Search for Long-lived Particles in the ATLAS Muon Spectrometer

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Long-lived particles in the LHC detector

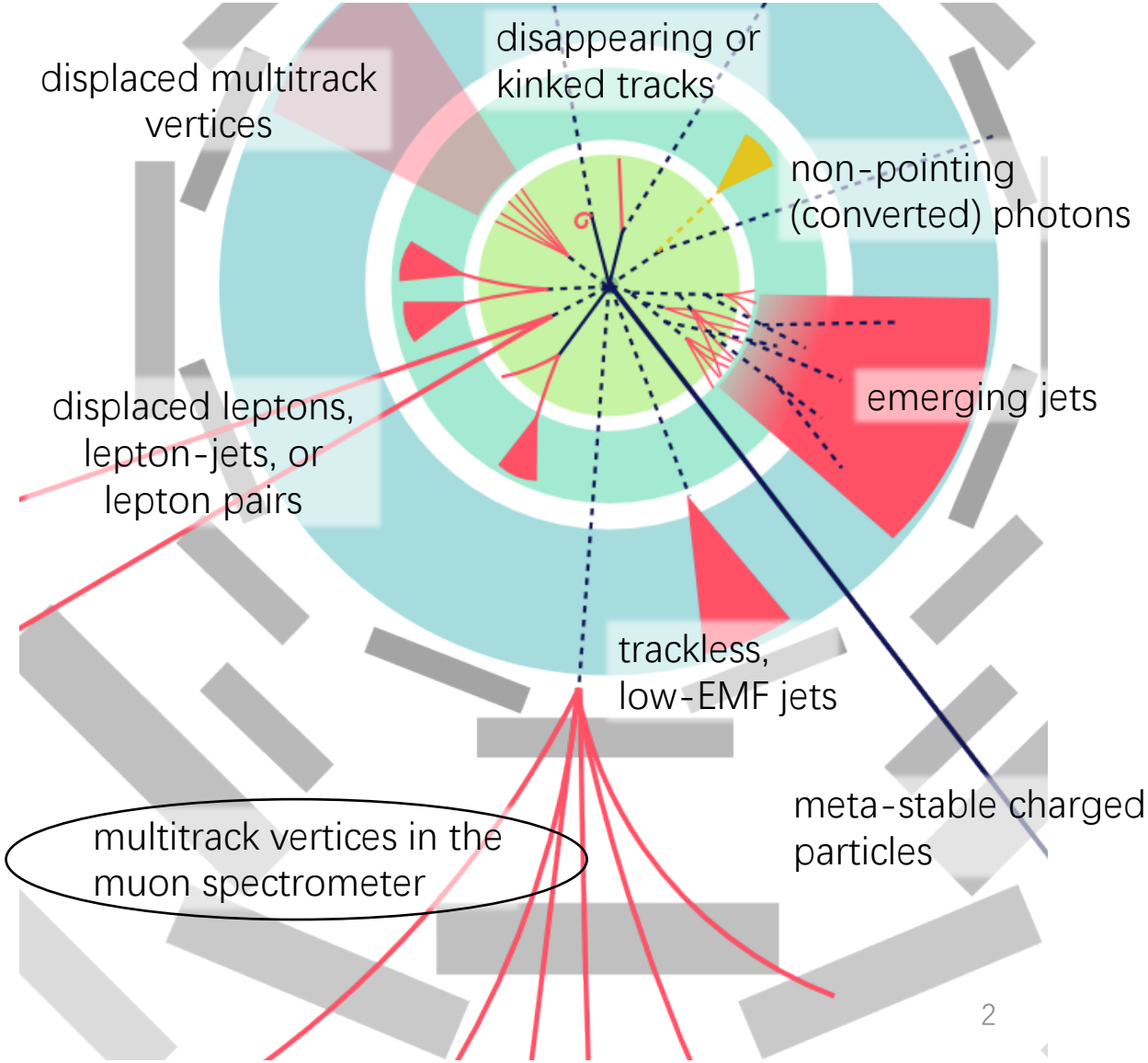
Long-lived particles(LLP) are predicted by a wide range of BSM scenarios. (SUSY, Higgs-portal, Gauge-portal, Dark matter, Heavy neutrino…)

Many decay modes can be used to characterize LLP signatures. (di-photon, single-photon, hadronic, semi-leptonic, leptonic…)

Lots of possible experimental signatures at the ATLAS or CMS detector!

