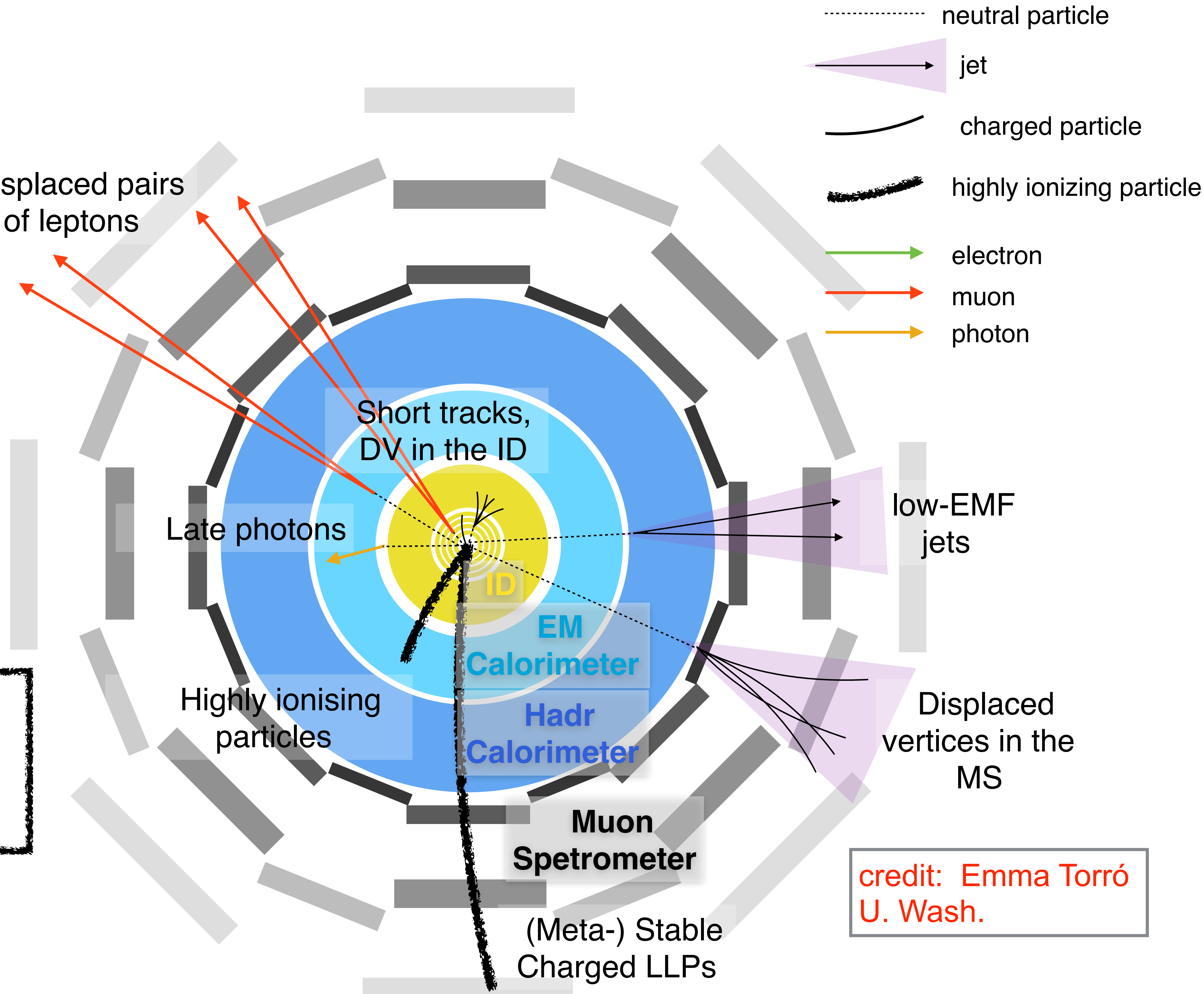
https://arxiv.org/abs/1810.12602

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 hight p_T lepton/jet/γ, 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 ATLAS Results

Selection of results that are

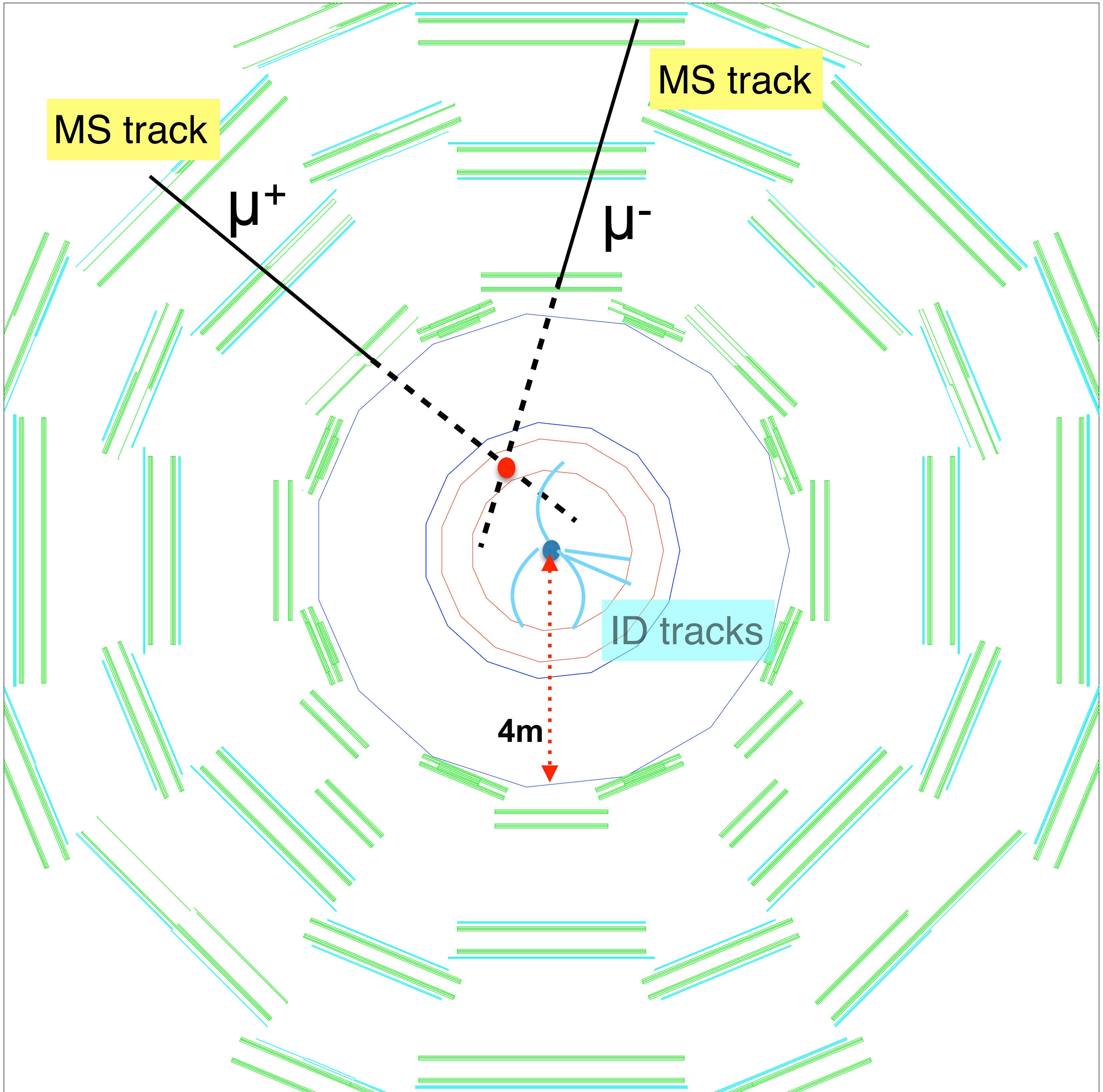
- relatively current
- representative of variety of techniques

