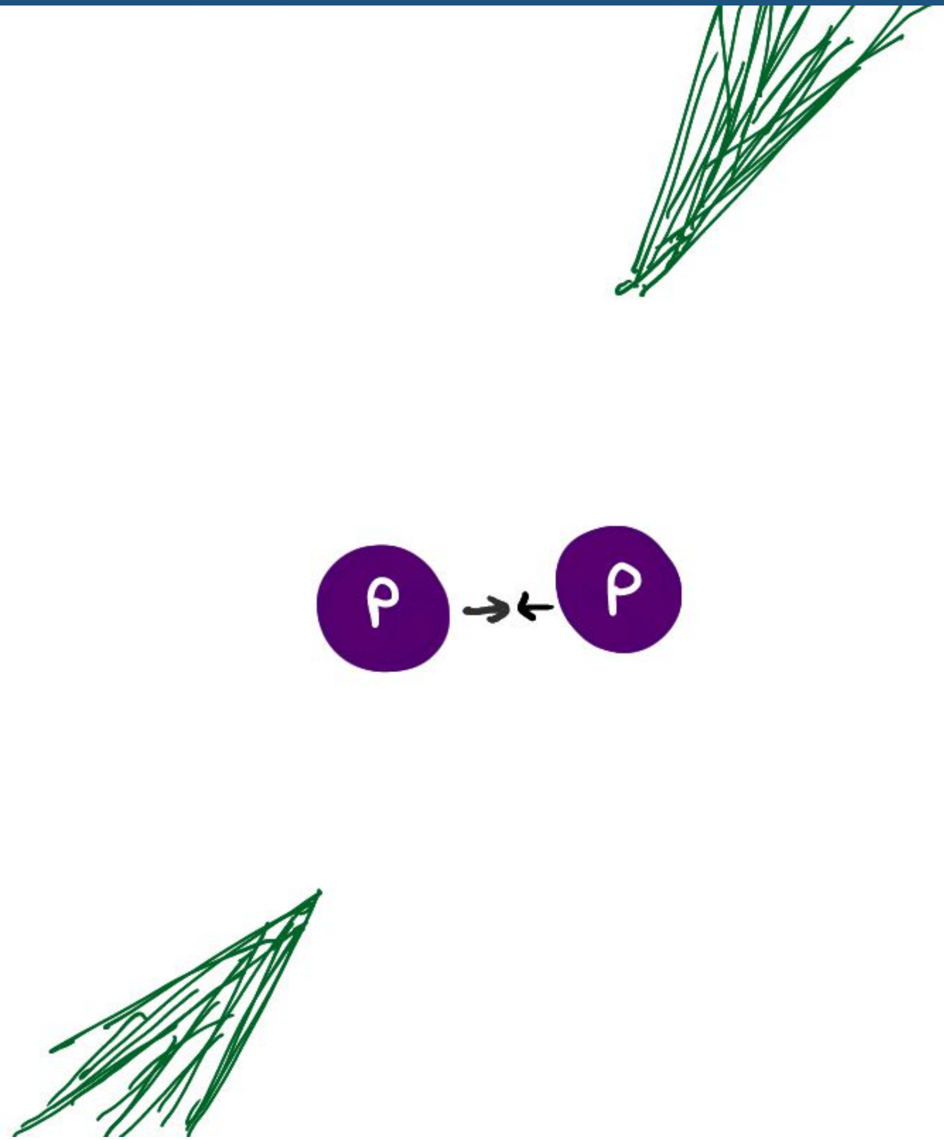
Searches for new physics with displaced vertex signatures at the ATLAS experiment in LHC Run 1

9 January 2016 – Epiphany2016

Heather Russell, on behalf of the ATLAS collaboration

A few hints of new physics here and there… but where are the undiscovered particles hiding???

Perhaps the new physics is ***not prompt***:



what are displaced vertices?

neutral, long-lived particles

decay **displaced** from the interaction point

leaving a **displaced vertex** signature

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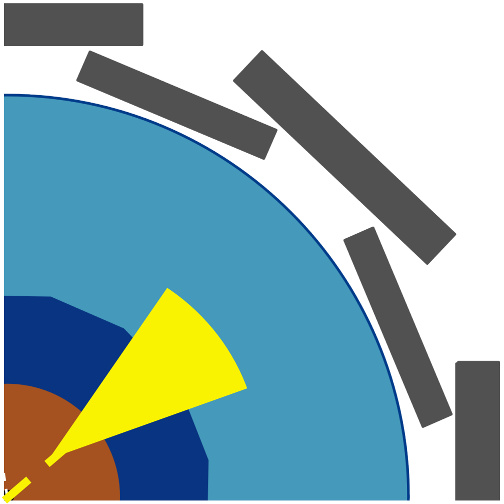
On ATLAS, we can **reconstruct** displaced decays in the:

Inner detector (ID)



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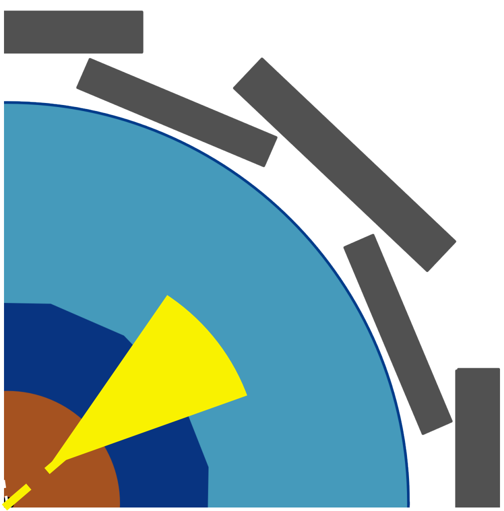
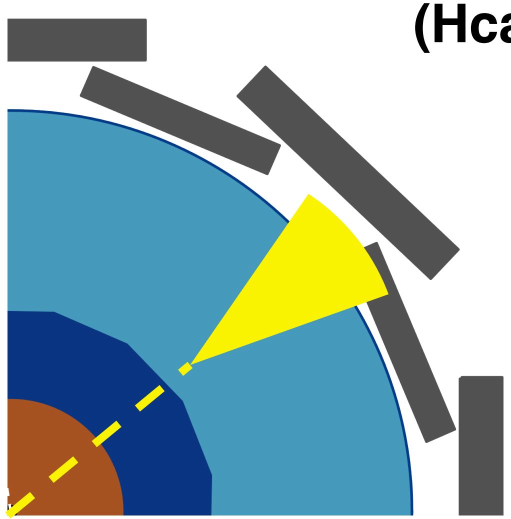


Hadronic calorimeter (Hcal)



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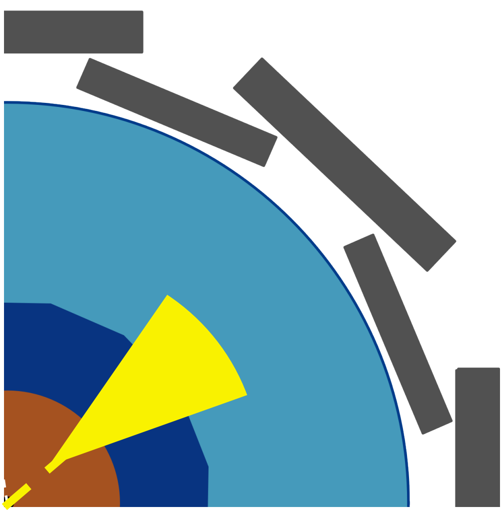

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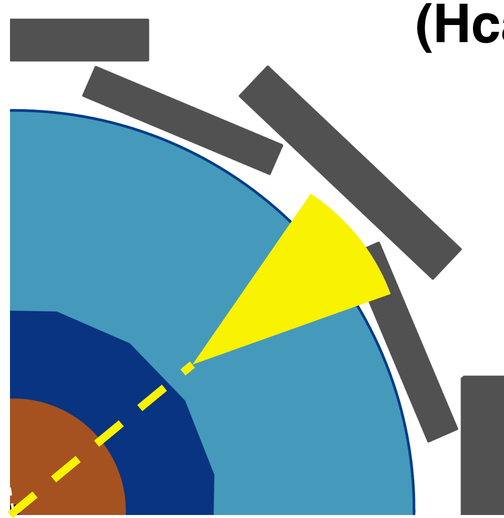
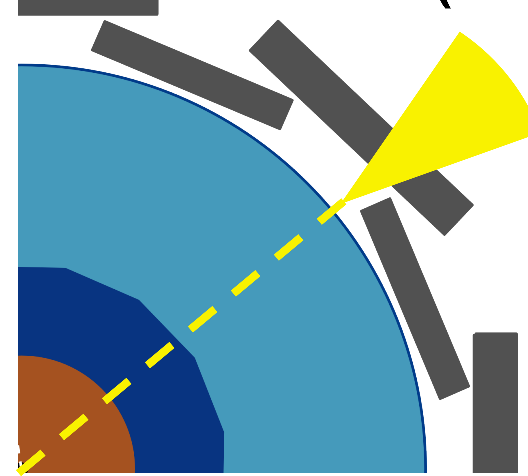


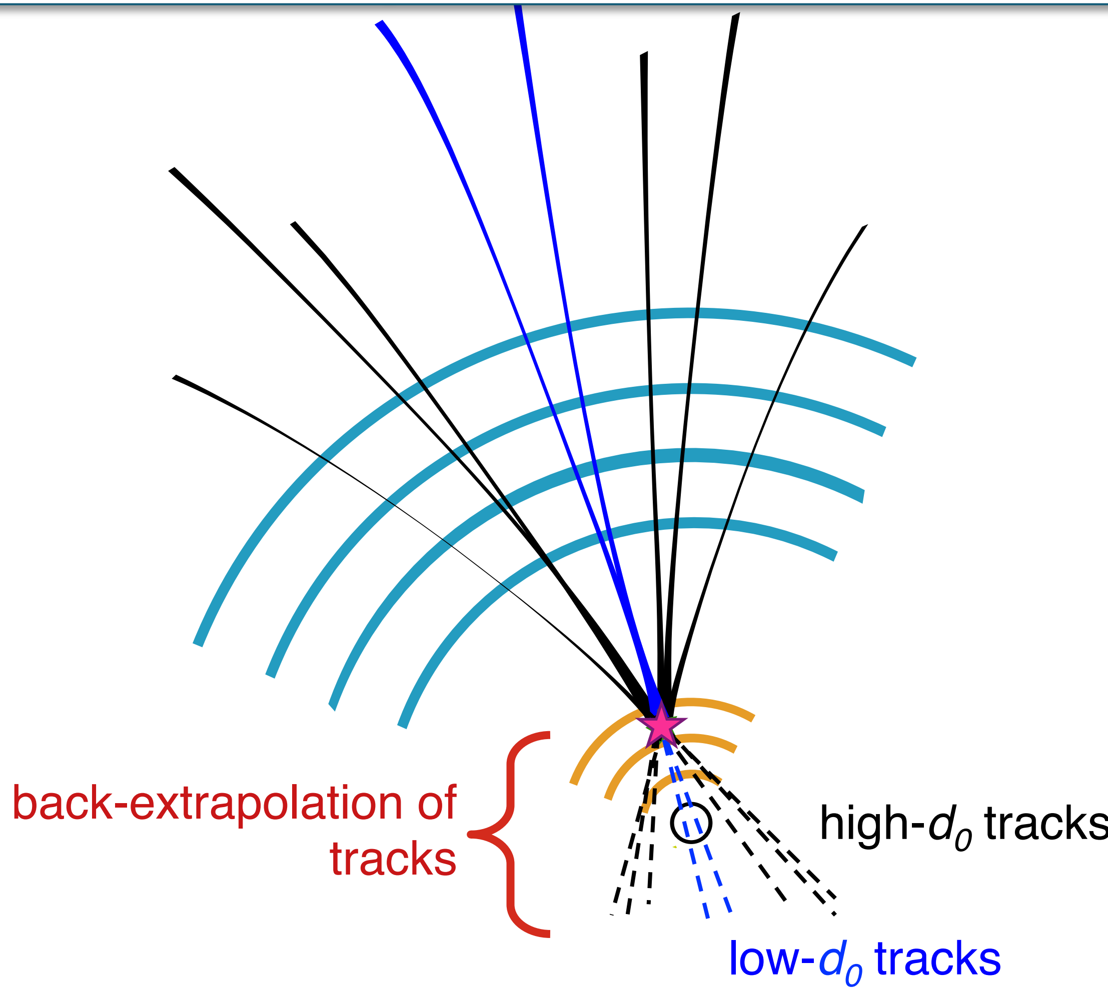
Muon spectrometer (MS)