Our search is here!

Figure from Heather Russell

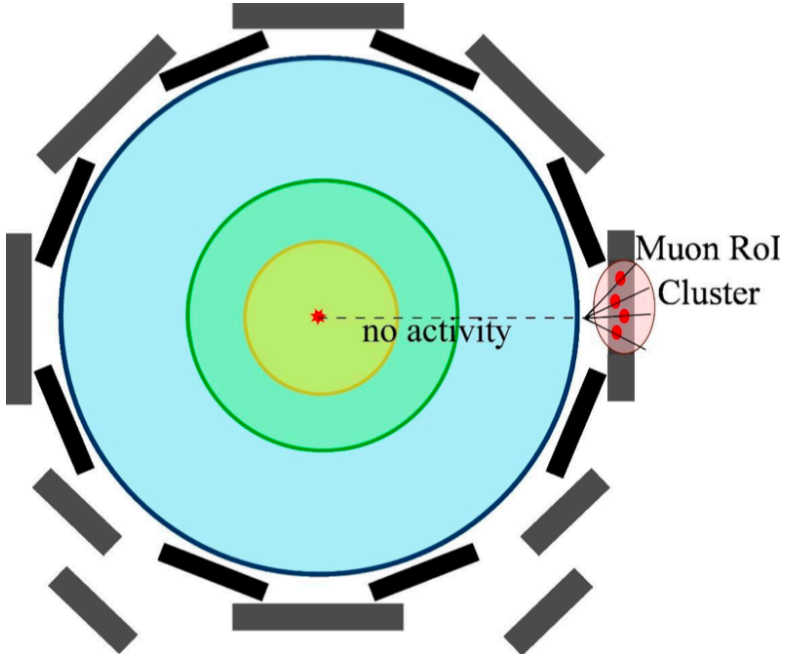


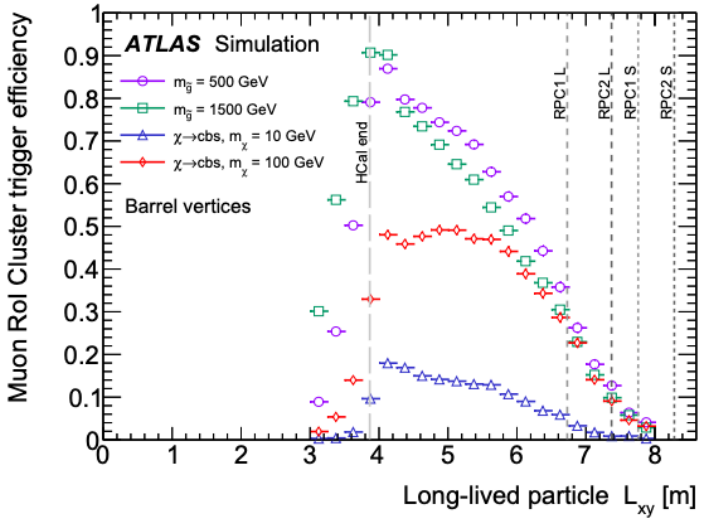
Triggers for LLP decay in the muon spectrometer

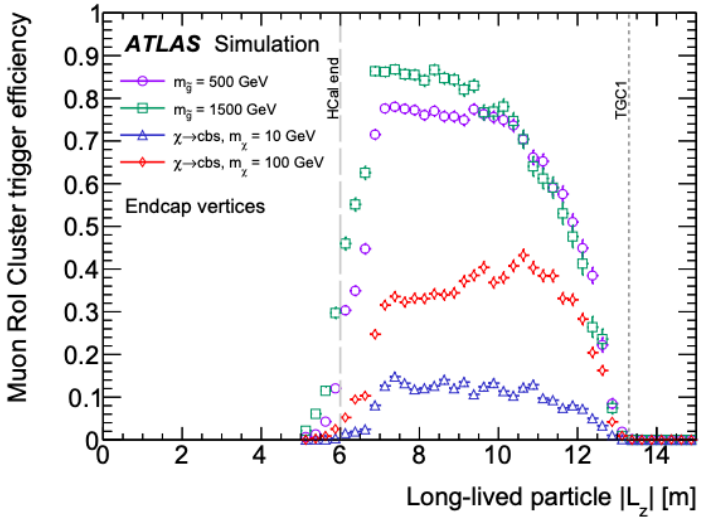
- **Muon RoI Cluster Trigger** targets on particles decaying to hadronic jets from the outer region of the HCal to the muon spectrometer (MS) middle station.