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

Displaced Dimuon Vertex

Phys. Rev. D 99 (2019) 012001

Displaced dimuon vertices using solely MS tracks



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

Sensitivity:
Decay lengths of 0.01 - 4m

Displaced Dimuon Vertex

Phys. Rev. D 99 (2019) 012001

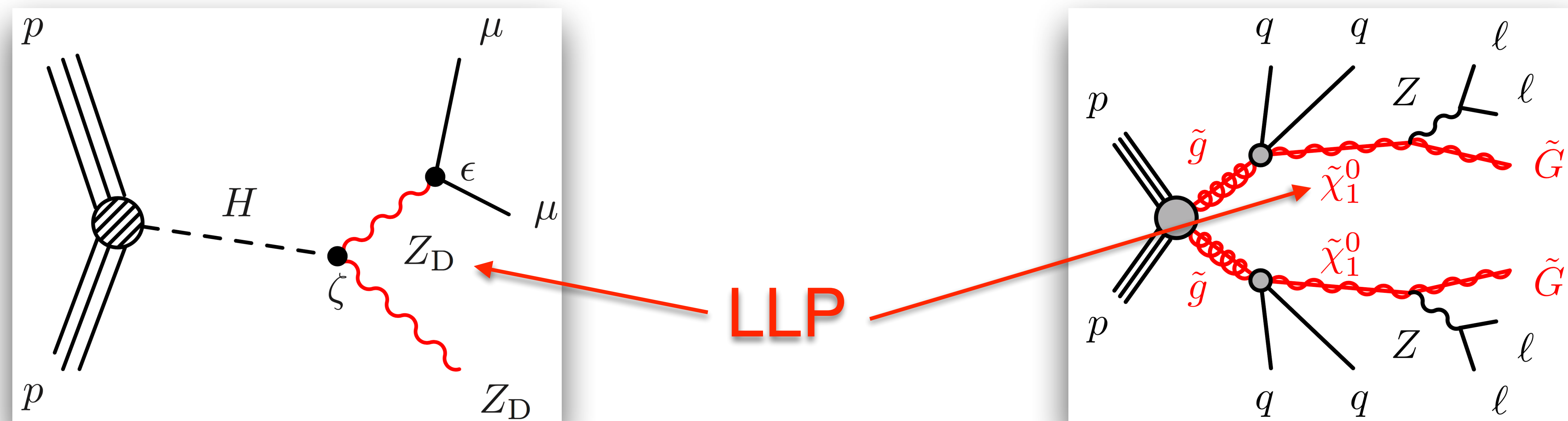
Interpretations: Signal Models

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)



Displaced Dimuon Vertex

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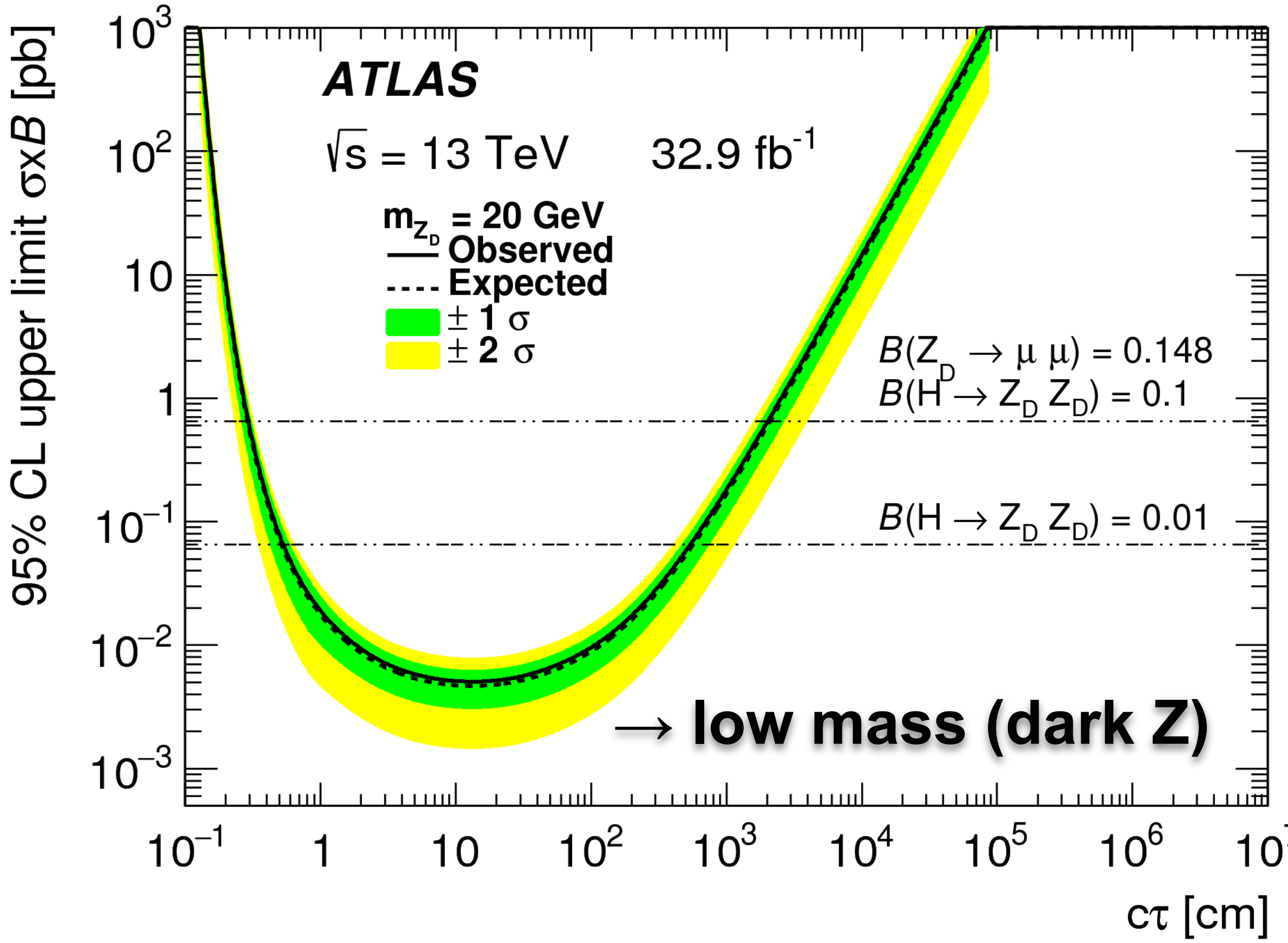
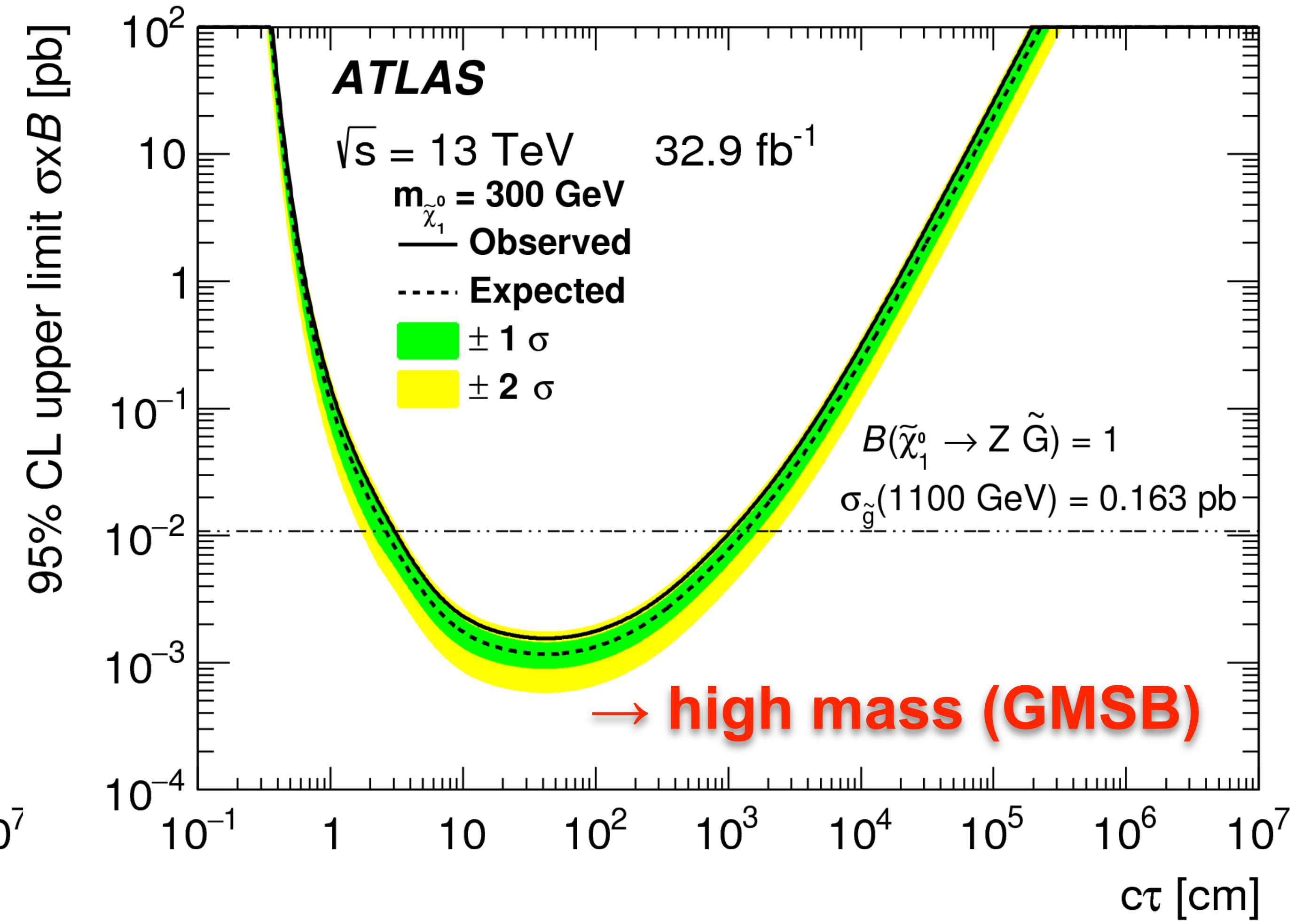