Detection and reconstruction of displaced decays

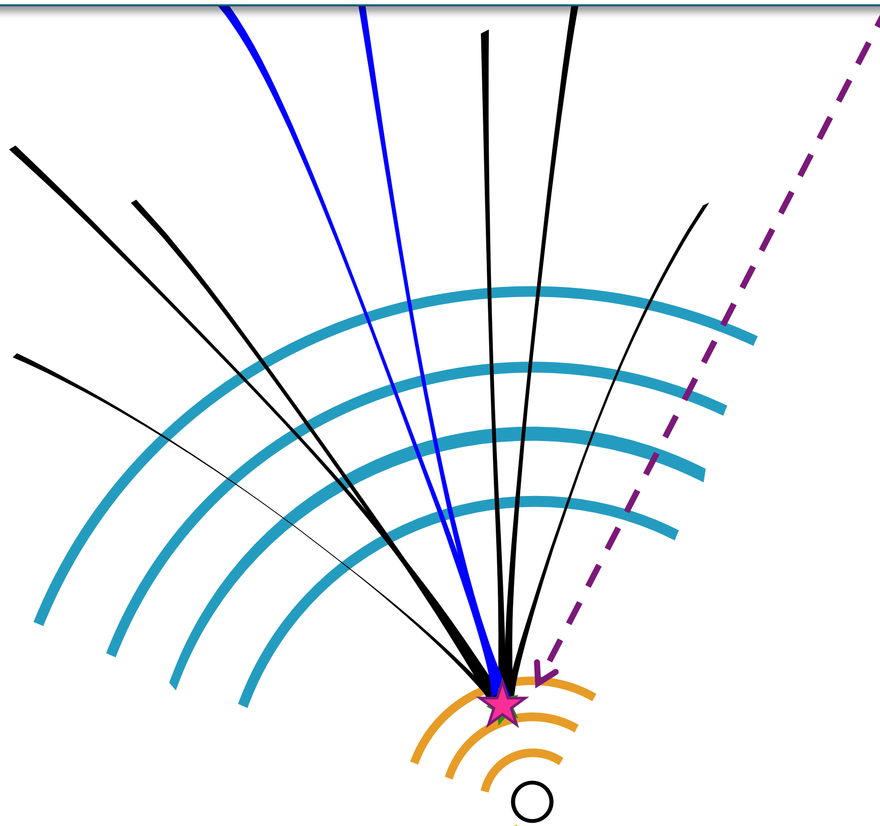
inner detector vertex reconstruction

1. ATLAS default tracking algorithm only reconstructs tracks with $d_0 < 10$ mm
   → *Modify to allow for **high-d_0 tracks***



Plots: Phys. Rev. D92, 072004 (2015), arXiv:1504.05162
2nd IDVx analysis: Phys. Rev. D92, 012010 (2015), arXiv:1504.03634

1. ATLAS default tracking algorithm only reconstructs tracks with $d_0 < 10$ mm
   → *Modify to allow for **high-d_0 tracks***
2. Standard primary vertex reconstruction finds vertices consistent w/ beam spot
   → *Use tracks from step 1, and modify to **allow displaced location***



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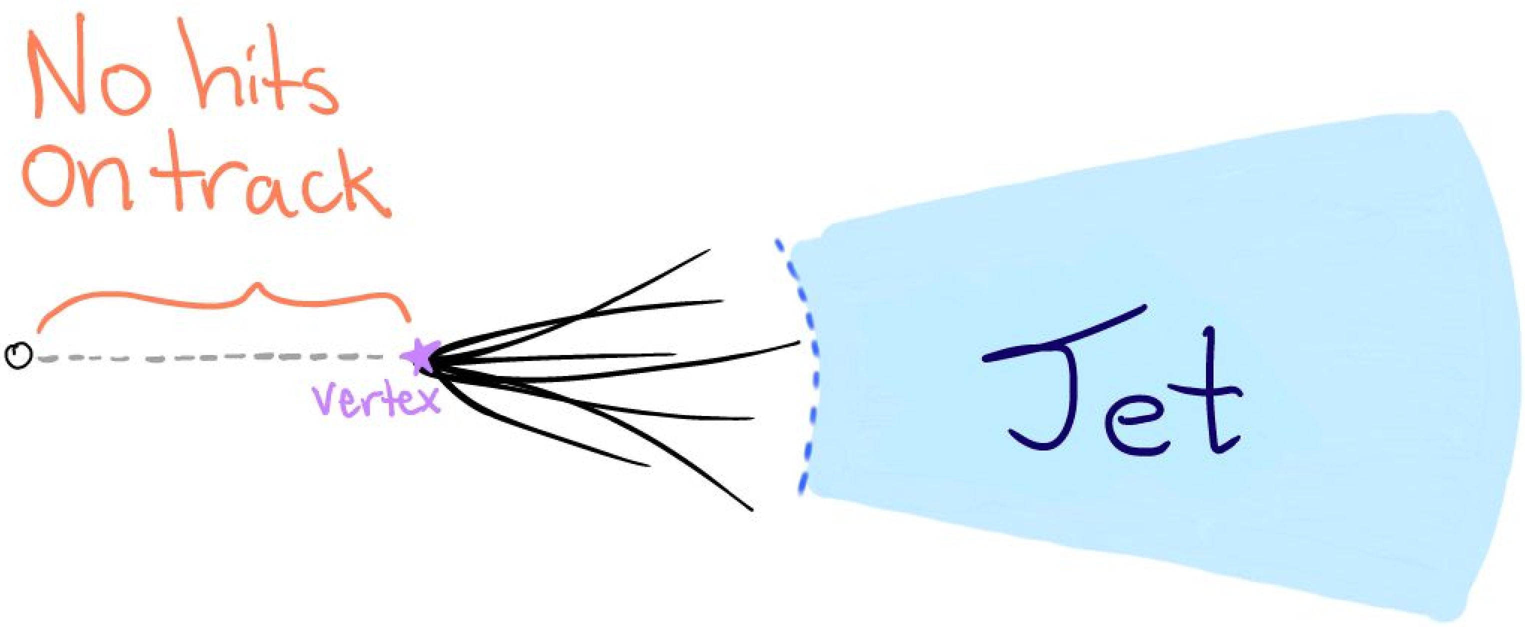
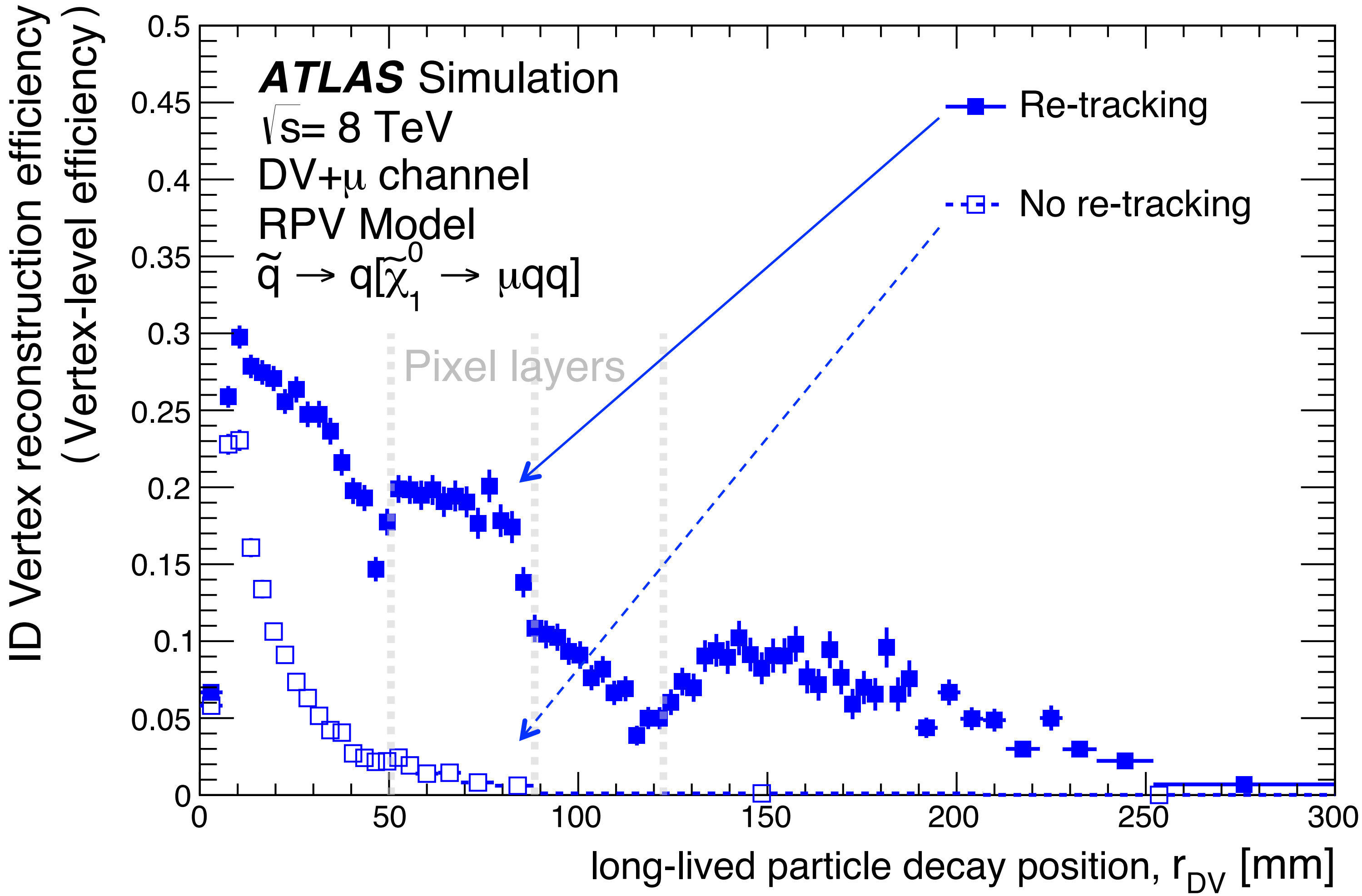
1. ATLAS default tracking algorithm only reconstructs tracks with $d_0 < 10$ mm
   → *Modify to allow for **high-d_0 tracks***
2. Standard vertex reconstruction finds vertices consistent w/ beam spot
   → *Use tracks from step 1, and modify to **allow displaced location***
3. No tracks with hits **before** the vertex
   → *Such tracks are removed, vertex is refit*