- Selection criteria: A cluster of at least three (four) L1 muon RoIs (region of interest) lying within a dR=0.4 radius in the MS barrel (endcaps).

- L1 muon RoIs are formed in a $\Delta\eta\times\Delta\phi = 0.2\times0.2$ region ($\Delta\eta\times\Delta\phi = 0.1\times0.1$ region) in the barrel (endcaps).



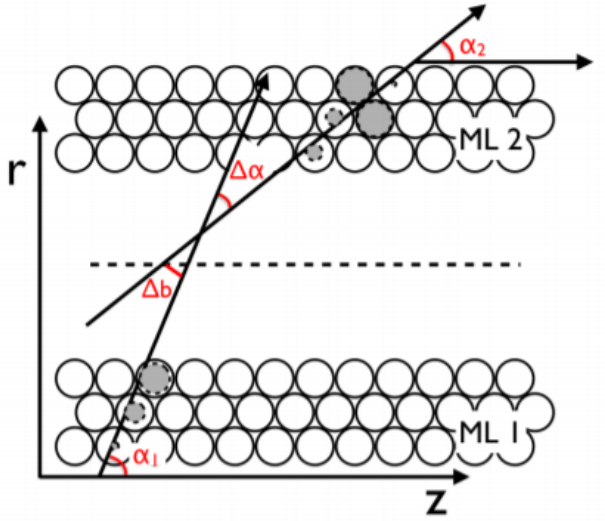




arXiv: 1811.07370

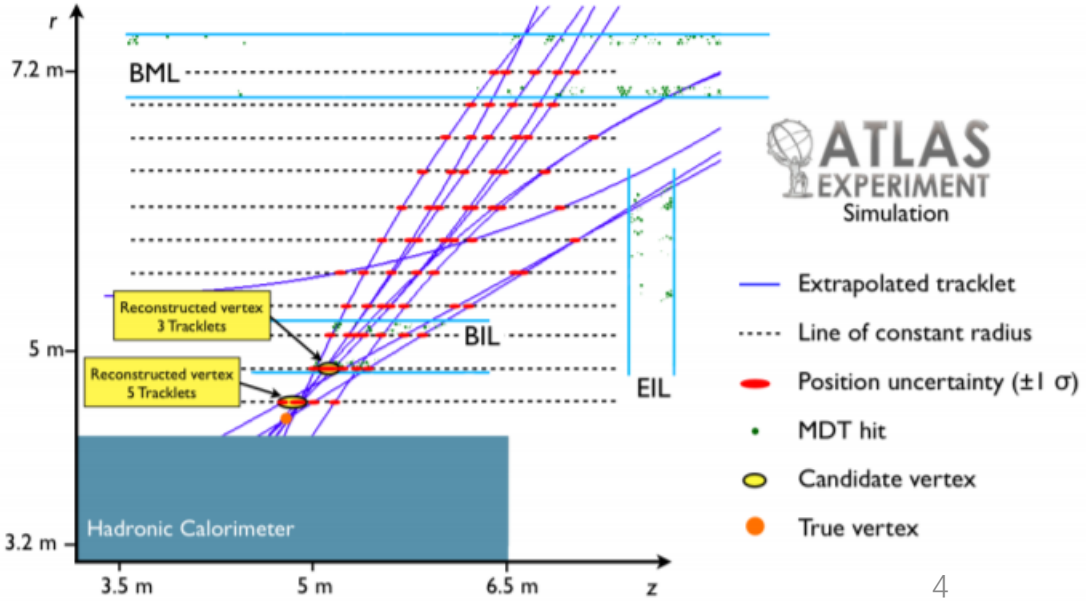
Vertex reconstruction in the muon spectrometer

- Vertex reconstruction in the MS is based on a tracklet-finding technique.
- Tracklet refers to the paired set of straight-line segments reconstructed in the two multilayers of monitored drift tube(MDT) chambers.
- MDTs in the barrel are located inside the magnetic field while the MDTs in the endcaps are not, which results in different reconstruction approaches for the barrel and endcaps.