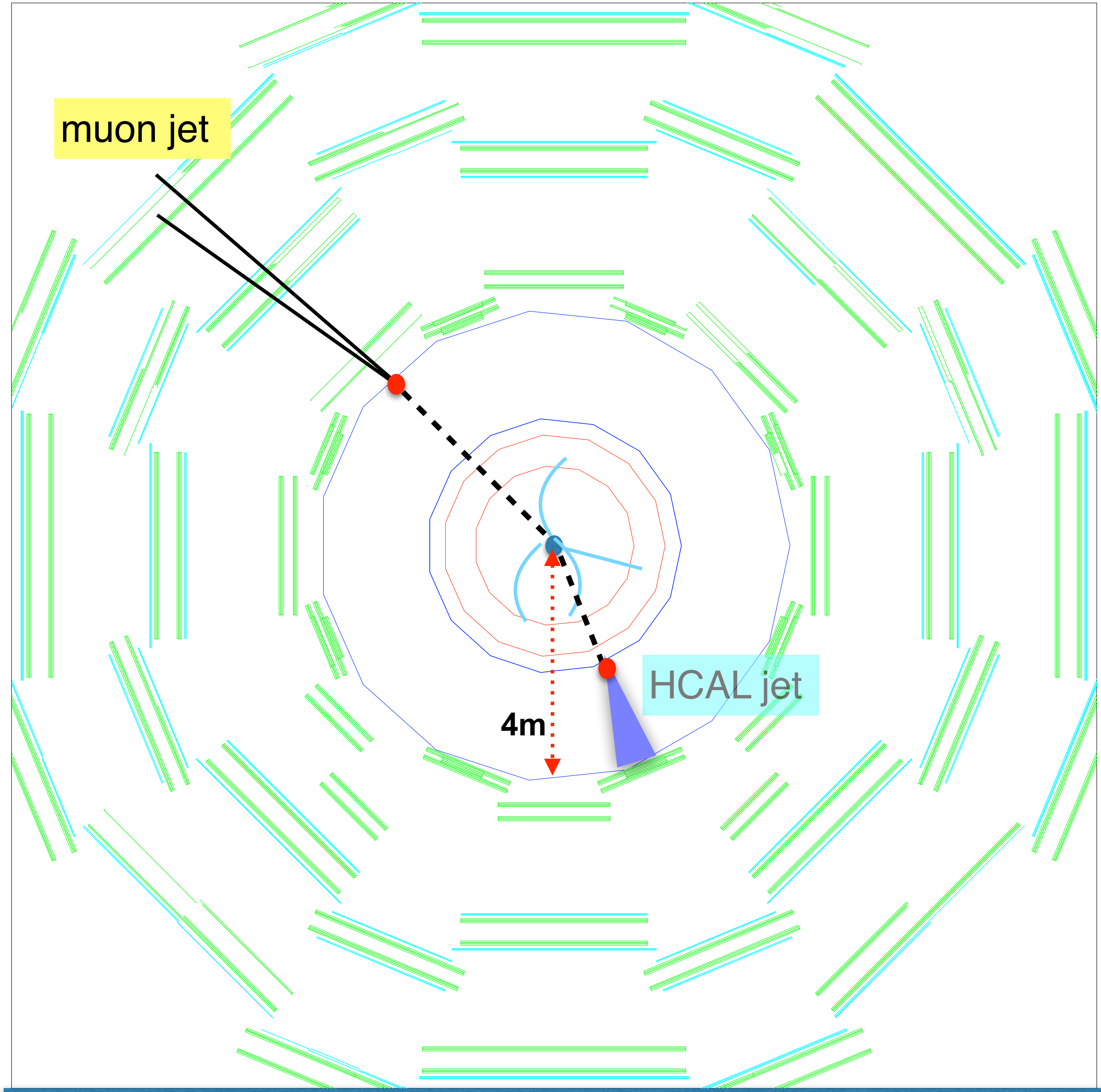
Exclude $1 < c\tau < 1000$ cm (approx)

$20 < m(Z_D) < 60$ GeV $400 < m(\chi) < 1000$ GeV

Displaced Muonic and Hadronic Jets

arXiv.org/pdf/1909.01246

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



- Pair-produced LLP

  μμ - μμ
  μμ - narrow HCAL jet
  HCAL jet - HCAL jet

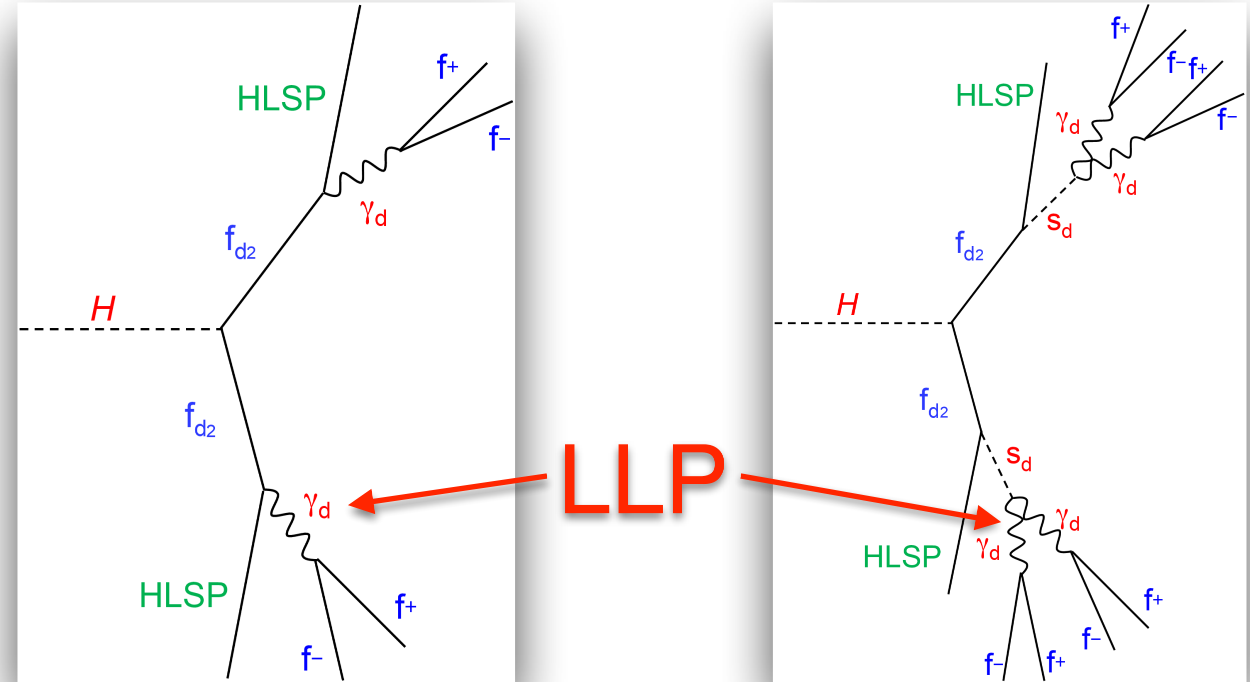
Sensitivity:

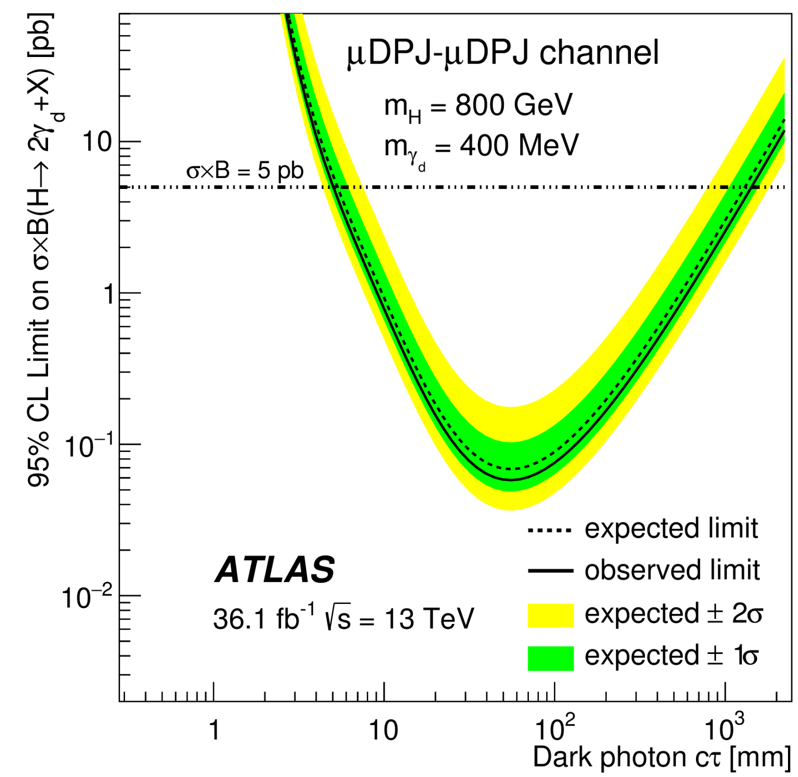
Decay lengths of 0.01 - 4m (μjet)

Decay lengths of 2 - 4m (hadjet)

Displaced Muonic and Hadronic Jets

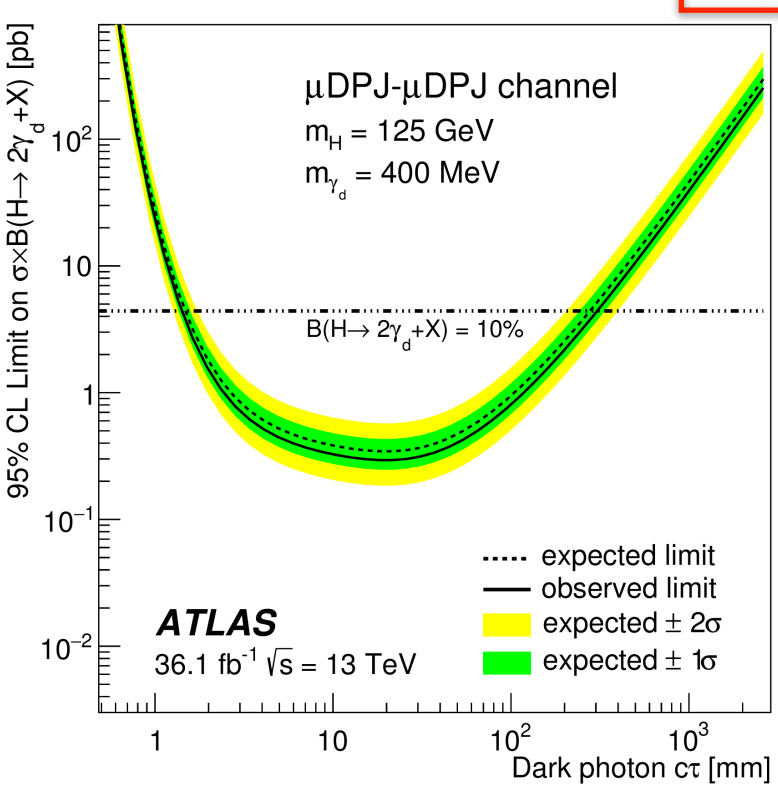
arXiv.org/pdf/1909.01246

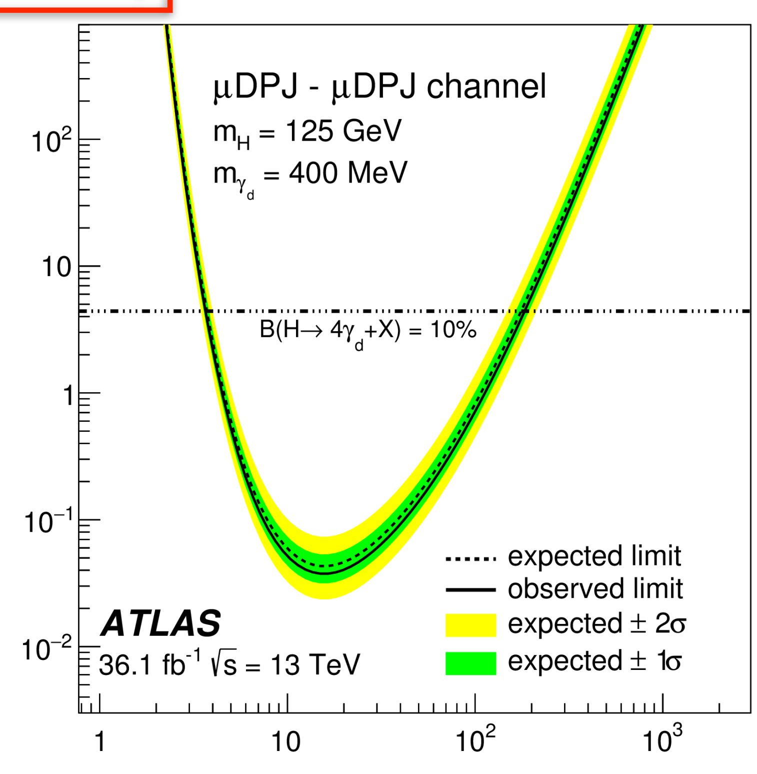


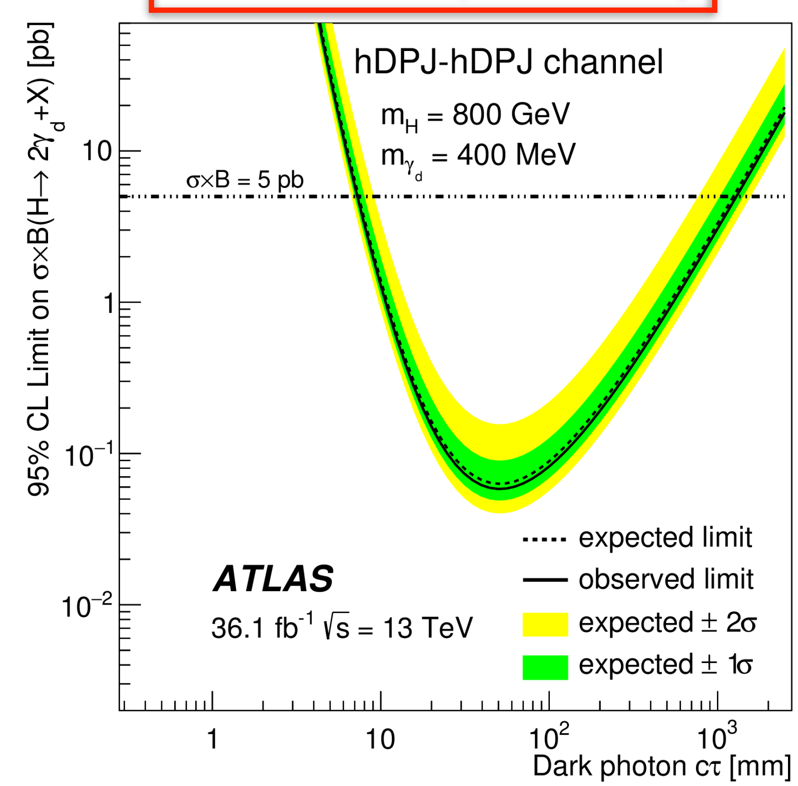


H (125 GeV)

BSM scalar (800 GeV)



