Working Group Summary:

Exploring upgrades to the ATLAS Muon System for LLP Searches

"New ideas in detecting long-lived particles at the LHC"
Workshop
LBNL

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Overview & Motivation

Consider LLPs with
long lifetime, hadronic decays, mass < few 100 GeV.

At (HL-) LHC main detectors, likely best possible sensitivity will come from ATLAS search for single DV in the Muon System.

Why? MS is shielded → lower background, and can trigger on LLP decay at L1.

However, projecting LHC8 (1605.02742) search to HL-LHC (1605.02742) suggests **punch-through backgrounds (PTBG) of O(100fb)**

Original goal of this study:
"If we could improve BG rejection by 10^6, then we could improve LLP sensitivity by ~1000. Could we add some simple new sub-detectors to the MS to reject punch-through?"

Conclusions

After "designing" a possible additional veto layer for the ATLAS MS, we concluded that we would just duplicate the 1st multi-layer of the MS
→ **Changed direction of the study to**
"How can you improve the MS single-DV analysis"?

Answer: in order, do the following.

1. Optimize track/calo vetos of activity below the Muon ROI.
Make sure reconstruction quality cuts on the objects-to-be-vetoed do not reduce veto efficiency.

2. Use the 1st multi-layer of the MS as a punch-through veto.
Some reduction in signal acceptance, and have to handle backsplatter from hadronic LLP decay, but could add a lot of veto power.

3. Material veto in MS between 1st and 2nd layer.
Reject DVs originating in structure/magnet. How much signal loss???

4. Study noise bursts (thank you Laura)

Here are the details

MS DV signal requirements

3+ tracks in MS to reconstruct DV. no material veto in MS.

Veto activity below ROI in calorimeter (no jet clustering just activation) and in inner tracker (veto tracks)

efficiency in barrel of ATLAS MS: 0.25*0.5~0.1 for r = 4-7m:

1504.03634, parameterized in 1605.02742

	r (m)	$\|z\|$ (m)	$\|\eta\|$	$\epsilon_{\text{trigger}}$	ϵ_{DV}
Muon Spectrometer (barrel)	(4, 6.5)	—	< 1.1	0.40	0.25
Muon Spectrometer (endcaps)	—	(7, 12)	(1.1, 2.4)	0.25	0.50