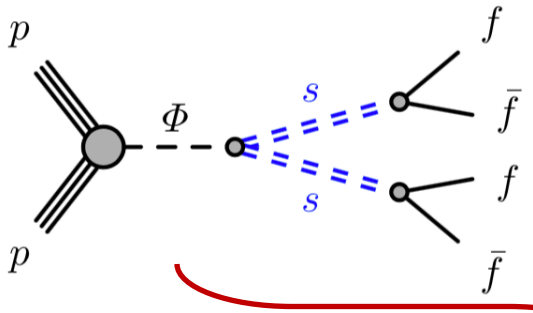
MDT chambers in the MS

arXiv: 1311.7070

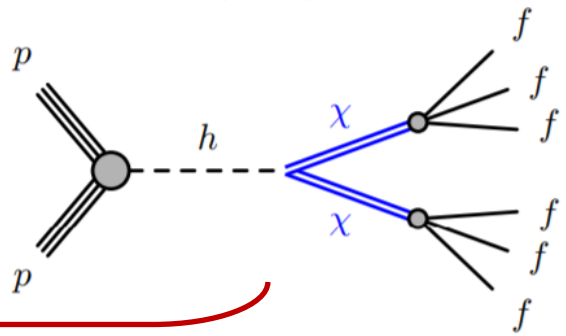


Analysis strategy

Hidden sector

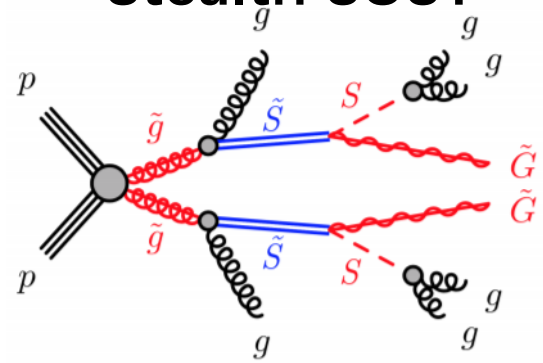


Baryogenesis



Search for 2 vertices OR 1 vertex + MET

Stealth SUSY



Search for 1 vertex + prompt jets

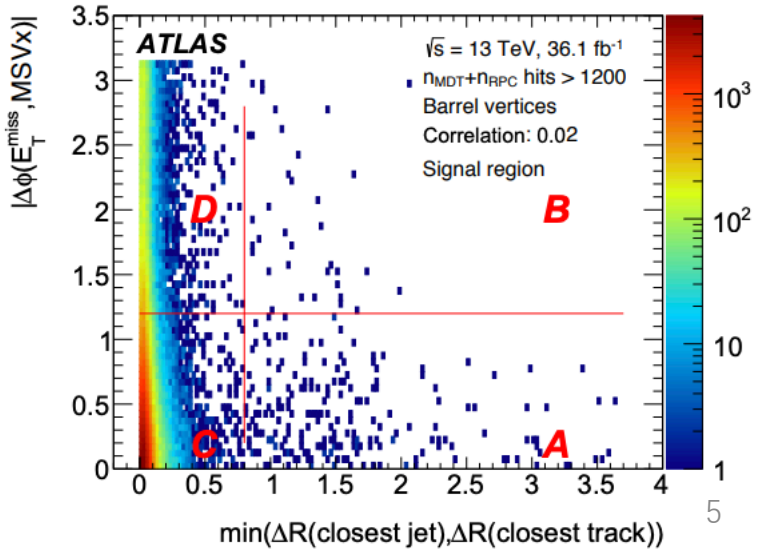
Background is mainly from the punch-through jets and is estimated by data-driven methods.

For 2-vertex search, background is modeled by data acquired with zero-bias trigger (fires on bunch crossing that occurs one LHC revolution after a luminosity trigger).

For 1-vertex search, background is estimated by the ABCD method.