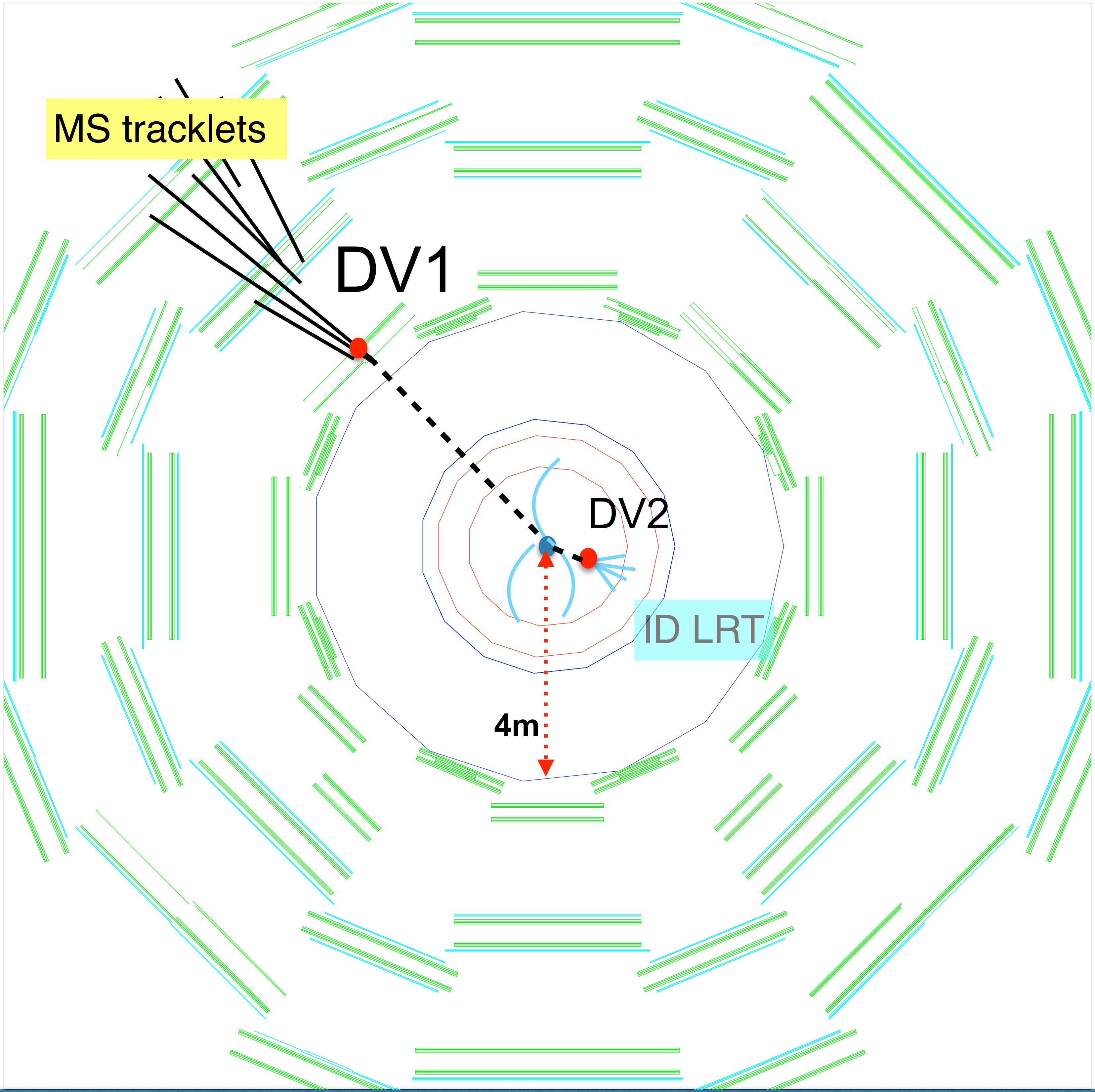




Displaced Vertices (DV): ID-MS

arXiv.org/pdf/1911.12575

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)

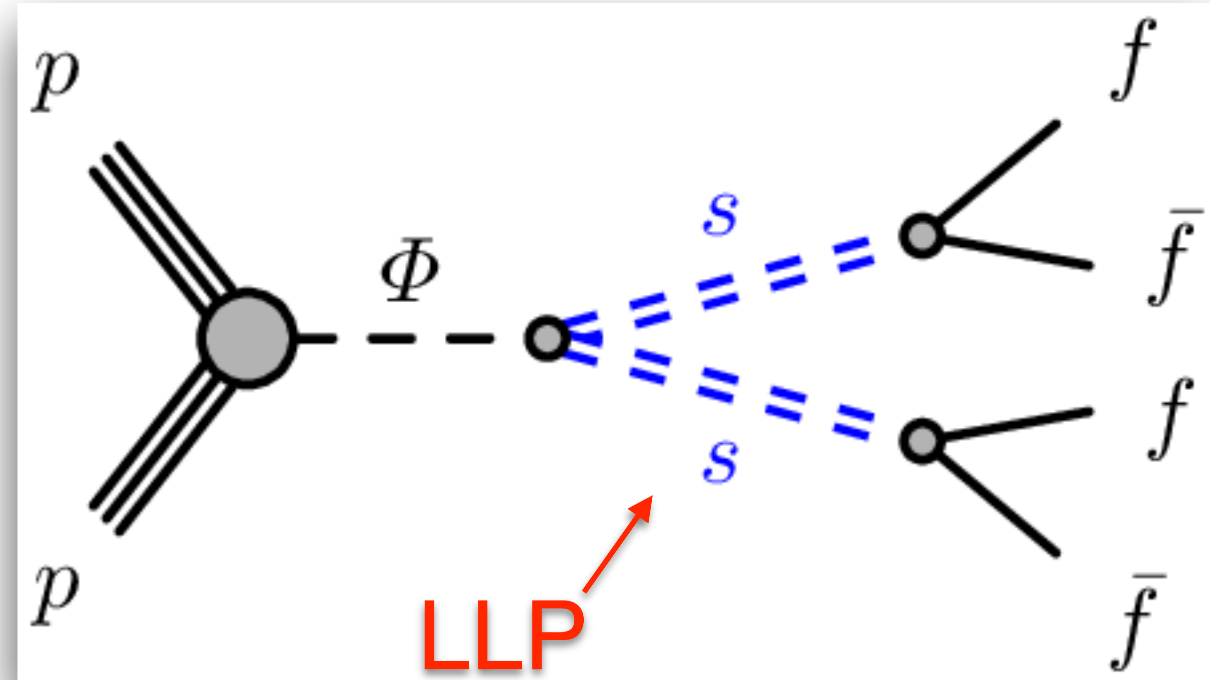
Decay lengths of 0.01 - 0.33m (DV2)

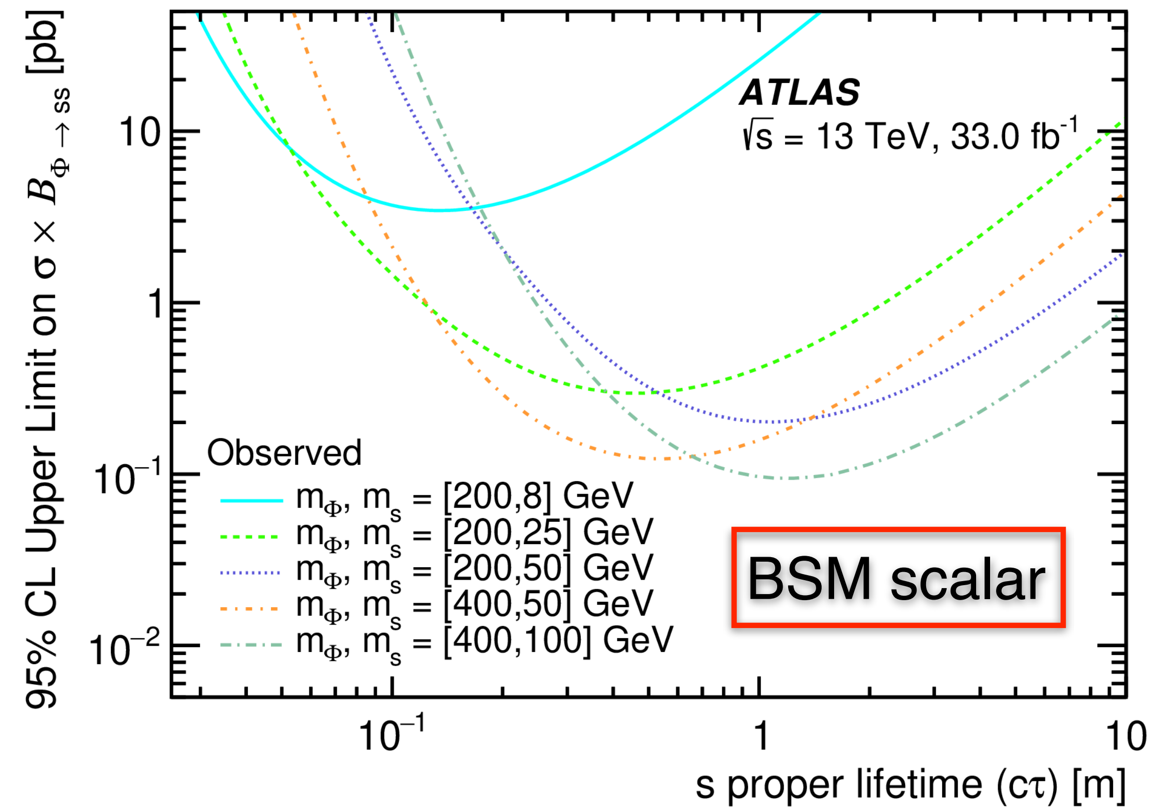
- MS tracklet DV used in other LLP analyses:
  - MS - MS
  - MS - Jet
  - MS - MET