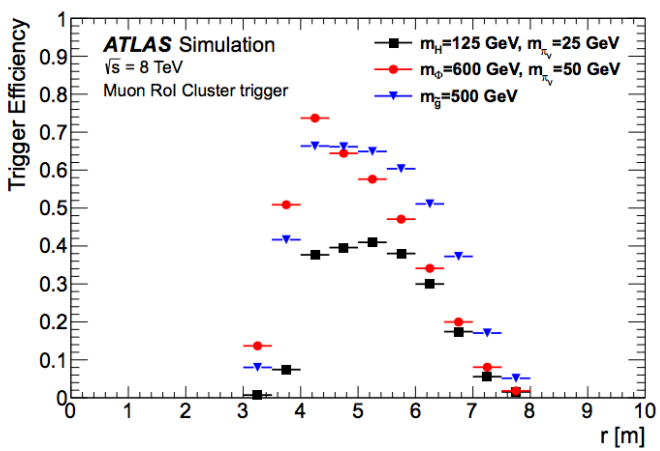
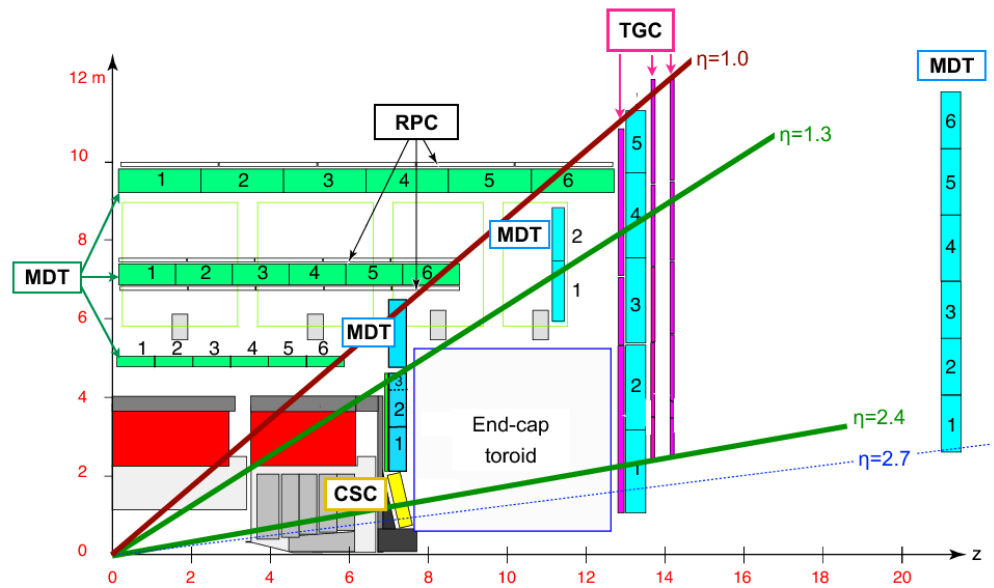
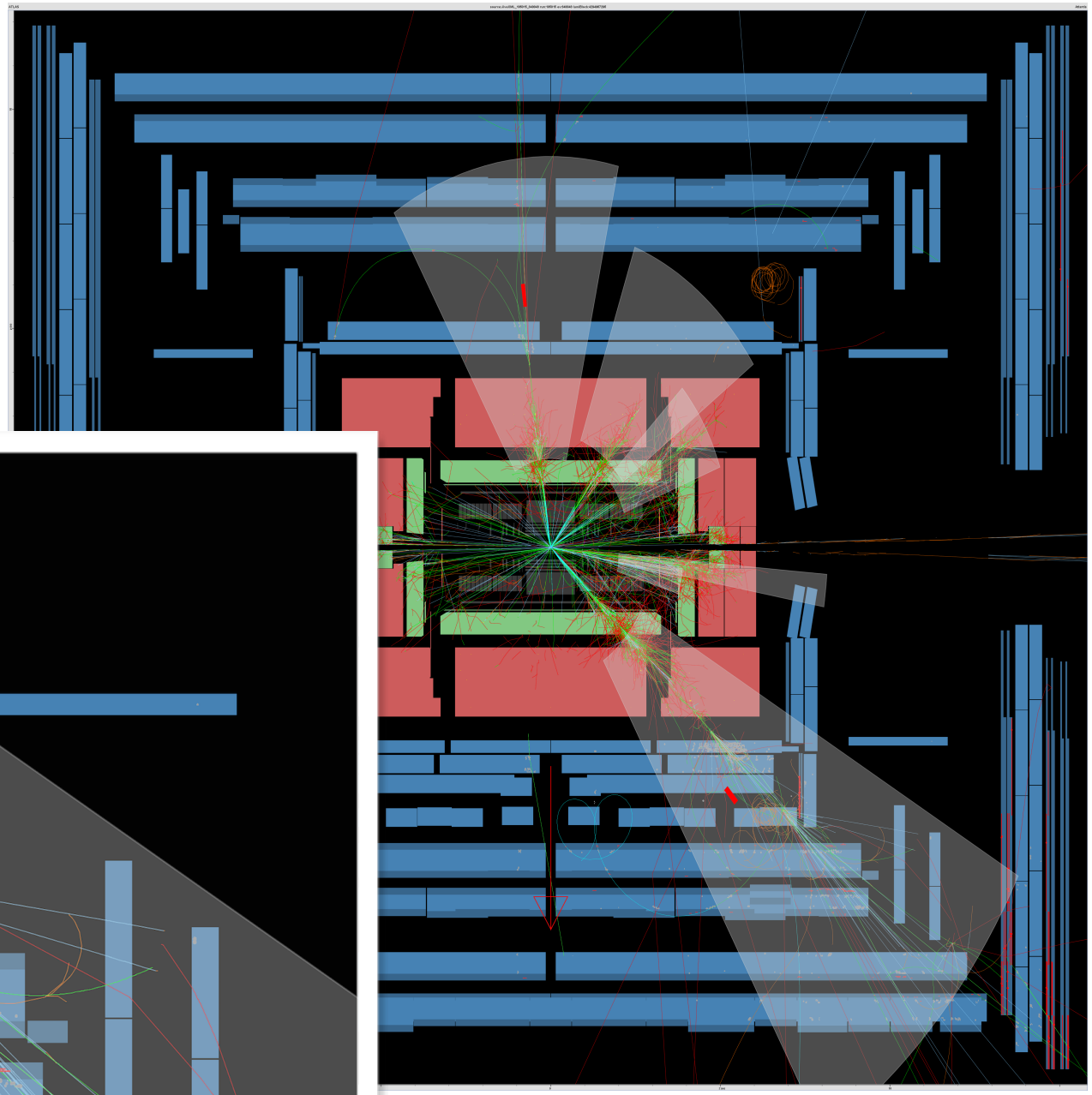