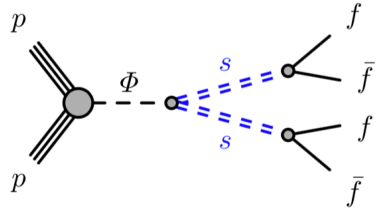
$$N_A^{\text{expected}} = N_B \times \frac{N_C}{N_D}$$

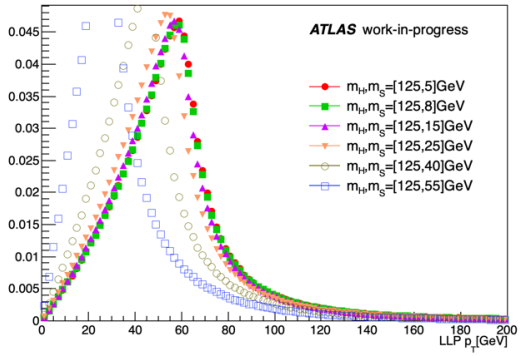
arXiv: 1811.07370

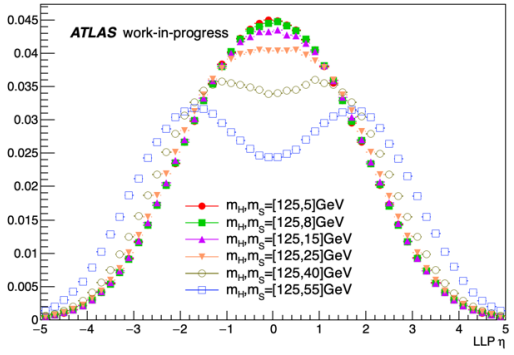


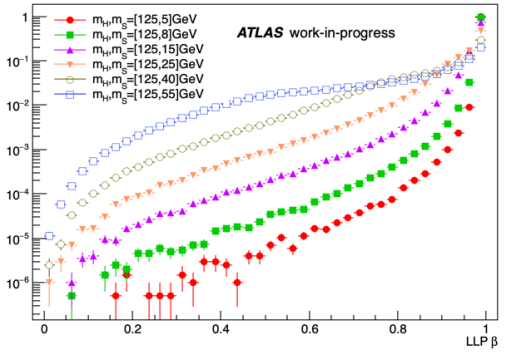
MC study for the full Run-2 analysis

- We validated the Hidden Sector signal kinematics with updated MC configuration (generators, PDFs …)







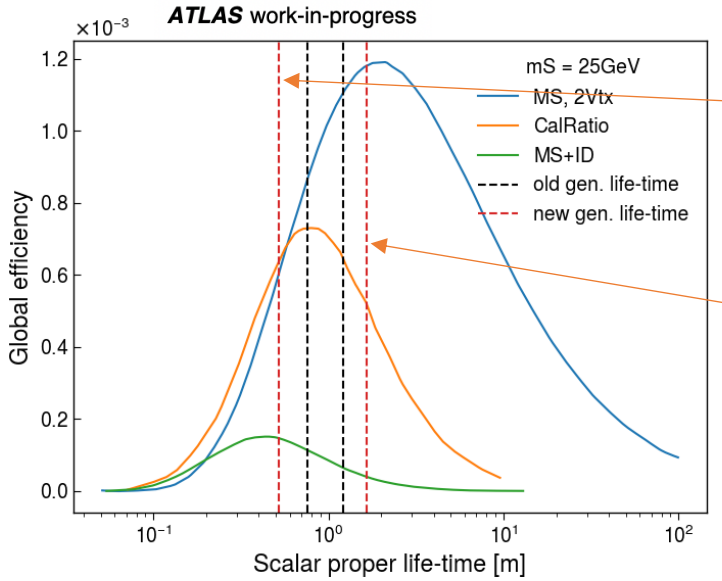


…

- Lifetime values are re-optimized in order to decrease the uncertainties in the signal regions.

MS+ID analysis: search for displaced jets in the Inner detector and MS

CalRatio analysis: search for displaced jets in the hadronic calorimeter



Chosen to increase the efficiency for the MS+ID analysis

Chosen to increase the efficiency for our MS analysis

Global efficiency from 2015-2016 analysis

- Fully simulated samples corresponding to period 2015-2018 have been produced

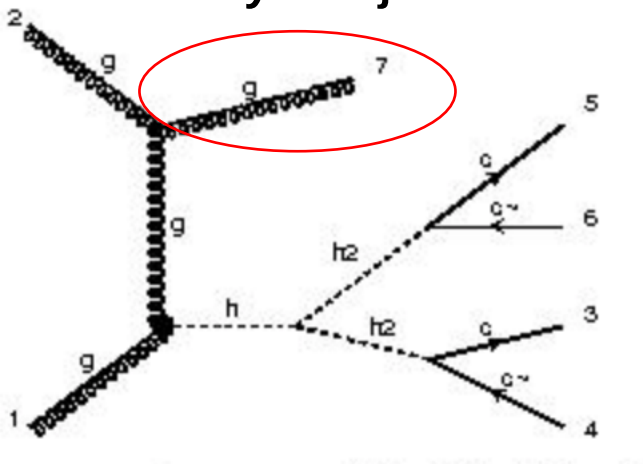
MC study for the full Run-2 analysis

Q: The signal sample is produced at the LO. Will the NLO jets affect the signal efficiency?