4. Jet must follow the vertex



Plots: Phys. Rev. D92, 072004 (2015), arXiv:1504.05162
2nd IDVx analysis: Phys. Rev. D92, 012010 (2015), arXiv:1504.03634

inner detector vertex reconstruction – efficiency



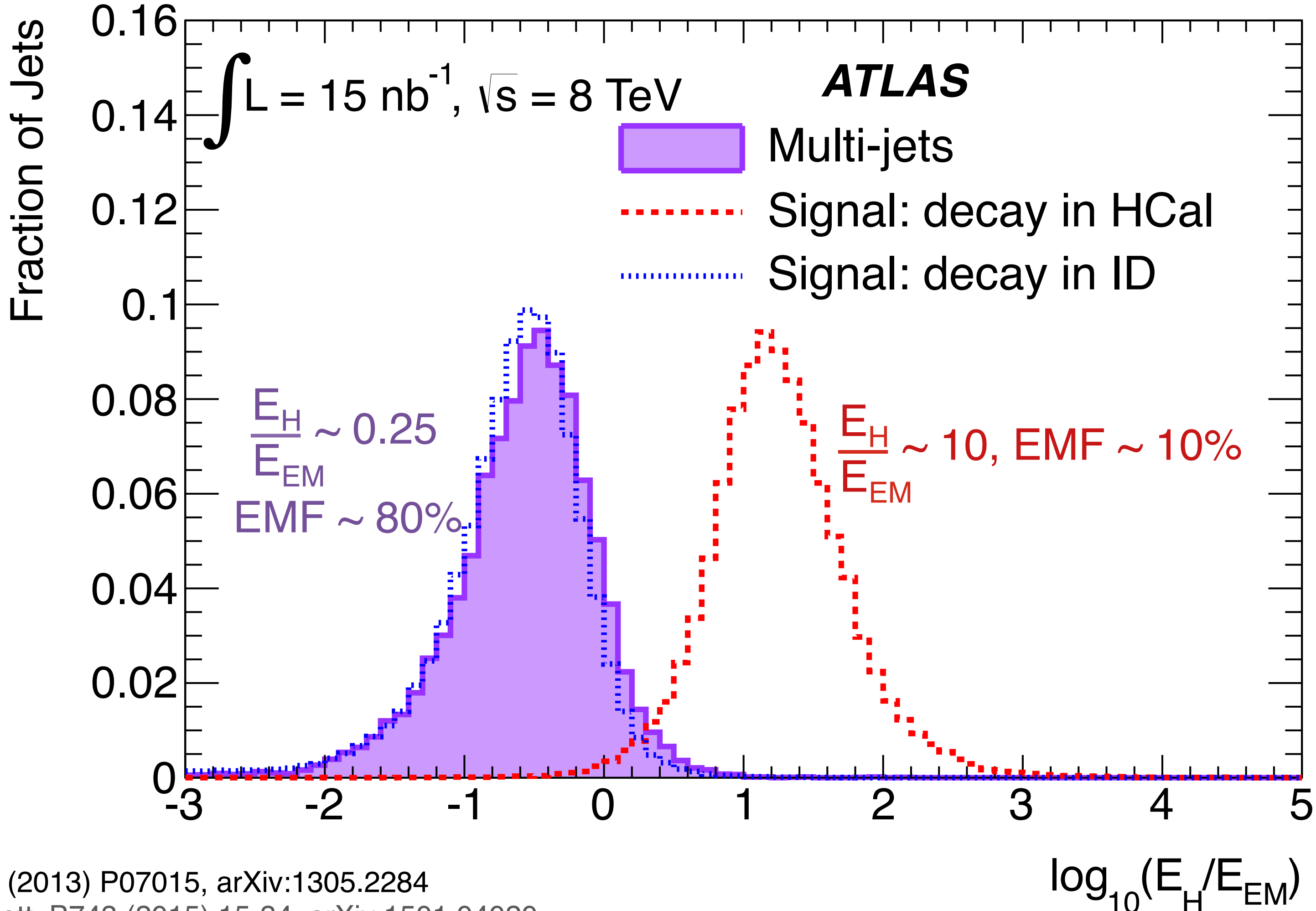
Plots: Phys. Rev. D92, 072004 (2015), arXiv:1504.05162

2nd IDVx analysis: Phys. Rev. D92, 012010 (2015), arXiv:1504.03634

hadronic calorimeter decays – definition

Decays in the HCal result in **narrow jets** that deposit a small fraction of energy in the ECal and are isolated from ID tracks

1. Dedicated trigger selects low-EMF jets with little track activity



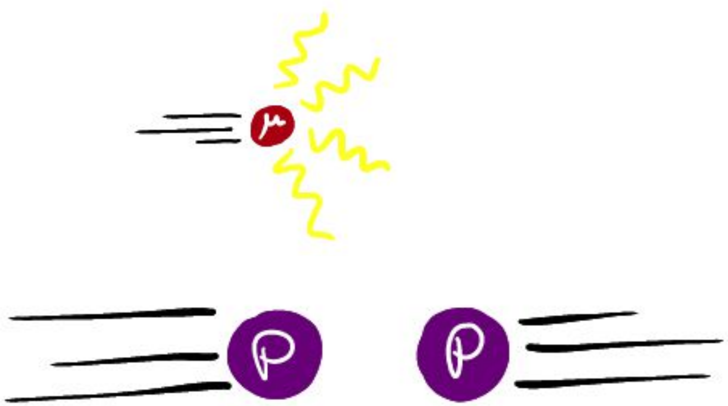
Trigger: JINST 8 (2013) P07015, arXiv:1305.2284
Analysis: Phys.Lett. B743 (2015) 15-34, arXiv:1501.04020

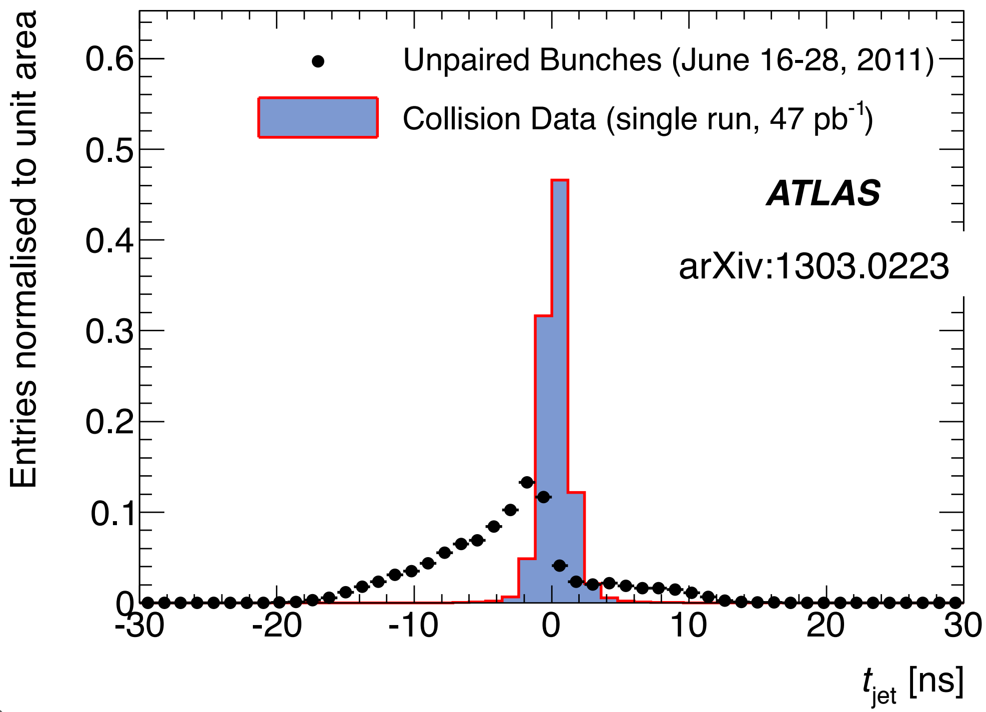
hadronic calorimeter decays – beam halo rejection

Decays in the HCal result in **narrow jets** that deposit a small fraction of energy in the ECal and are isolated from ID tracks

2. Cell and jet timing cuts, muon segment matching to remove beam halo background

Beam halo from muon bremsstrahlung causes low-EMF jets with a skewed timing distribution:

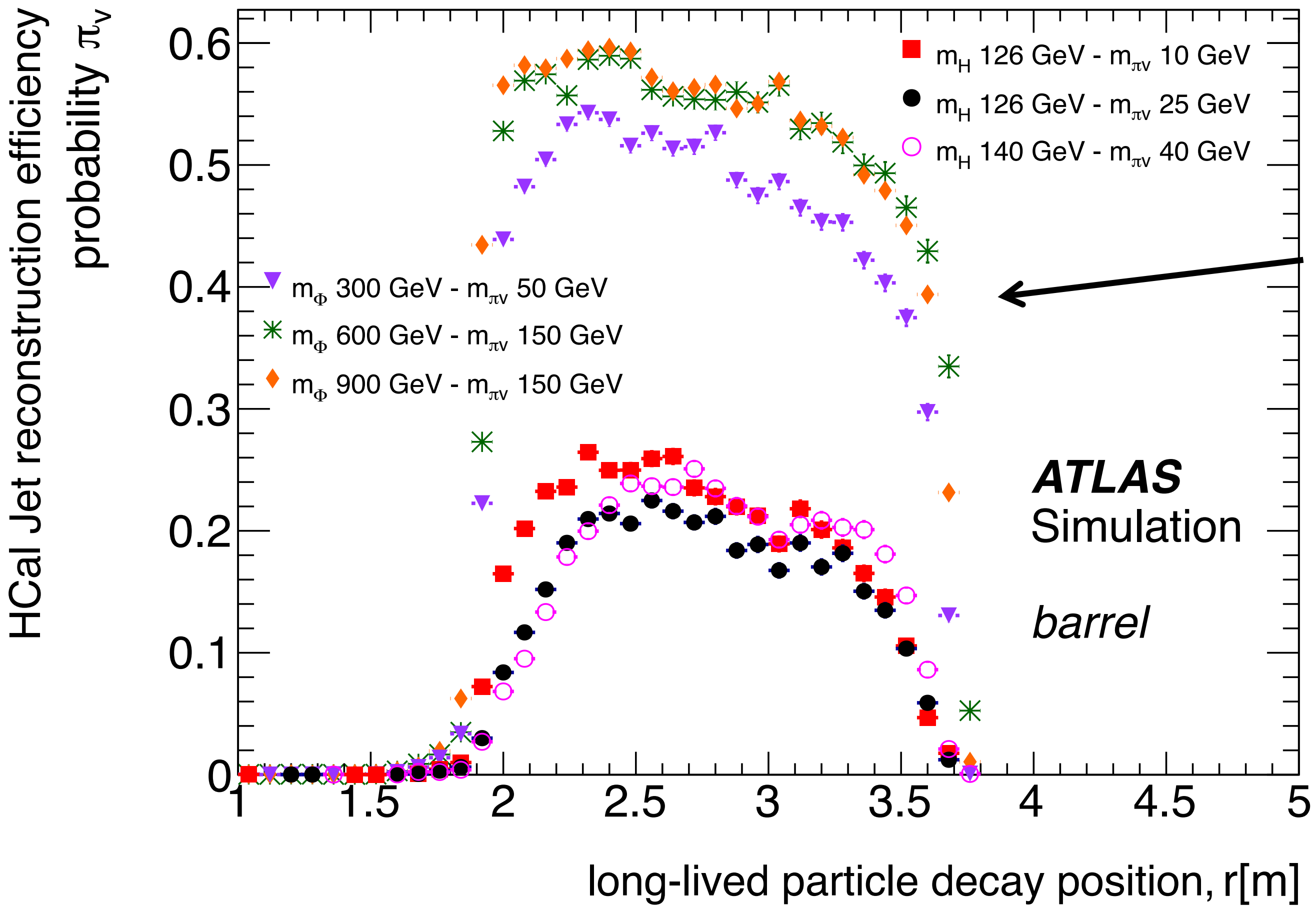




Trigger: JINST 8 (2013) P07015, arXiv:1305.2284
Analysis: Phys.Lett. B743 (2015) 15-34, arXiv:1501.04020

Decays in the HCal result in **narrow jets** that deposit a small fraction of energy in the ECal and are isolated from ID tracks

3. Jet energy, track isolation requirements



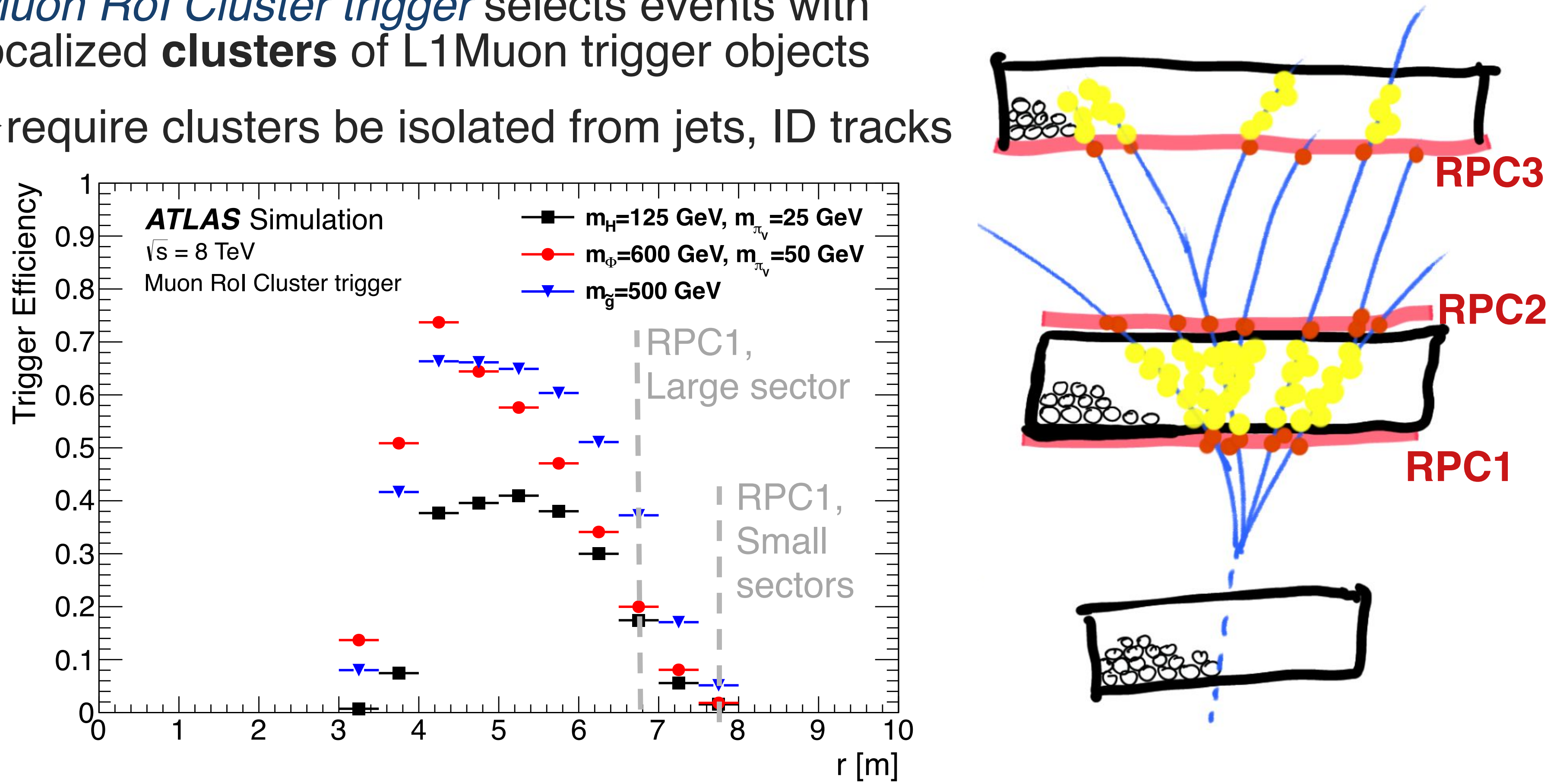
Higher mass decays more likely to pass jet energy cuts

Trigger: JINST 8 (2013) P07015, arXiv:1305.2284
Analysis: Phys.Lett. B743 (2015) 15-34, arXiv:1501.04020

muon spectrometer decays - triggering

Muon RoI Cluster trigger selects events with localized **clusters** of L1Muon trigger objects

➢require clusters be isolated from jets, ID tracks

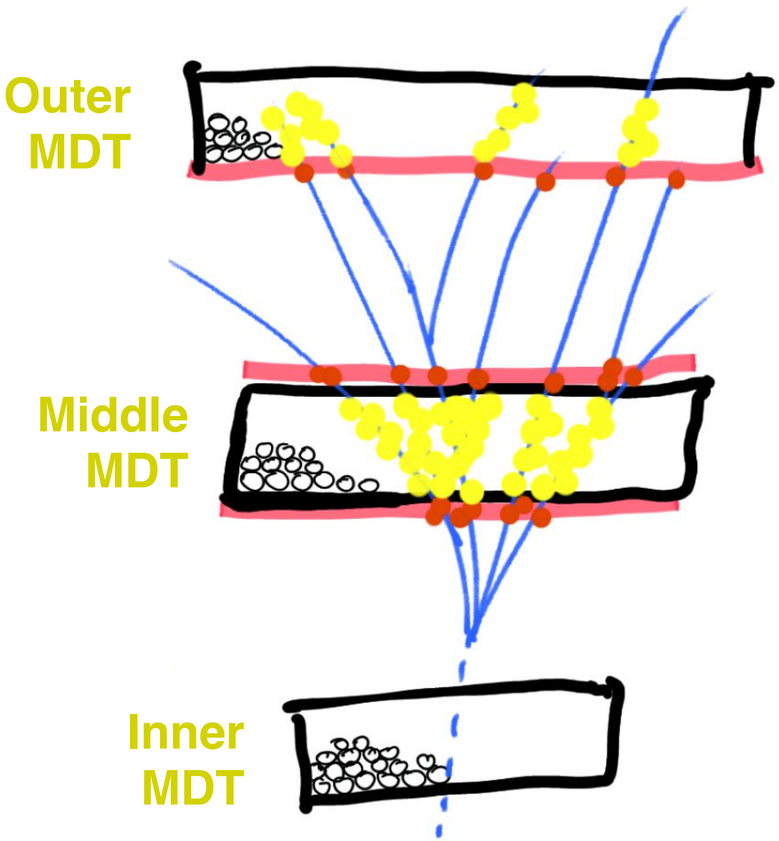


- Efficiency decreases as decay approaches RPC1 → jets are too narrow
- No efficiency past RPC1 – need hits there to form L1 Muon trigger objects
- Efficiency in the endcaps is slightly higher

Trigger: JINST 8 (2013) P07015, arXiv:1305.2284
Efficiency: Phys. Rev. D92, 012010 (2015), arXiv:1504.03634

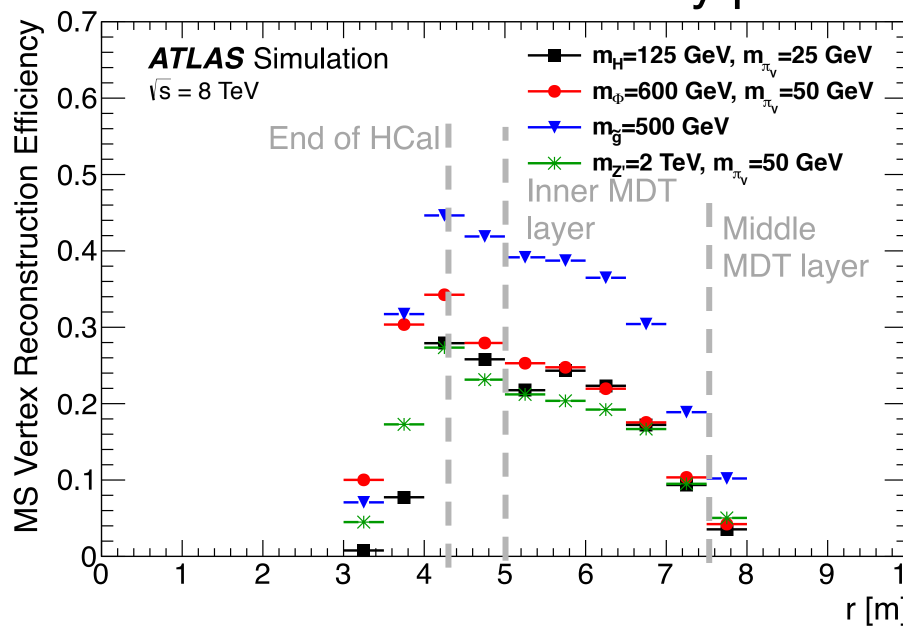
muon spectrometer vertex reconstruction

Purpose-built algorithm reconstructs tracklets and vertices from MDT hits



Require **isolation** from **tracks and jets** to minimize backgrounds from punch-through jets

Efficiency in the barrel as a function of LLP decay position:



No efficiency much past middle MDT layer → need time for decay products to spread out to make enough tracks

Vx reco: JINST 9 (2014) P02001, arXiv:1311.7070
Efficiency: Phys. Rev. D92, 012010 (2015), arXiv:1504.03634