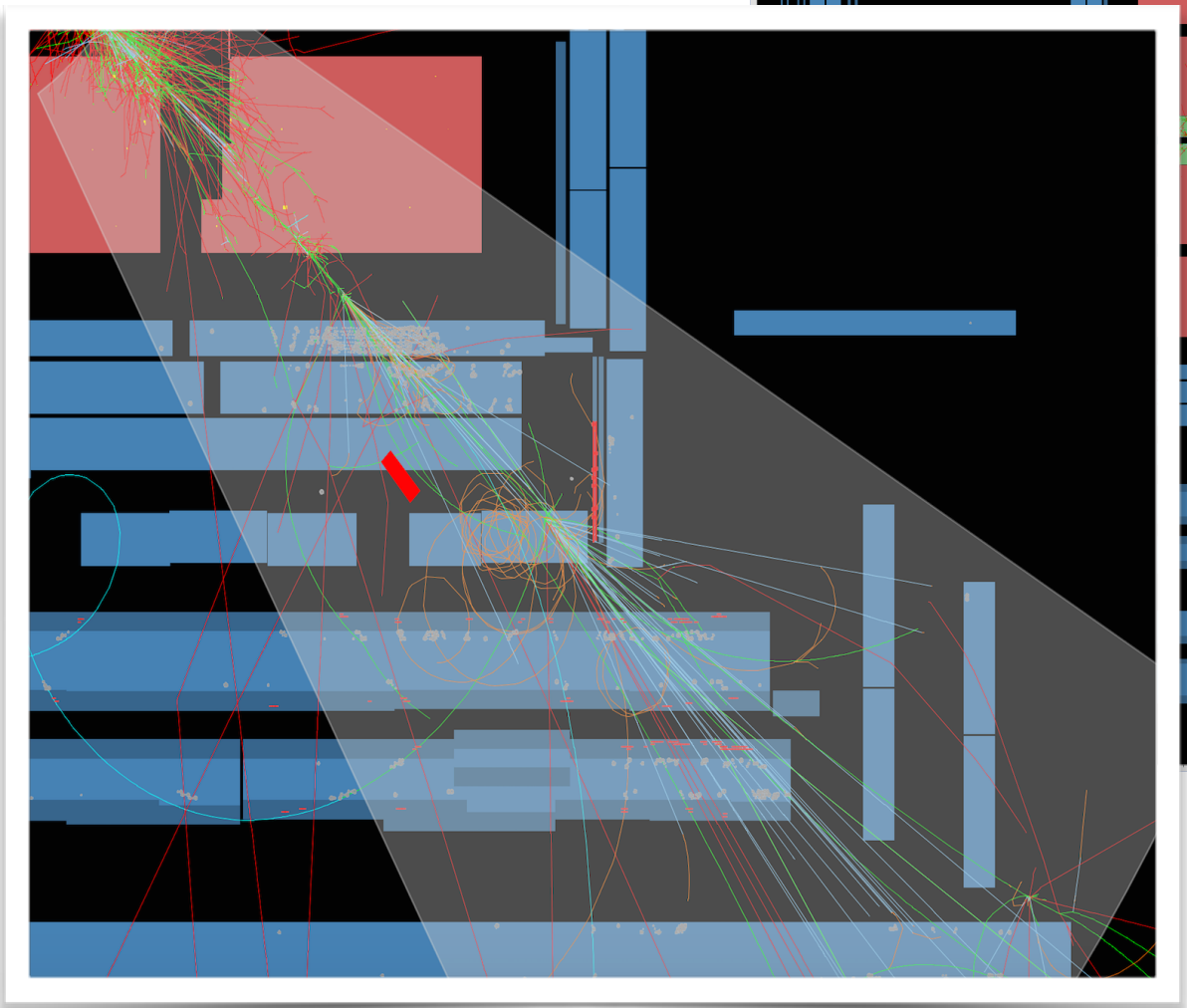
FIG. 2. Efficiency for the Muon RoI Cluster trigger in the barrel as a function of the decay position of the long-lived particle for three simulated benchmark samples.