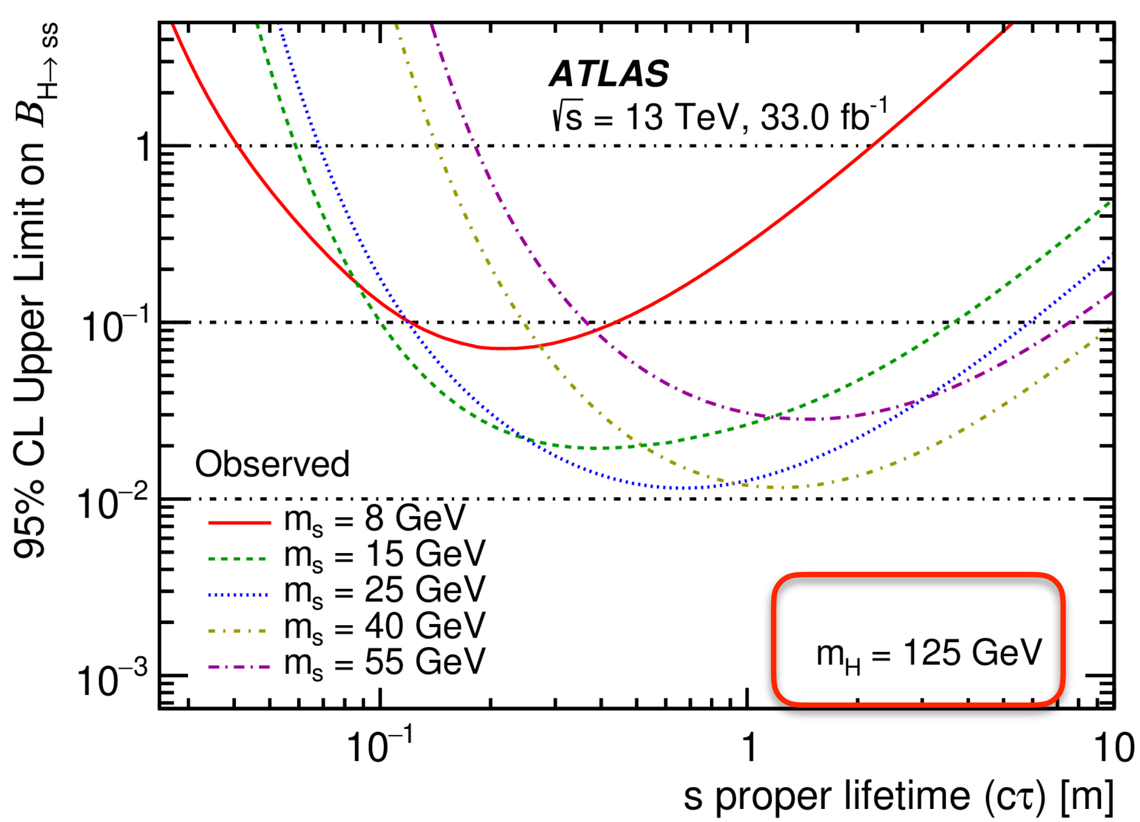
Phys. Rev. D99 052005 (2019)

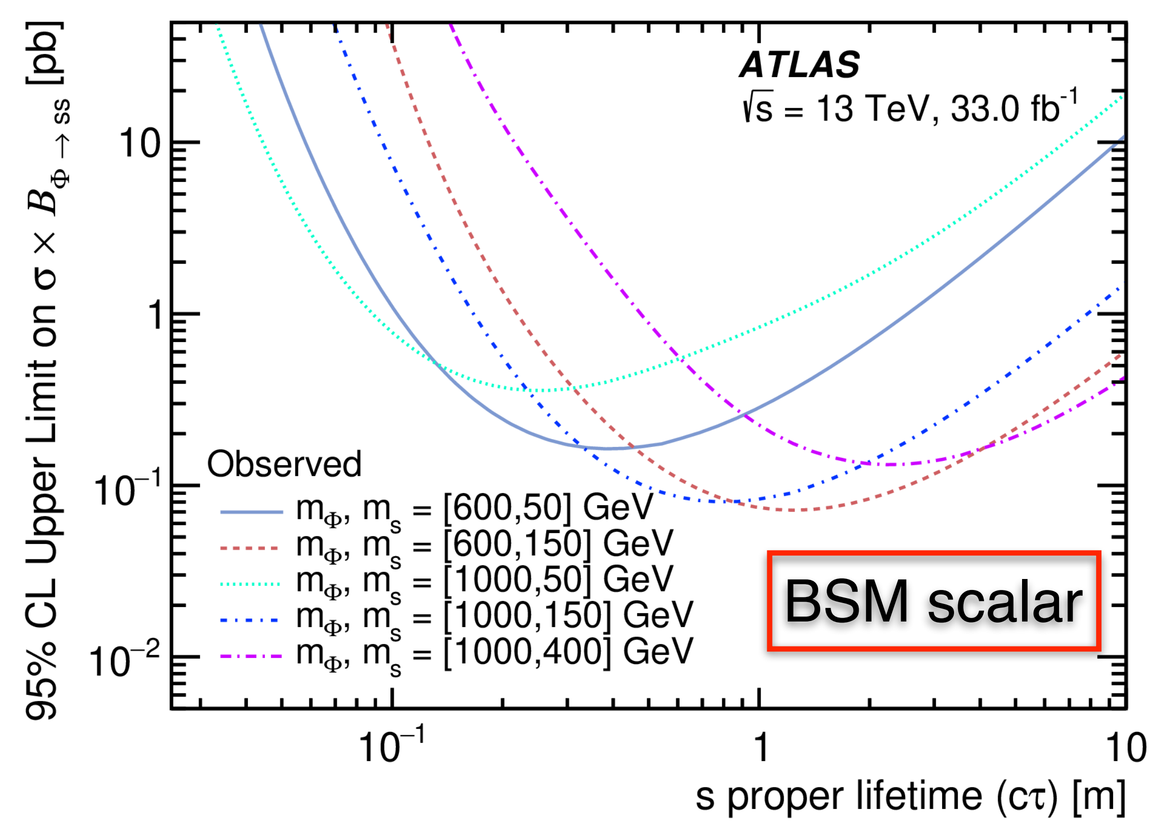
Displaced Vertices (DV): ID-MS

arXiv.org/pdf/1911.12575





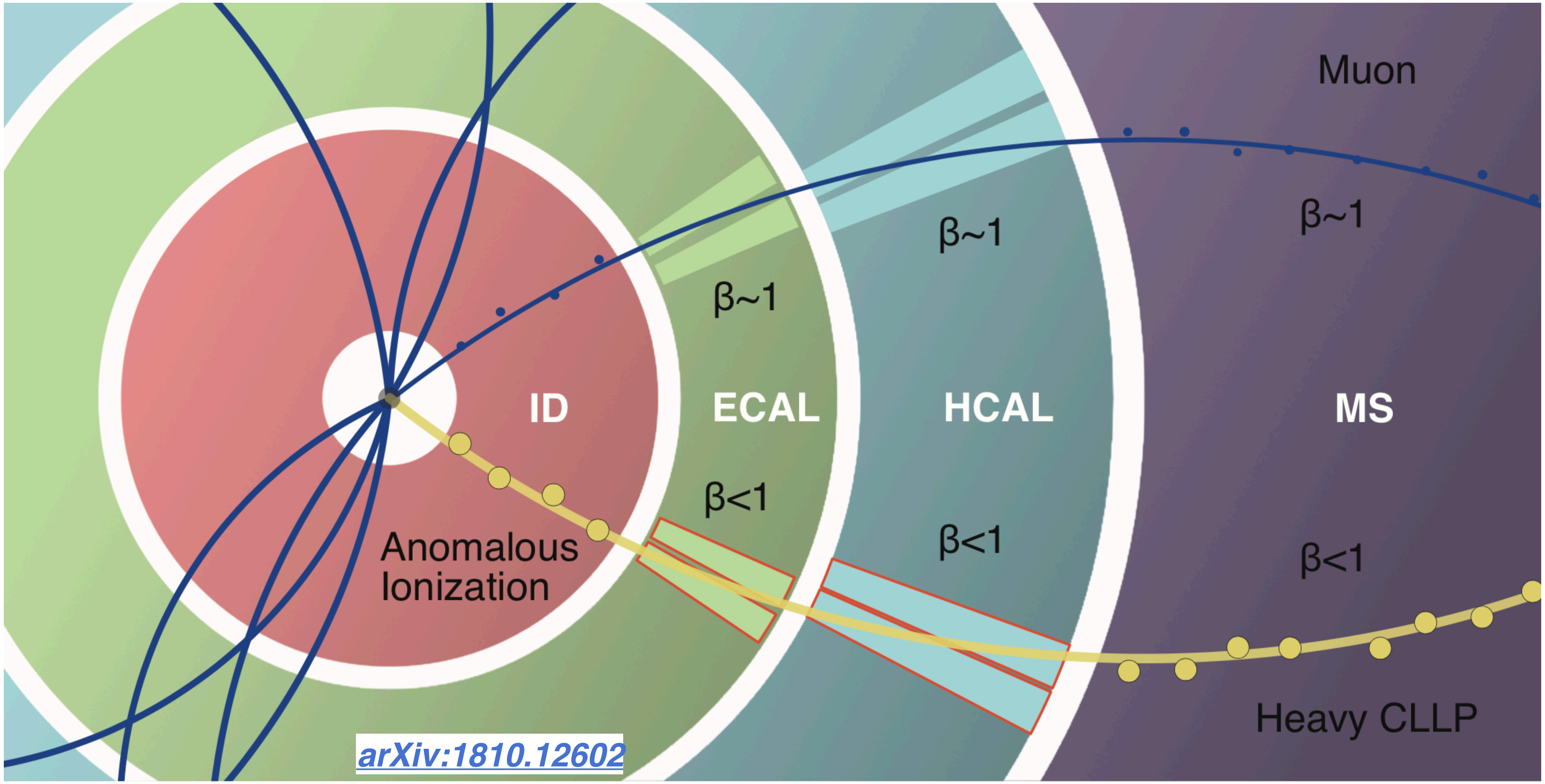




Highly-Ionizing Particles (HIPs)