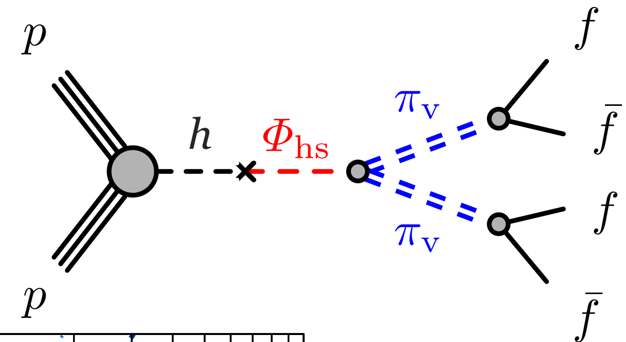
Results

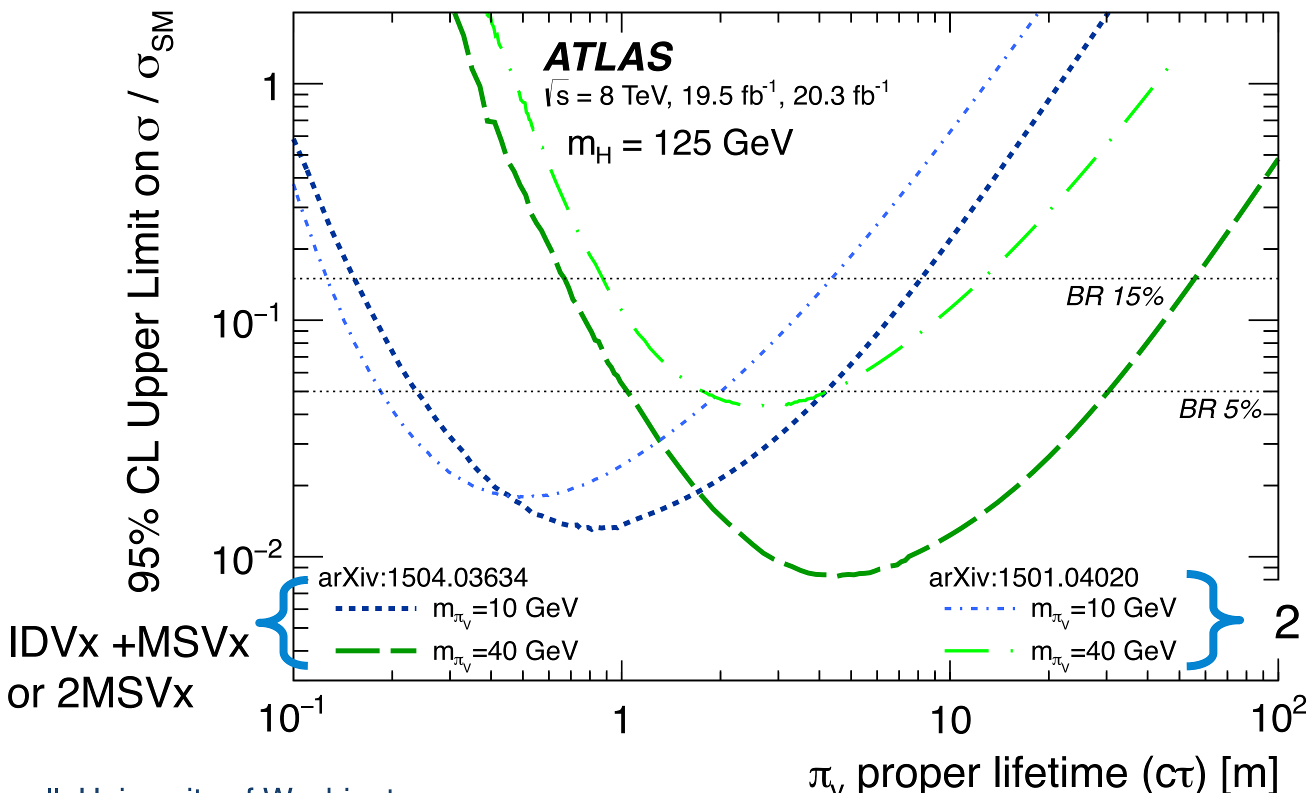
8 TeV searches with two displaced objects

1. Two HCal decays (low-EMF jets)
2. ID vertex + MS vertex or 2MS vertices*

Phys.Lett. B743 (2015) 15-34, arXiv:1501.04020
Phys. Rev. D92, 012010 (2015) ,arXiv:1504.03634
*one signal model uses a 2 ID vertex signature as well

- Final event selection includes **two** displaced objects for background reduction
- Example model: Higgs boson decays to long-lived scalar pairs
- No excess found in any topology → set limits



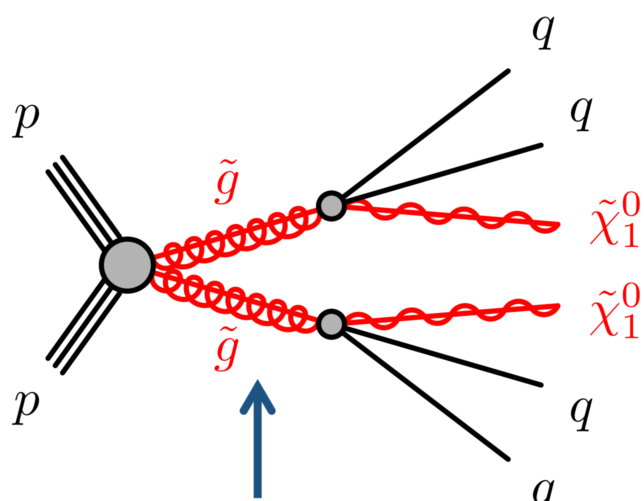


8 TeV searches with one displaced vertex

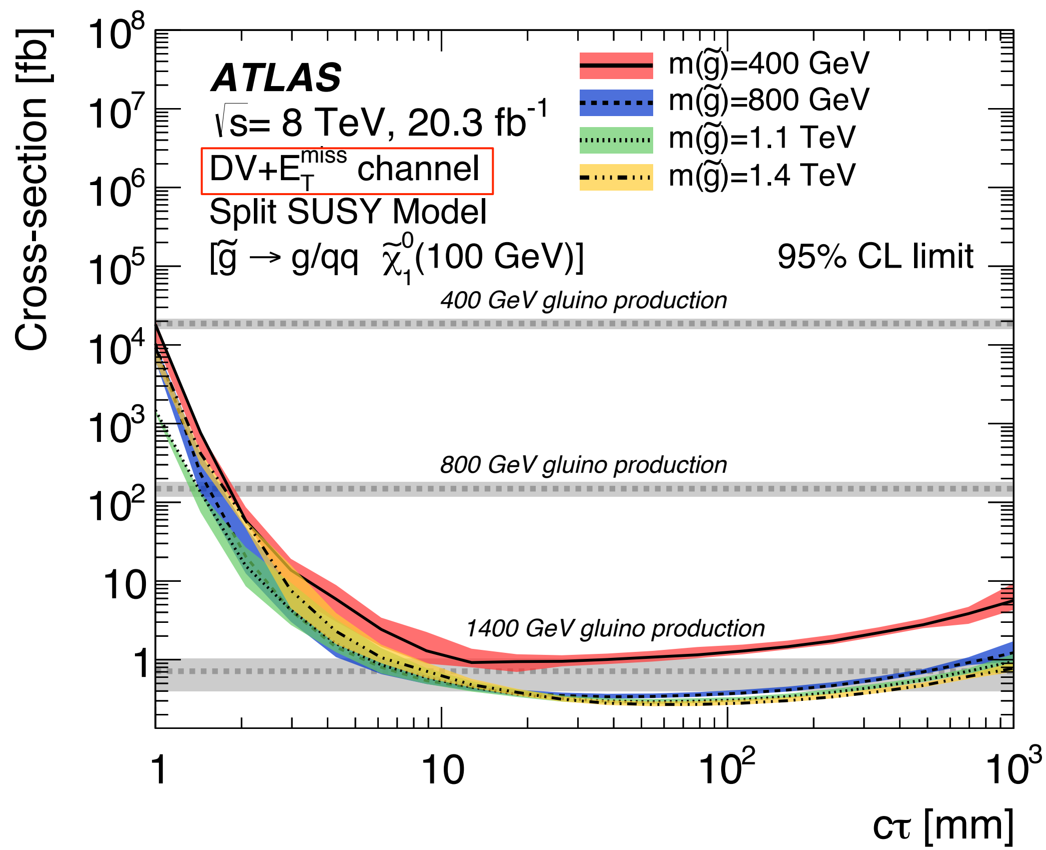
3. ID Vertex + [jets, missing transverse energy, muon, electron]

Phys. Rev. D92, 072004 (2015)
arXiv:1504.05162

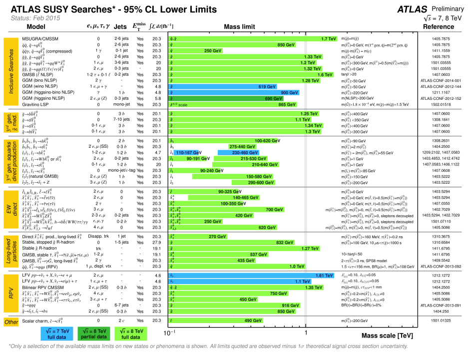
- No excess found in any topology → set limits.
- e.g.: Split SUSY model with pair-produced gluinos



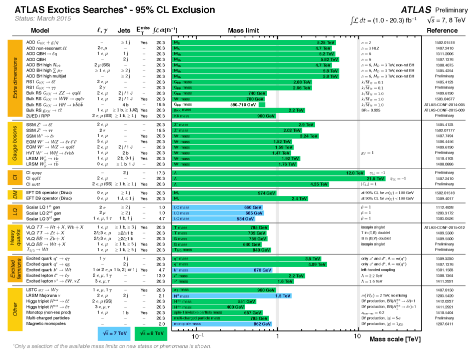
long-lived,
neutral gluinos



Summary – I

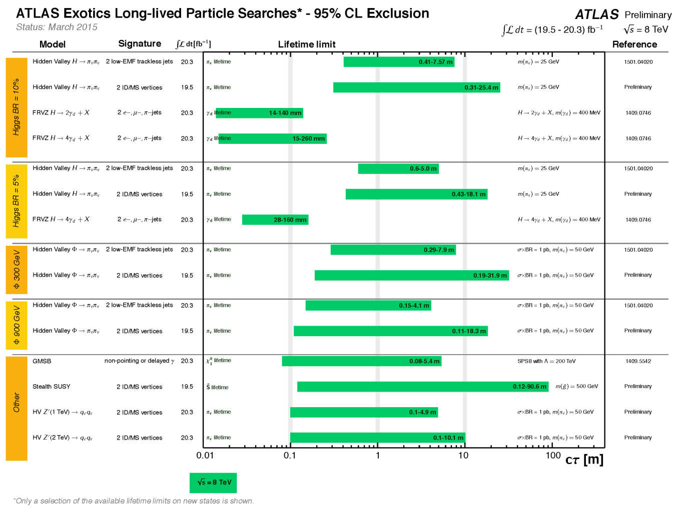


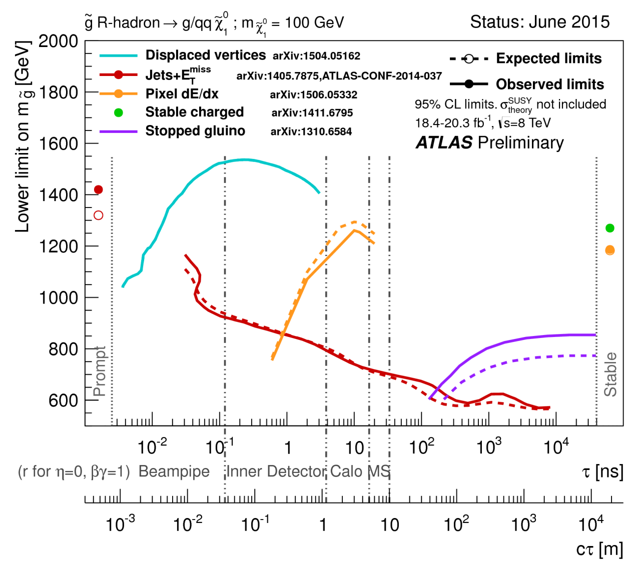
+



= No new prompt physics.