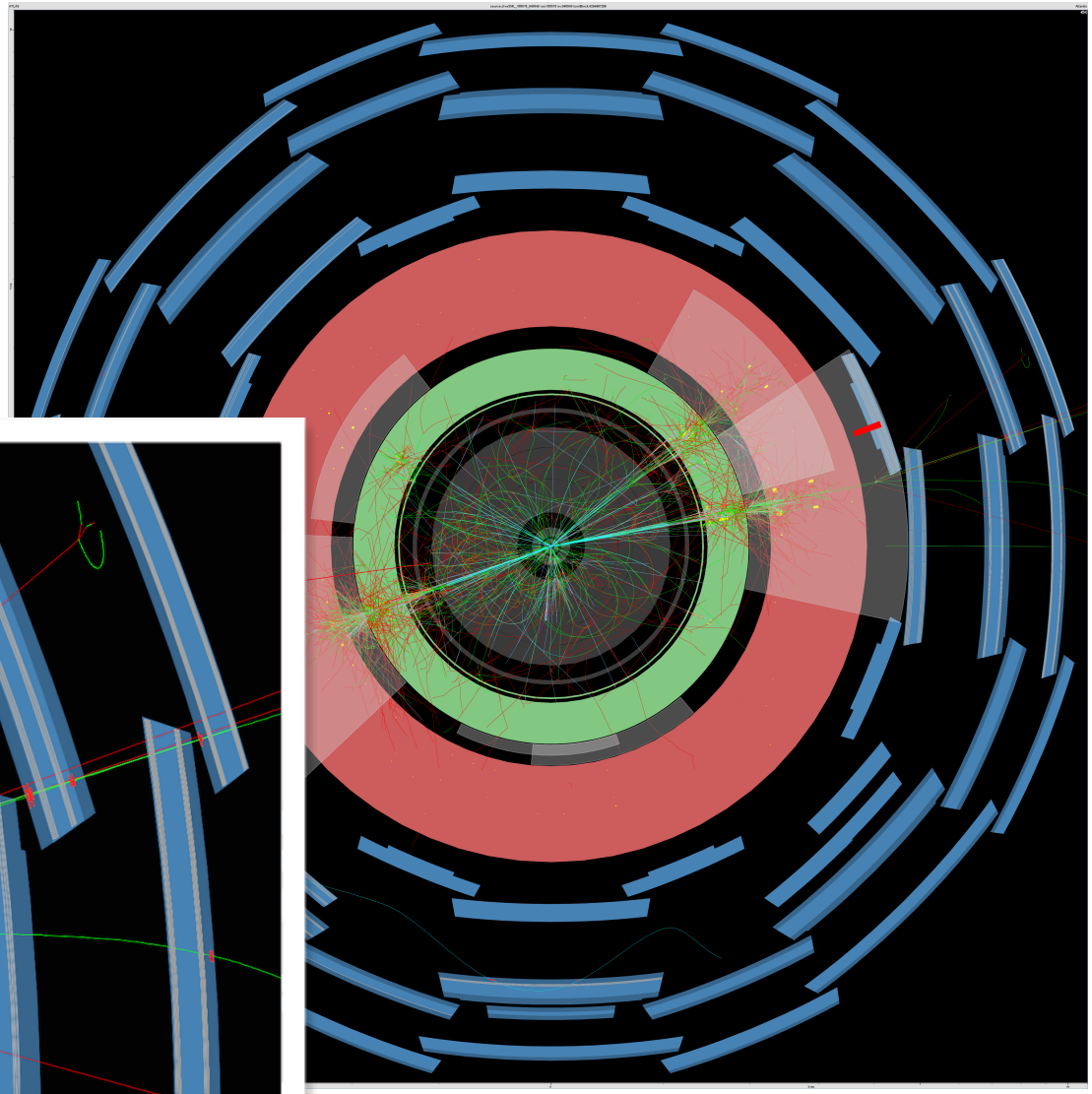
Few-100fb-equiv of punchthrough background to 1-DV search