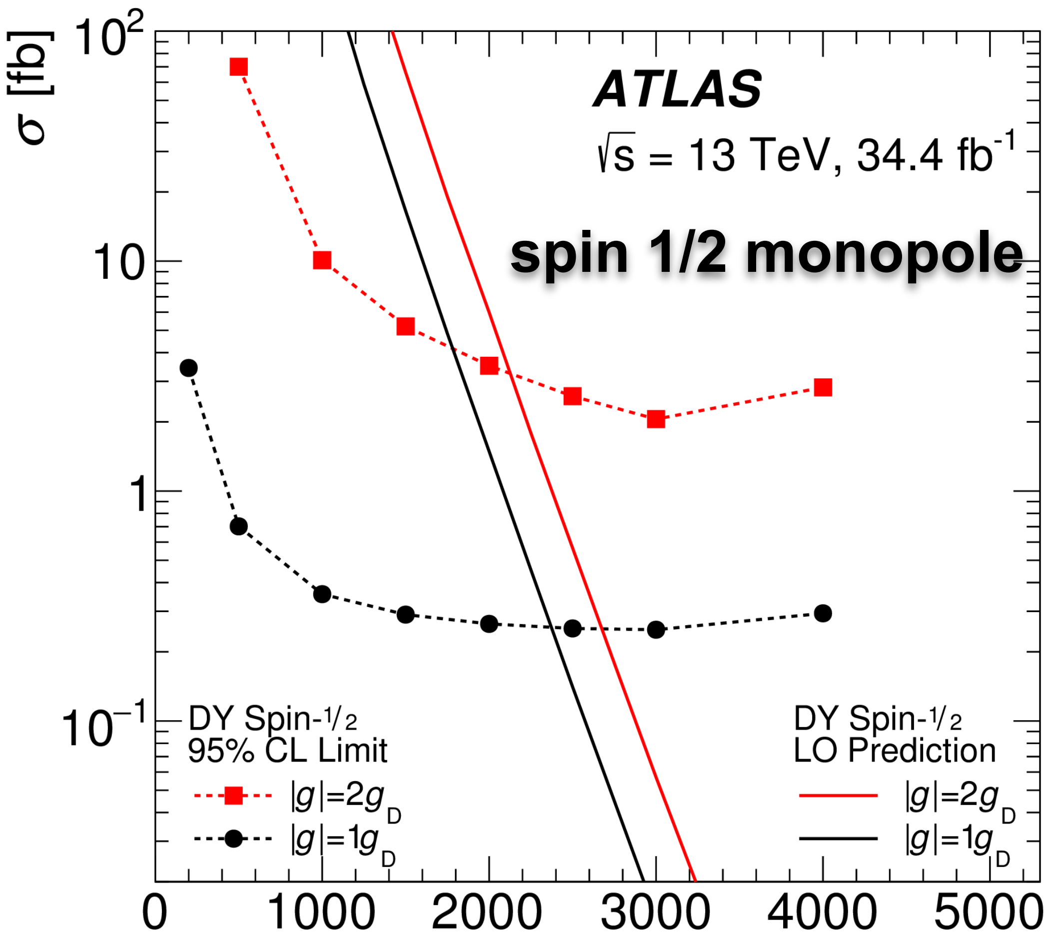
arXiv:905.10130

- 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



Highly-Ionizing Particles (HIPs)

- 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 ± 0.4
- No events observed in signal region

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

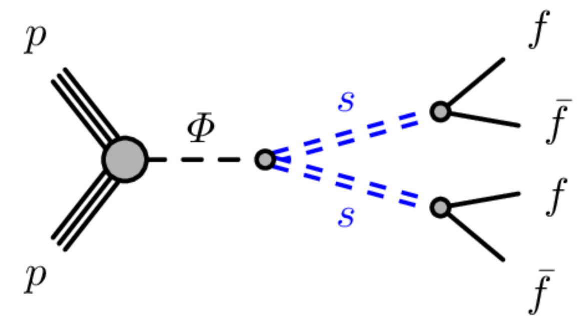
	$\|g\| = 1g_D$	$\|g\| = 2g_D$	$\|z\| = 20$	$\|z\| = 40$	$\|z\| = 60$	$\|z\| = 80$	$\|z\| = 100$
Spin-0	1850	1725	1355	1615	1625	1495	1390
Spin-1/2	2370	2125	1830	2050	2000	1860	1650

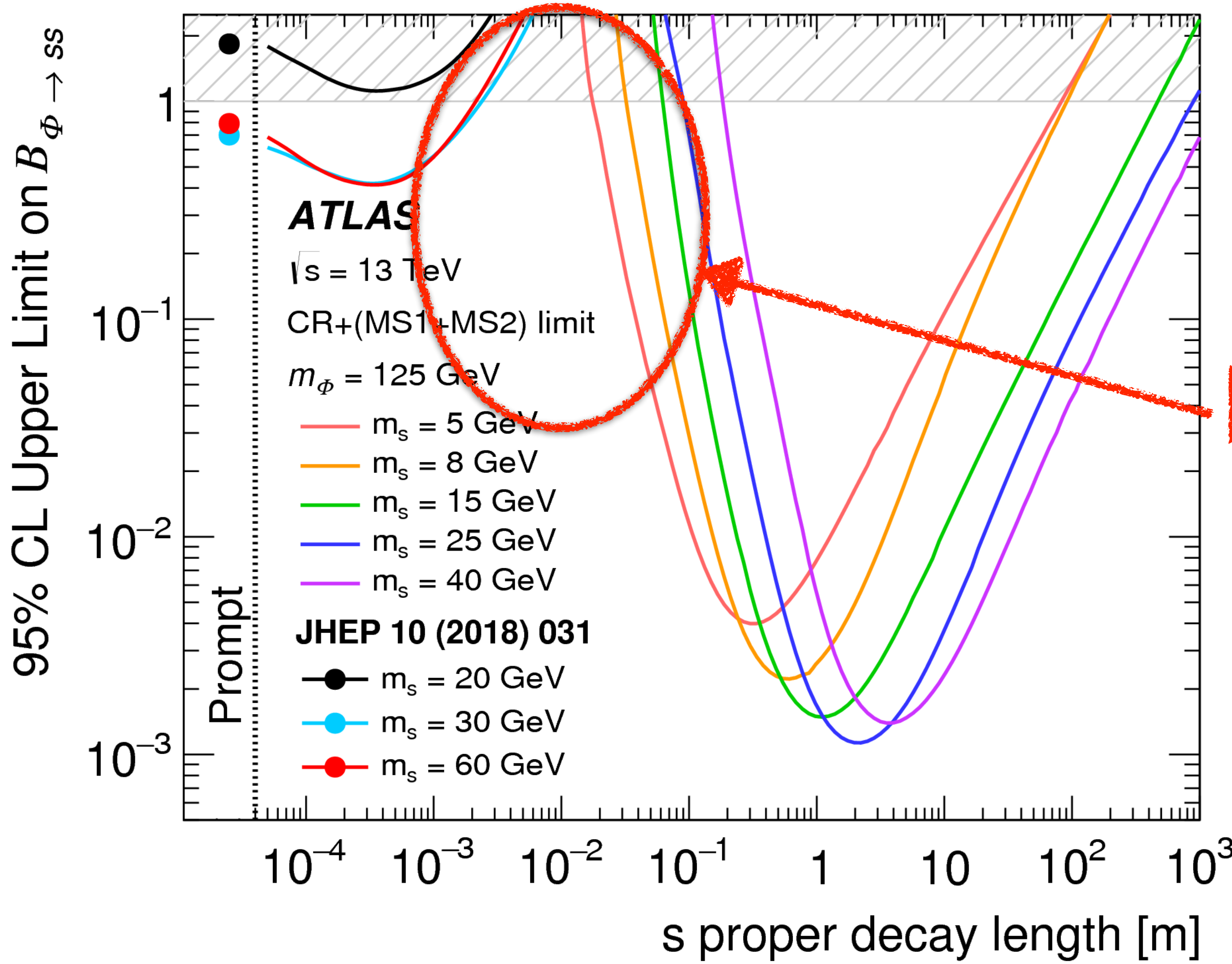
Conclusion

- 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 $\rightarrow$ will double the Run 2 sample
  - New triggers $\rightarrow$ 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)