And, unfortunately,





No new displaced physics either.

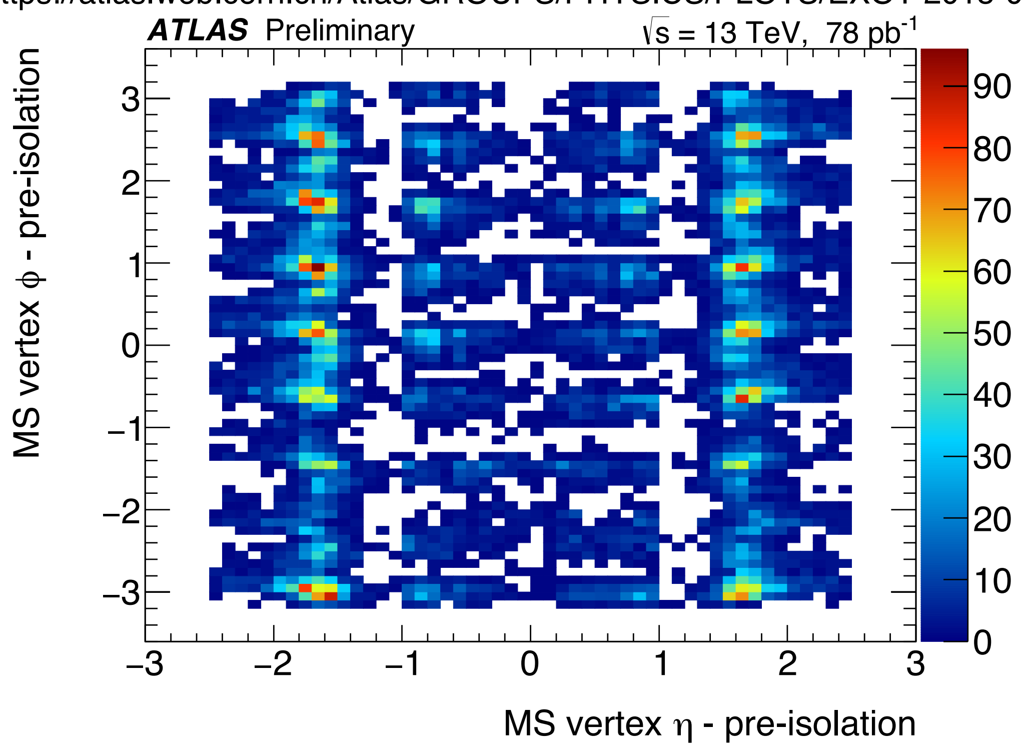
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/

Summary – II

…however!

- We have novel tools to detect displaced decays in three subsystems:
  Inner detector, hadronic calorimeter, and muon spectrometer
- Well-defined triggers and reconstruction algorithms for displaced decays
- Results with the 2015 dataset are coming soon!

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/EXOT-2015-008/



backup material

References

Technical papers:

1. Triggers for displaced decays of long-lived neutral particles in the ATLAS detector:
   JINST 8 (2013) P07015, arXiv:1305.2284, TRIG-2012-02
2. Standalone vertex finding in the ATLAS muon spectrometer:
   JINST 9 (2014) P02001, arXiv:1311.7070, PERF-2013-01
3. Characterisation and mitigation of beam-induced backgrounds observed in the ATLAS detector during the 2011 proton-proton run:
   JINST 8 (2013) P07004, arXiv:1303.0223, DAPR-2012-01

Long-lived particle searches:

1. Search for long-lived neutral particles decaying into lepton jets:
   JHEP11(2014)088, arXiv:1409.0746, EXOT-2013-22
2. Search for pair-produced long-lived neutral particles decaying to jets in the ATLAS hadronic calorimeter:
   Phys.Lett. B743 (2015) 15-34, arXiv:1501.04020, EXOT-2012-28
3. Search for long-lived, weakly interacting particles that decay to displaced hadronic jets:
   Phys. Rev. D92, 012010 (2015), arXiv:1504.03634, EXOT-2013-12
4. Search for massive, long-lived particles using multitrack displaced vertices or displaced lepton pairs:
   Phys. Rev. D92, 072004 (2015), arXiv:1504.05162, SUSY-2014-02

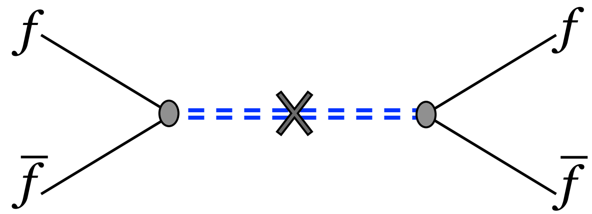
8 TeV searches and sensitivity regions*

…for ***hadronically***-decaying ***neutral, long-lived*** particles (LLPs):

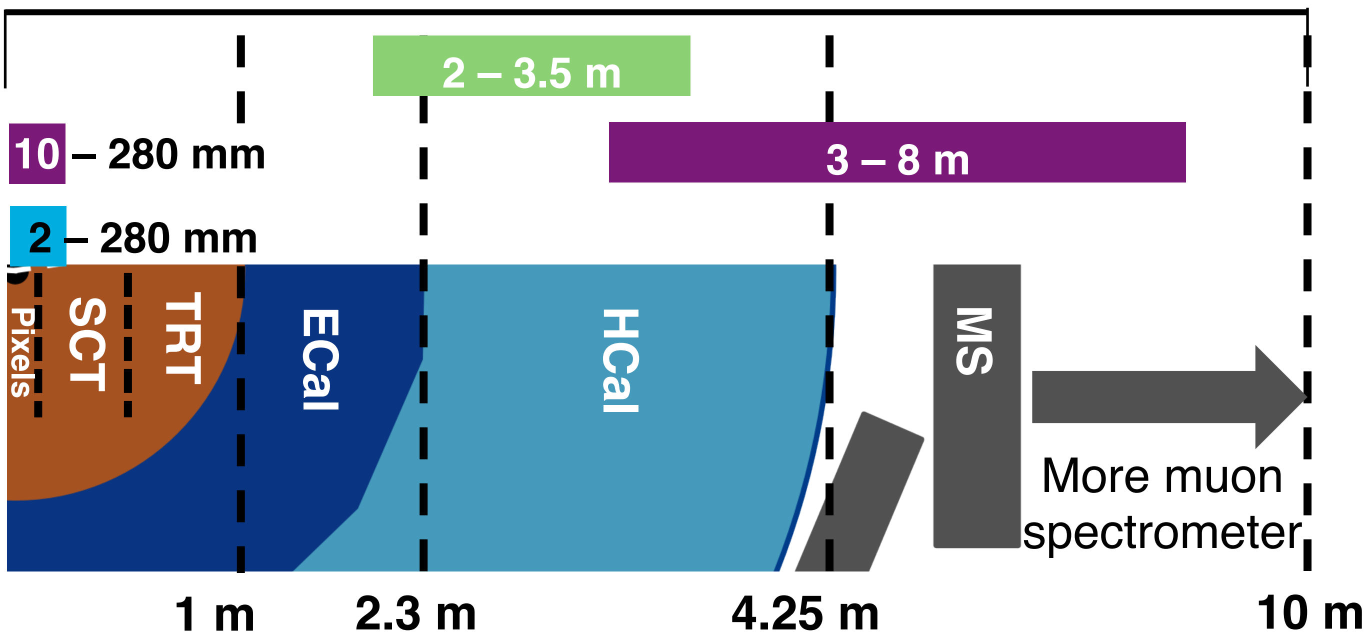
*For decays in the barrel

1. Two decays in the hadronic calorimeter (arXiv:1501.04020, EXOT-2012-28)
2. Two decays in the inner detector or muon spectrometer or one in each (arXiv:1504.03634, EXOT-2013-12)

e.g.:



3. One decay in the inner detector + X (arXiv:1504.05162, SUSY-2014-02)

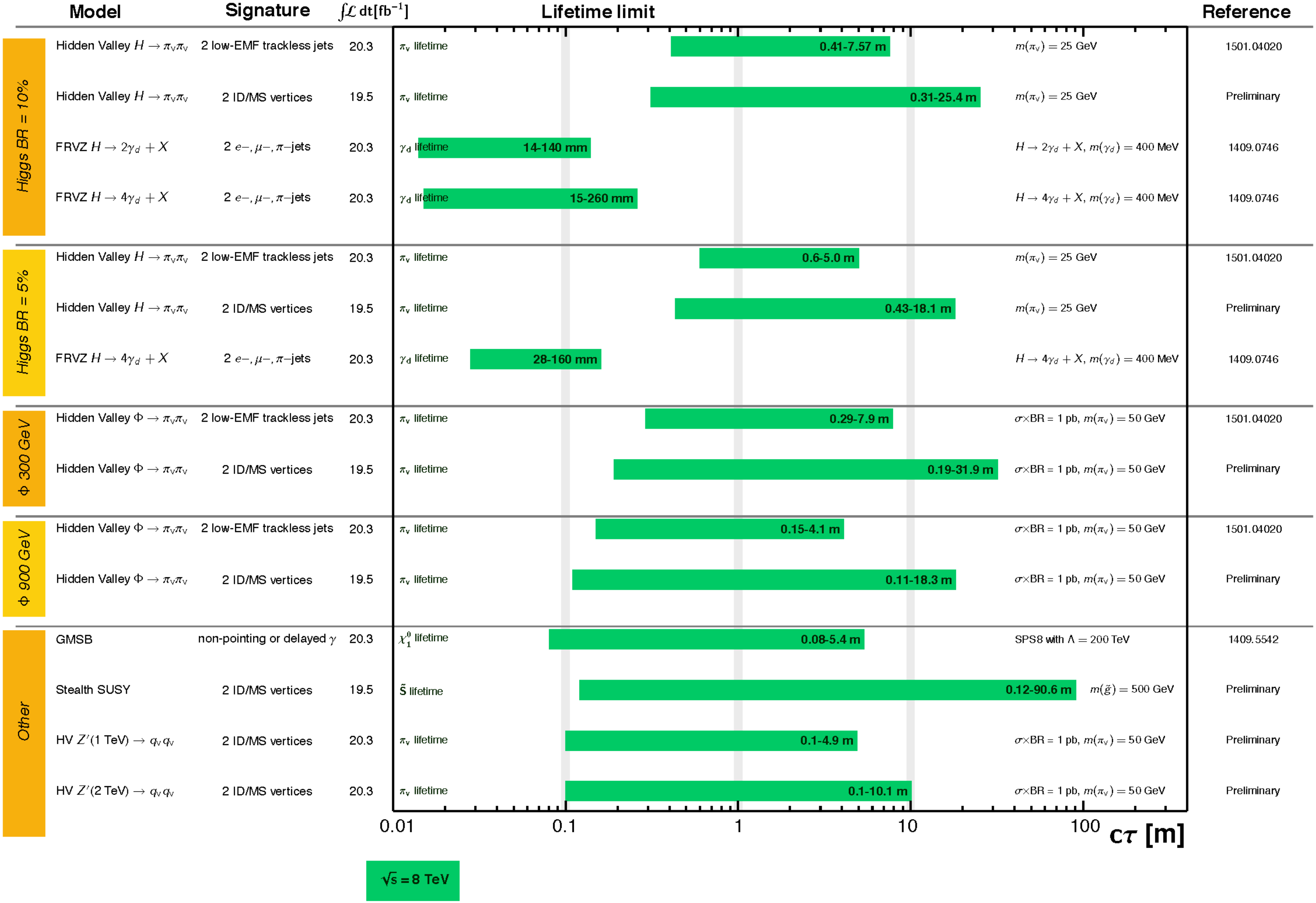


ATLAS Exotics Long-lived Particle Searches* - 95% CL Exclusion

Status: March 2015 https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/

ATLAS Preliminary

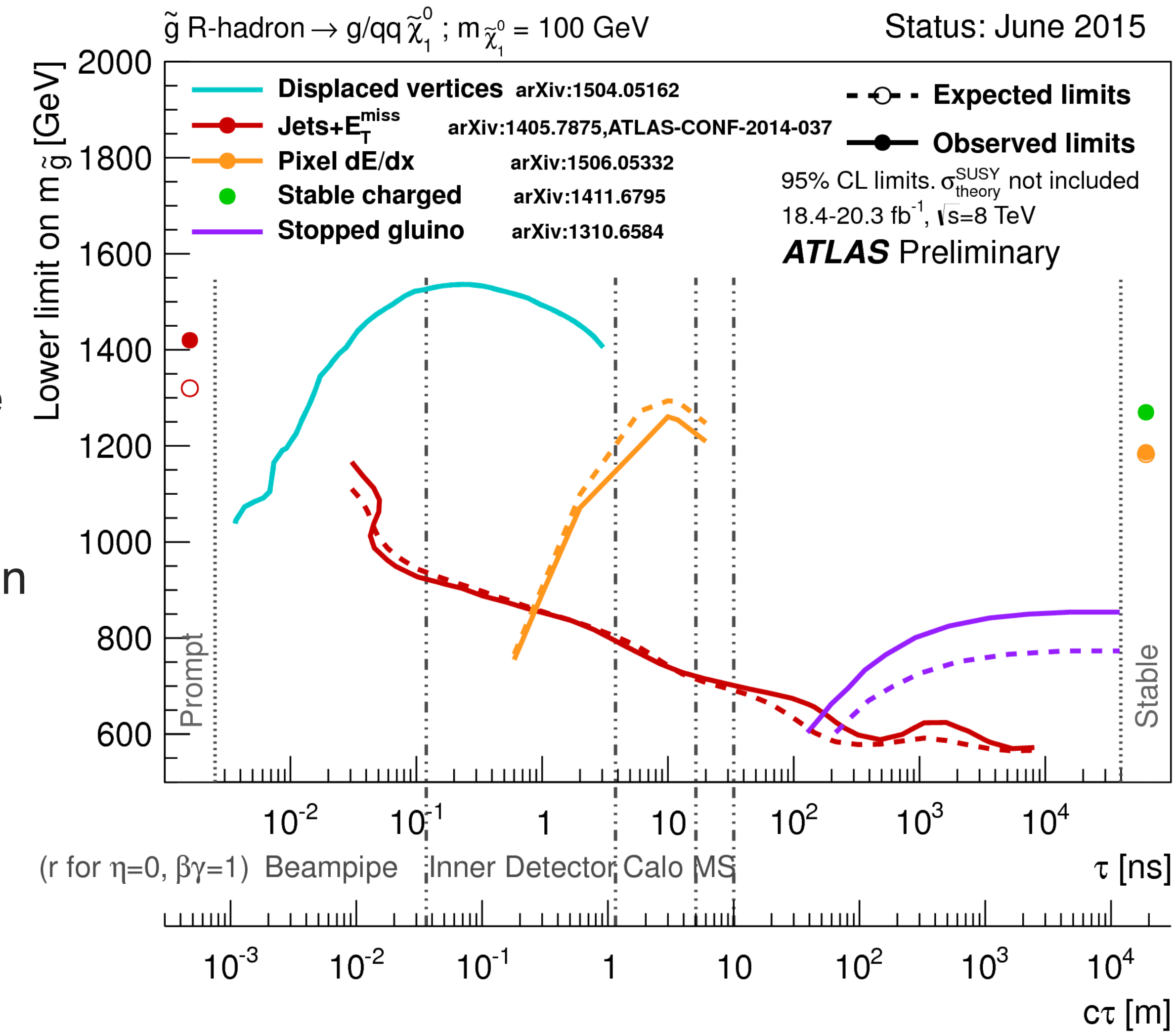
$\int \mathcal{L}\,dt = (19.5 - 20.3)$ fb^{-1} $\sqrt{s} = 8$ TeV



*Only a selection of the available lifetime limits on new states is shown.

Other SUSY long-lived searches

- ID Vertex + [jets, MET, muon, electron]
- Jet+MET search, reinterpreted for metastable gluinos
- Metastable *charged particles* with large ionisation energy loss
- Out-of-time gluino decays



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/

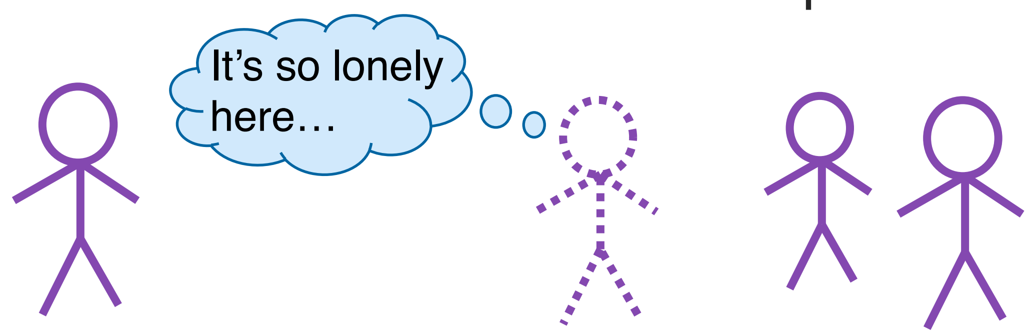
Aside – hidden sectors

Sets of particles + interactions that are scalars under the standard model gauge groups.

Without additional phenomenology, hidden sector particles:

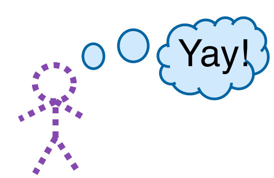
- Won't be produced by standard model particles
- Won't decay to standard model particles
- Won't have *any* interactions with standard model particles – and our detectors are all made out of standard model particles!

They are… *hidden.*



For hidden sector particles to be produced or decay, need some coupling between hidden sector and standard model

small couplings = long lifetimes!



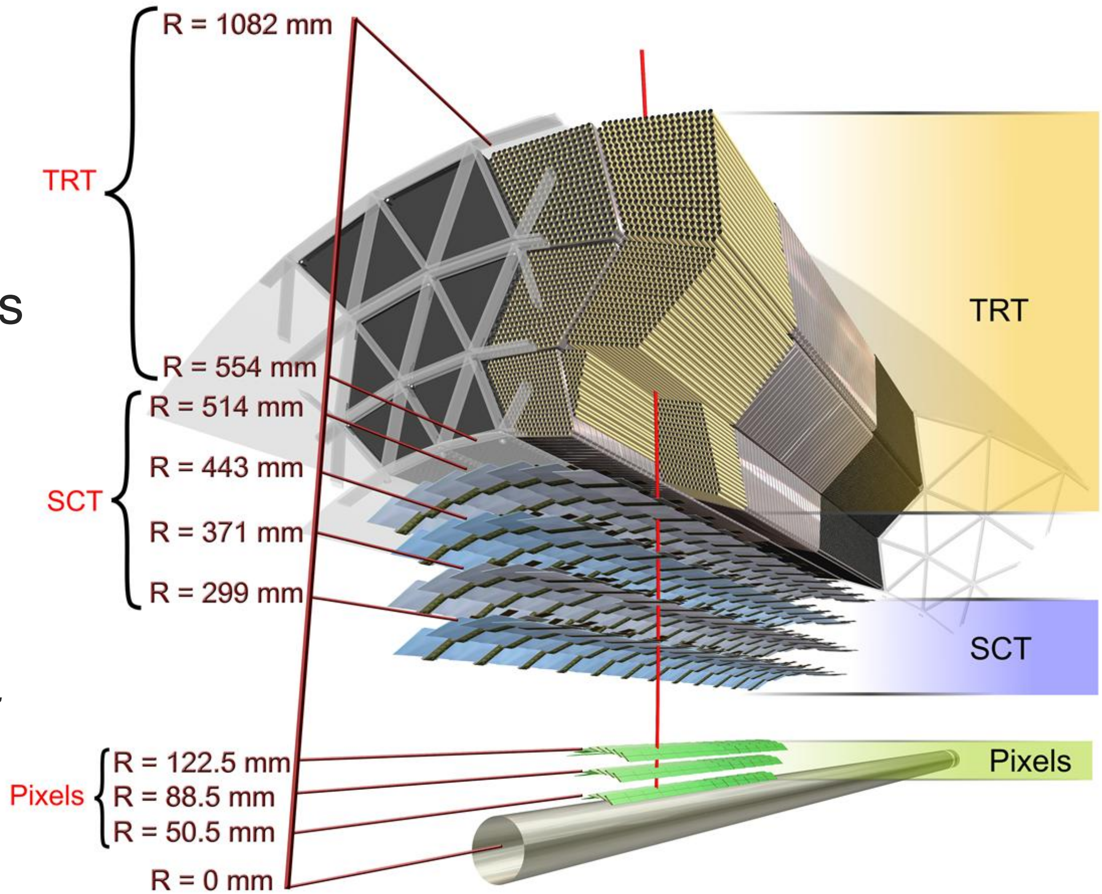
inner detector geometry[1]

- 2 T solenoidal magnetic field (along z) allows for charge/ momentum measurements
- Pixels and silicon microstrip trackers (SCTs) allow for precise tracking measurements