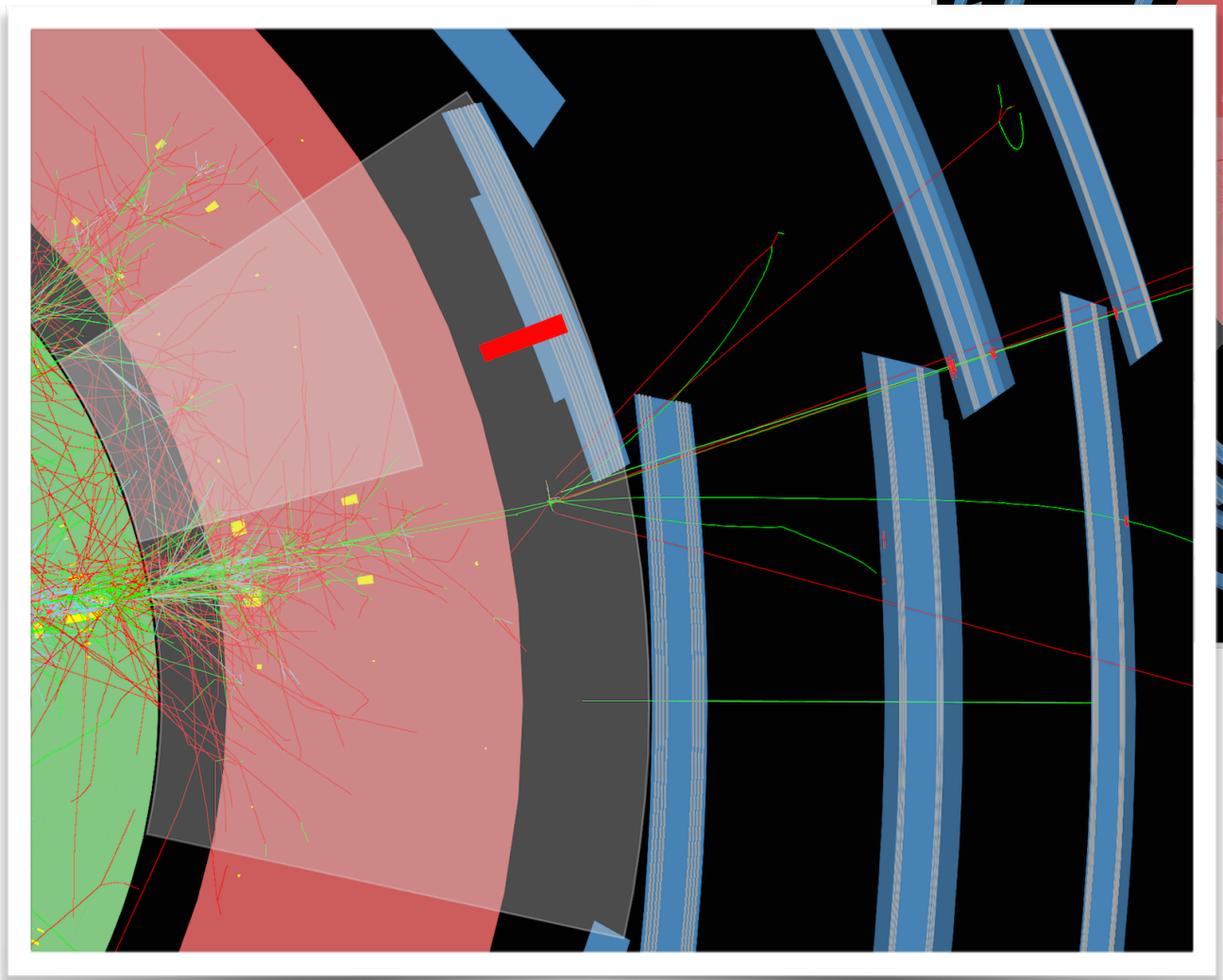
Punch-Through (GEANT)





Punch-Through (GEANT)





Adding a Punchthrough Veto Detector

Could you add a layer of detector between the MS and the HCAL to provide additional vetoing of punchthrough charged particles?

You'd need many cm layers of scintillator to get `sufficiently perfect' punch-through detection/veto.

Avoid constant activation due to cavern backgrounds.
Radiation loads and cavern background photon spectrum:
http://cdsweb.cern.ch/record/1457509/files/ATL-MUON-PROC-2012-005.pdf
https://cds.cern.ch/record/814823/files/gen-2005-001.pdf

Upshot:
- LOTS of 10 MeV photons flying around, to avoid quasi-constant activation need 10+cm of lead. Can't add that much, the MS has a day job…
- Could avoid photon activation by replacing scintillator by … RPCs….

⇒ JUST USE THE 1st MS MULTI-LAYER AS A PUNCHTHROUGH VETO??!

The current detector already has the potential features you need…

New Direction: Strategies for MS 1DV Searches?

What if you use the 1st MS multi-layer layer as a punchthrough veto?

Issues:

1) LLP decaying hadronically gives backsplash (final state particles flying backwards) "a lot of the time" depending on mass. Make sure this does not kill signal efficiency

2) 1st multi-layer is vital for Muon ROI trigger, without it, no trigger.