LLP Combination: CR/MS-MS

Eur. Phys. J. C 79 (2019) 481





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

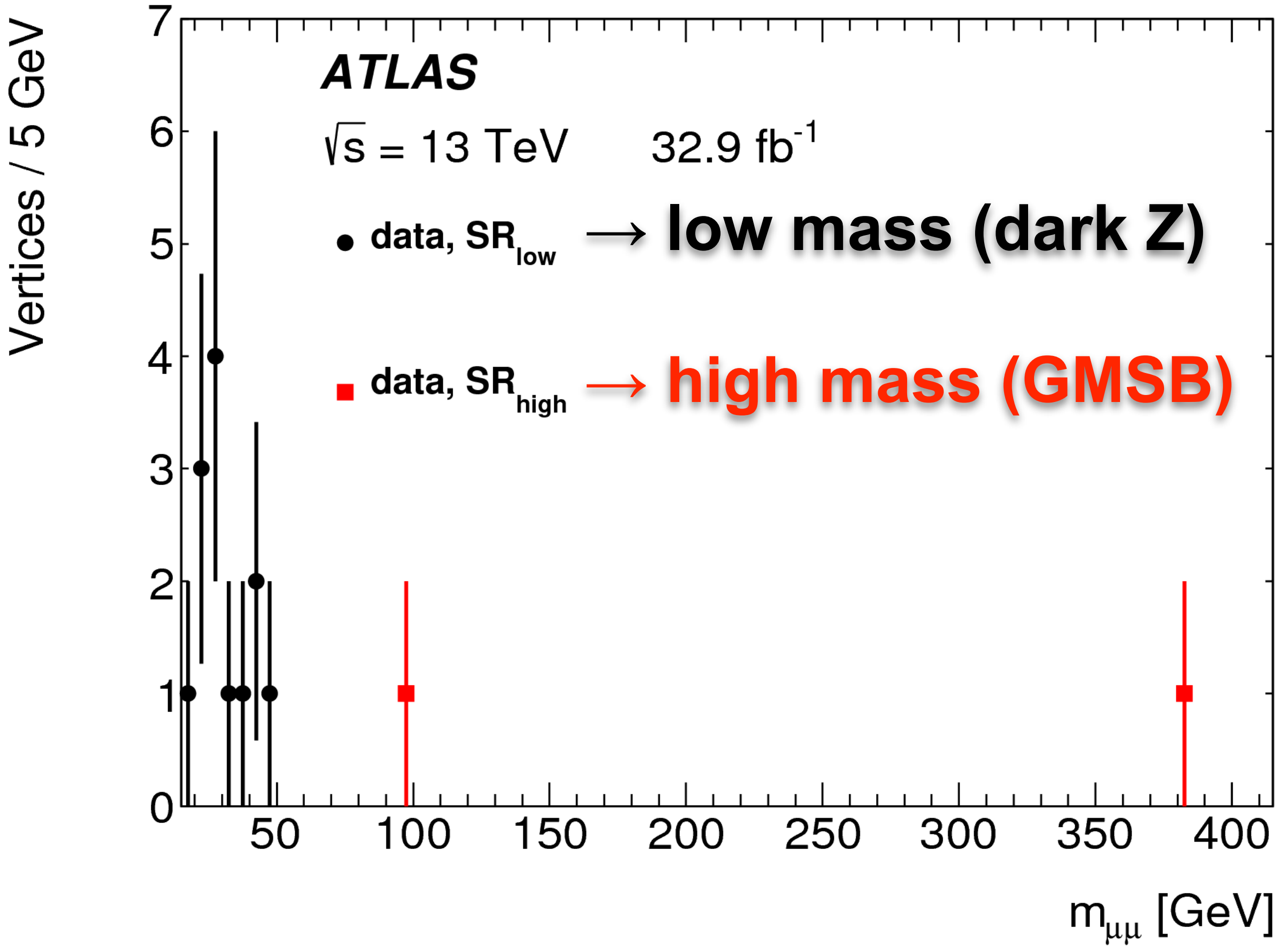
- Gap: cover with new analyses

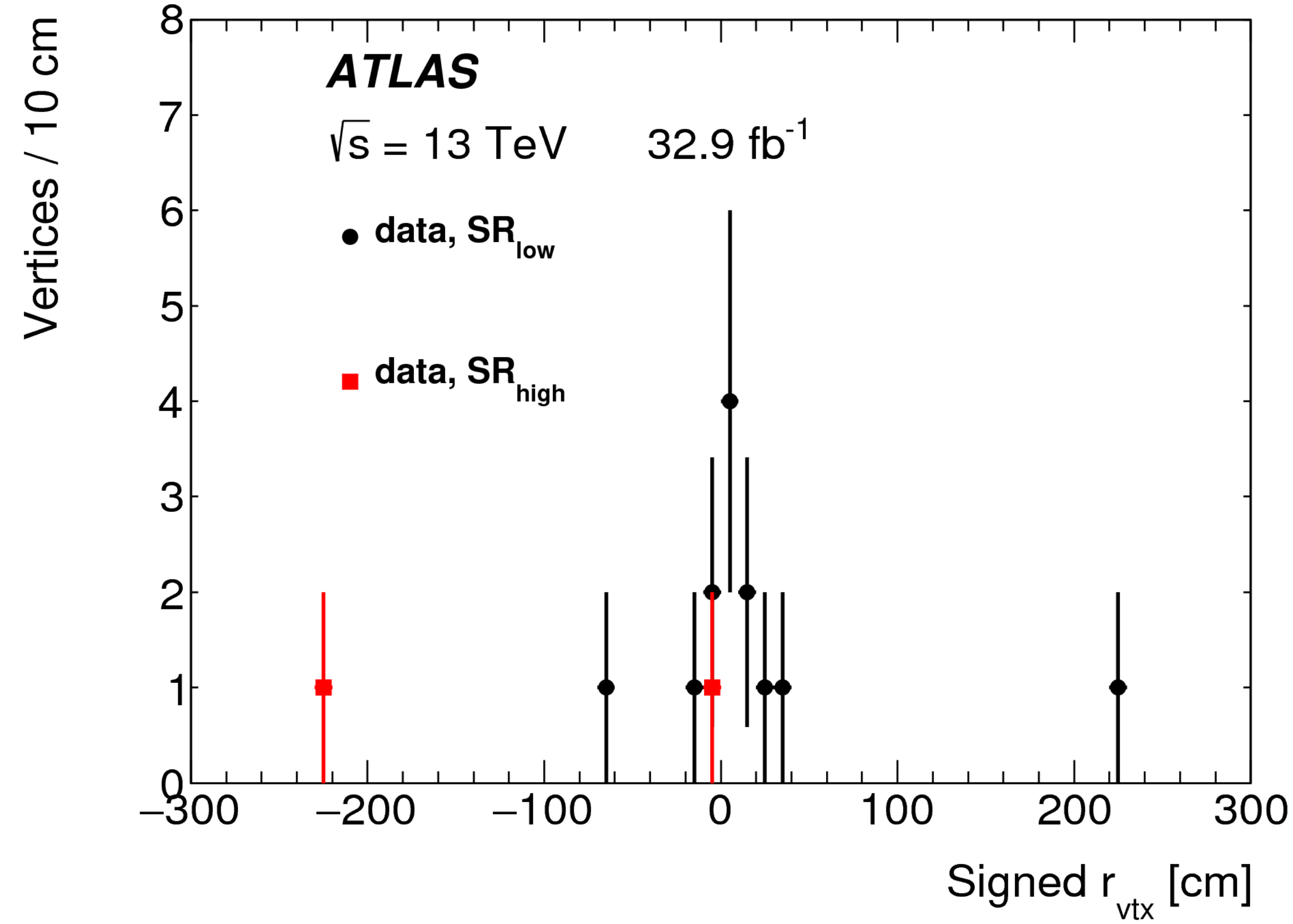
Backup Material

work in progress…

Displaced Dimuon Vertex

Phys. Rev. D 99 (2019) 012001





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

Observed number of vertices and vertex positions consistent with background prediction