<u>Barrel resolution:</u>

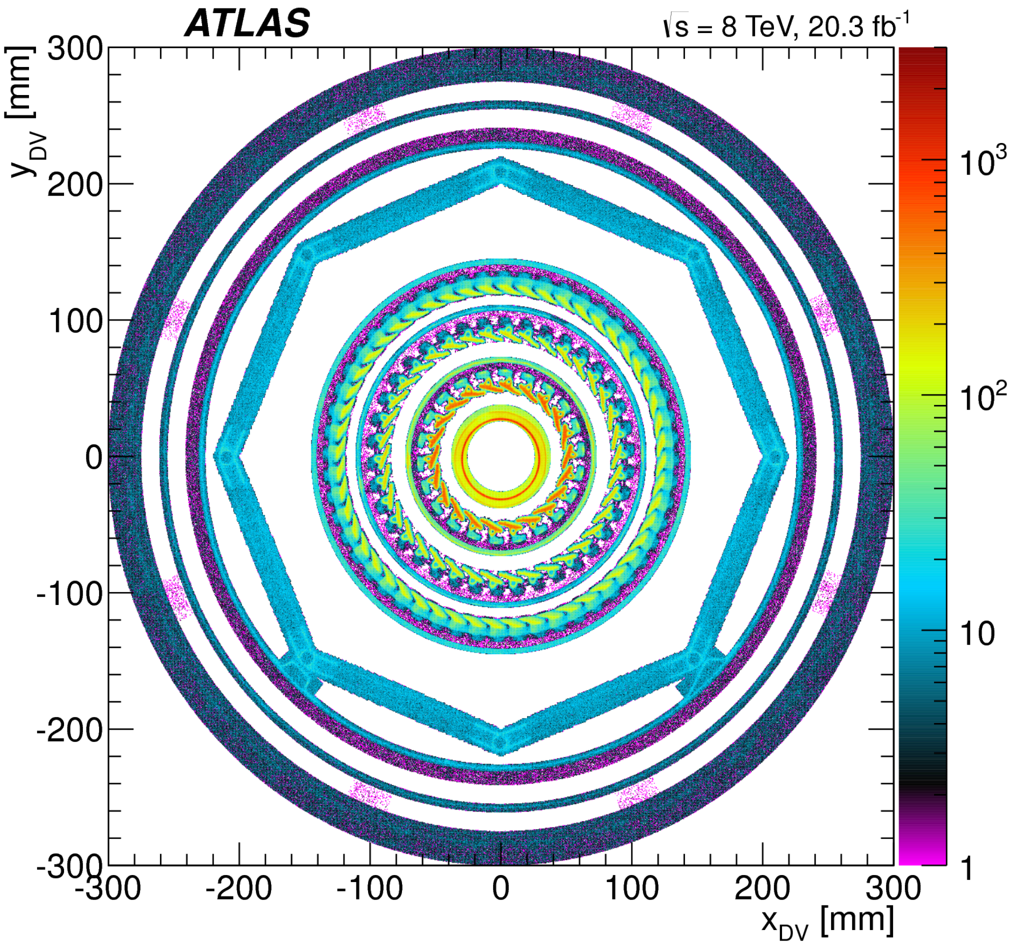
- Pixels:
  10 µm in (R-φ), 115 µm in z
- SCT:
  17 µm in (R-φ), 580 µm in z

- **Good (transverse) resolution allows for precise tracking + vertex reconstruction**



[1]Expected Performance of the ATLAS Experiment: arXiv:0901.0512v4

5. Remove all vertices consistent with hadronic material interactions



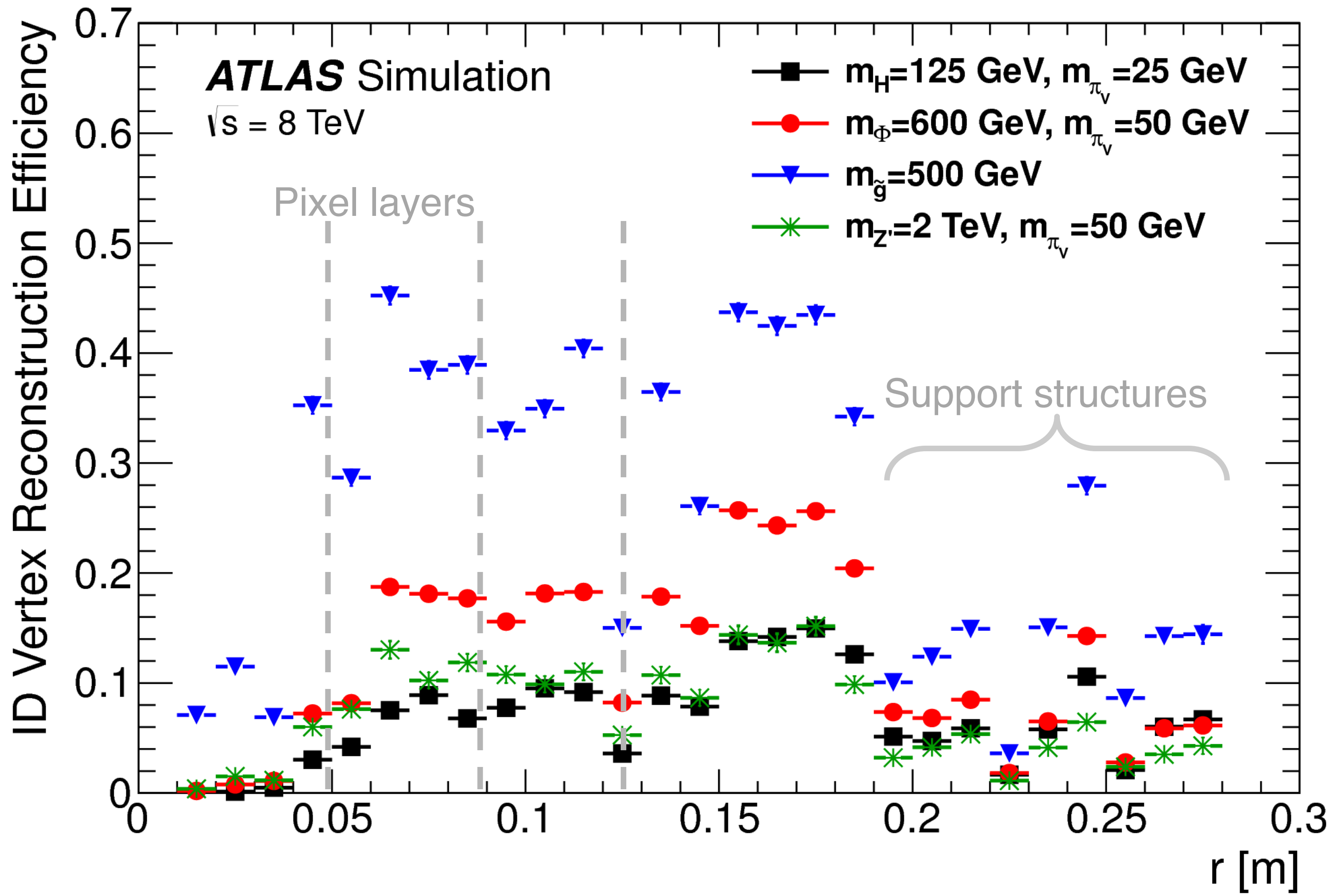
Density of < 5-track vertices reconstructed within the inner detector material

Plots: Phys. Rev. D92, 072004 (2015), arXiv:1504.05162

2nd IDVx analysis: Phys. Rev. D92, 012010 (2015), arXiv:1504.03634

ID vertex reconstruction efficiency

Phys. Rev. D92, 012010 (2015), arXiv:1504.03634



Jaggedness is caused by the application of the material veto – lower efficiencies correlate to a radius where there is material present

ID vertex reconstruction – quality criteria details

Determine a set of *good vertex criteria* (GVC) to **minimize number of background vertices** (from multi-jet events)

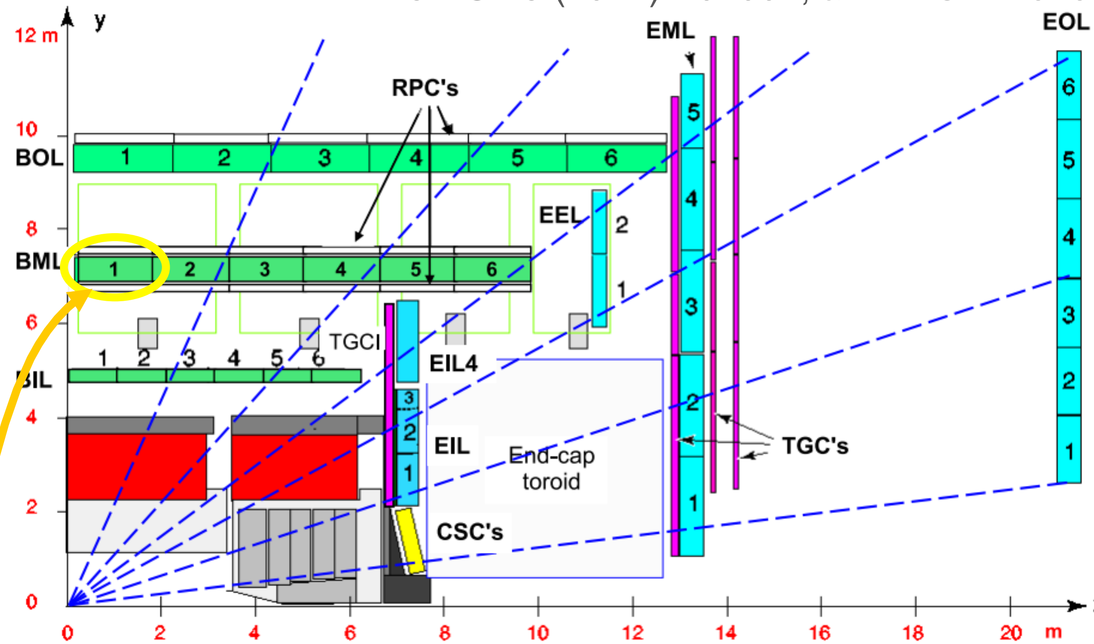
Background vertices	Signal vertices	Criteria*
Low track-multiplicities (< 6 tracks/vertex)	Higher track-multiplicities	nTracks > 5 (7)
Vertices not necessarily followed by a jet	Vertices should be followed by a jet	dR(vtx,jet) < 0.4 (0.6)
Can be from random tracks crossing a low-track multiplicity secondary vertex	All tracks come from same vertex	X^2 prob. of fit > 0.001

*(values in parentheses are for Hidden Valley Z' signal benchmarks – a model with a busier final state than just two LLPs)

muon spectrometer – geometry

- Air-core toroid magnetic field ~0.5 T in barrel, 1 T in endcaps, symmetric in φ
- Resistive Plate Chambers (RPCs) used for triggering, provide φ information for MDT hits (TGCs in endcaps)
- Muon drift tubes (MDTs) used for vertex finding.
    - Avg. resolution: 35μm/chamber, limiting factor is tube resolution

JINST 9 (2014) P02001, arXiv:1311.7070



Longitudinal cross section