3) Reduce signal acceptance by ~ 0.5. (OK..)

→ do this veto off-line

→ veto events based on "segments" (tracklets) between reconstructed DV and IP **very selectively**

How well would this work? **NEED TO STUDY THIS IN DATA**

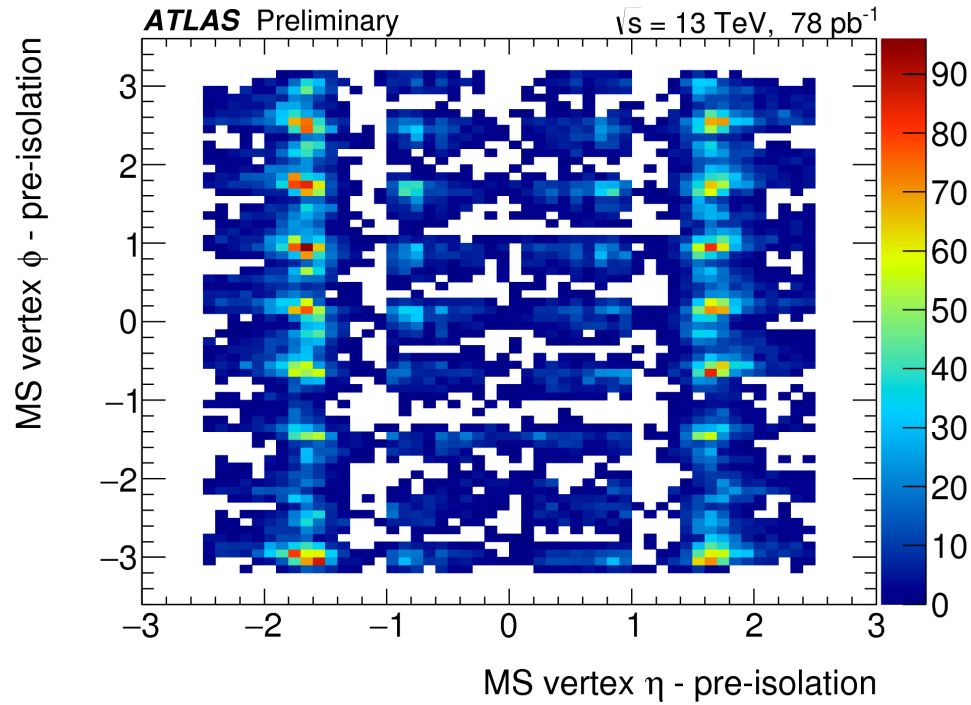
New Direction: Strategies for MS 1DV Searches?

Material Veto?

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

It looks like you could cut out a lot of BG by vetoing DVs from material…

Issues:
1) DV resolution in MS is not amazing: O(0.4m)
2) the signal DV reconstruction eff kinda follows this distribution as well..



How well would this work? **NEED TO STUDY THIS IN DATA**

New Direction: Strategies for MS 1DV Searches?

Improving Calo/Track veto?

Make sure you're not too picky about what trips your veto!

The calorimeter veto below ROI is already "dumb", just activity, not jet clustering etc. That's good. (Make sure we don't make it smarter!)

There is also a veto on track activity below the ROI.
Are there any quality cuts on tracks below the ROI that we could loosen off-line to make the veto more efficient at rejecting background?

What do the event displays of the punchthrough events that pass MS single-DV signal requirements look like???

NEEDS TO BE STUDIED!

New Direction: Strategies for MS 1DV Searches?

Laura Jeanty: Noise Bursts?

Study noise bursts in the MS in low/no lumi data.

Existing analysis imposes cuts to reduce these, but maybe there are other forms of noise which mimic DV in the muon system without punchthrough… ???

Could then estimate the rate of these in the standard data and study rejection strategies.

Upshot

Turns out the ATLAS MS already has the main ingredients we envisioned to improve punchthrough rejection. Is it possible to do much better than existing analysis? Need to study the strategies we suggest here!

What kind of improvements to LLP sensitivity could be envisioned?
All of the strategies we suggest carry a signal acceptance cost that limit your sensitivity even in the hypothetical background-free regime.

If background was switched off magically now, possible improvement in LLP xsec reach is ~500-1000x better.
With the above signal costs, a factor of < ~ 100 seems like the maximum possible sensitivity gain.

If you can buy a factor of (say) 50 with lots of work, that's a worthwhile target!