To answer this question, we estimate the NLO effect from the process with one extra jet radiation using CKKW algorithm using Madgraph and Pythia8.

What does CKKW do?

Only ISR jet is of our interest



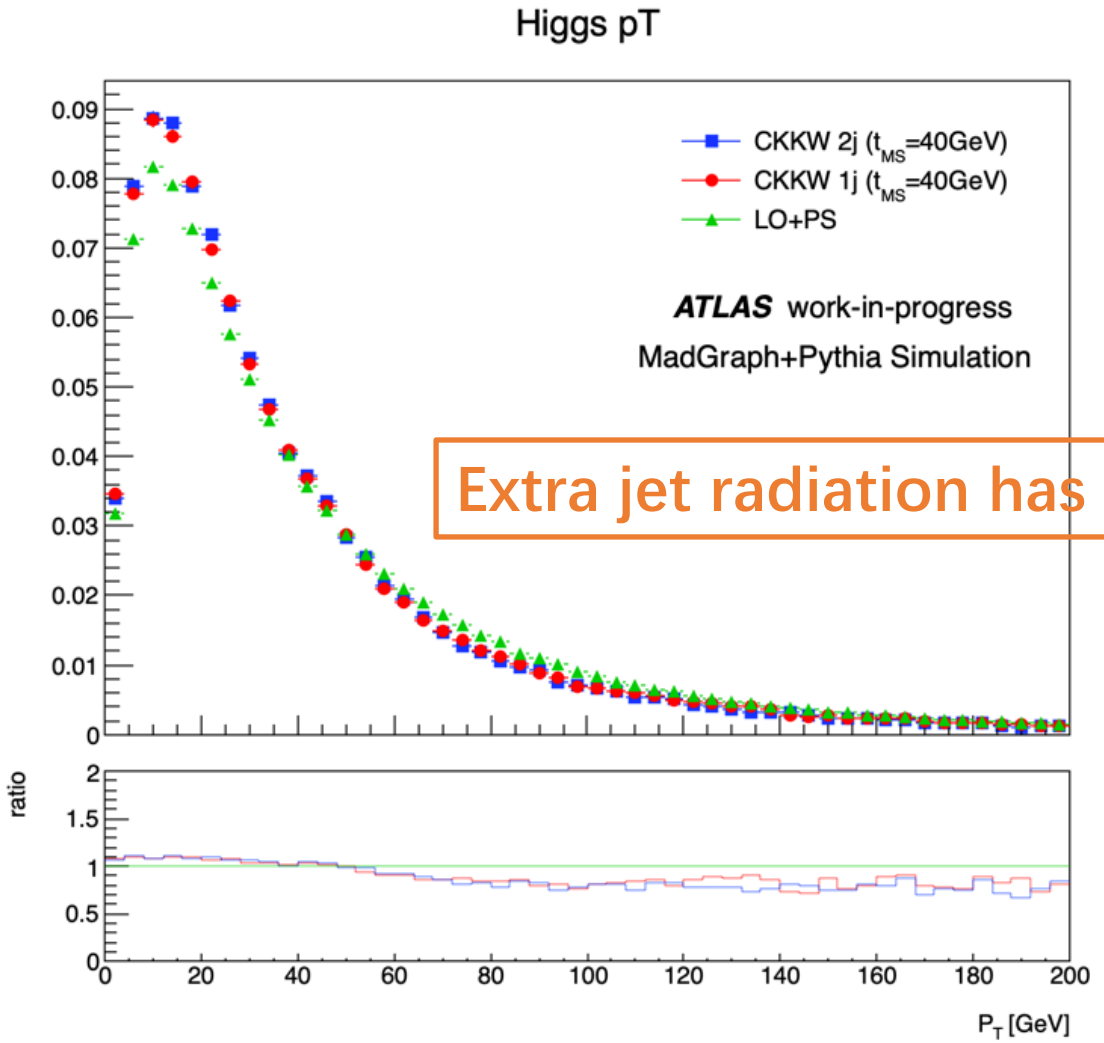
Hard & well-separated jet: calculated by the matrix-element, which is regularized by a jet cutoff t_{MS}

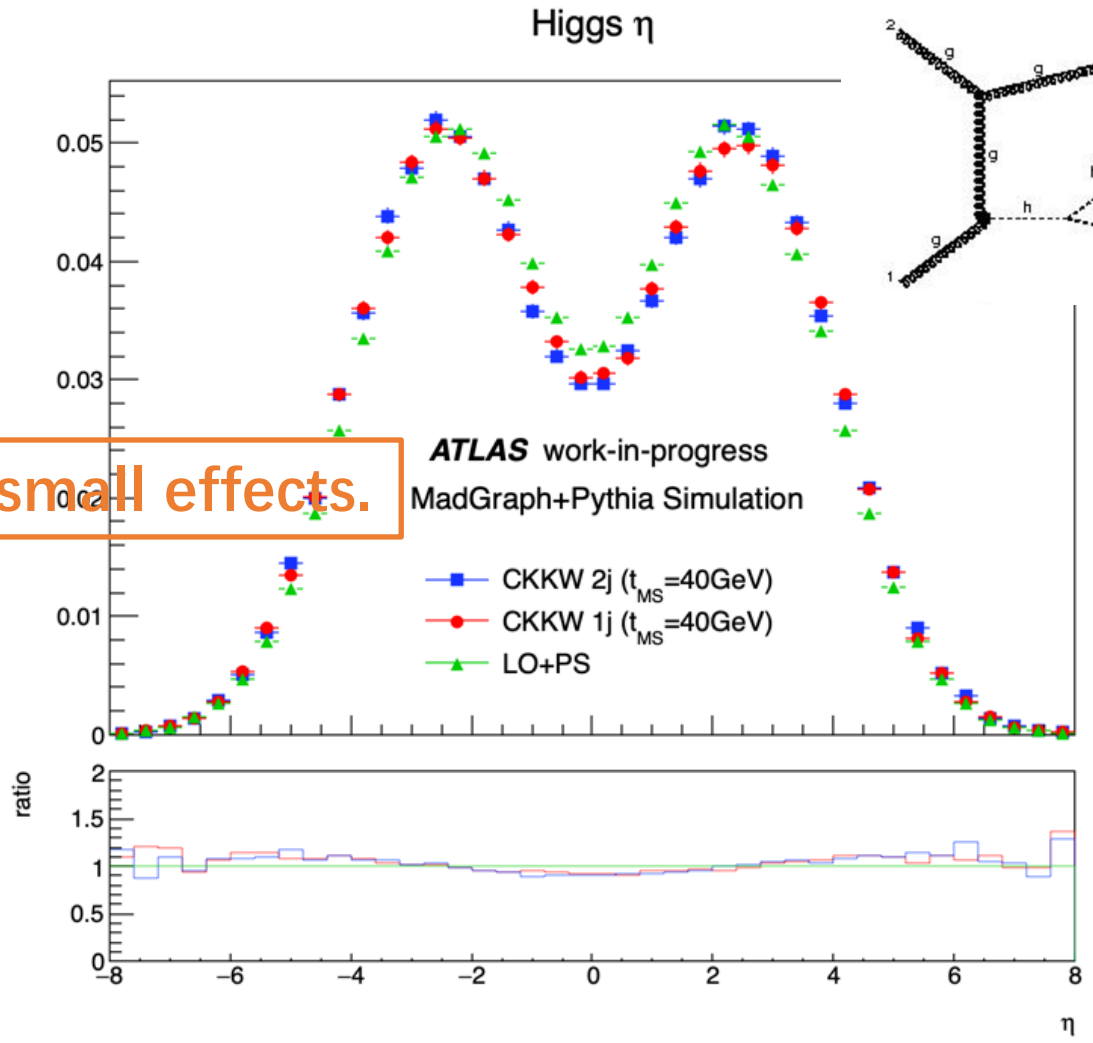
Soft & collinear jet: modeled by the parton shower

CKKW algorithm will combine these two parts properly. arXiv: 1109.4829

MC study for the full Run-2 analysis

- We studied the effects from 1 extra jet or 2 extra jets. (t_{MS} is set to 40GeV)





Extra jet radiation has small effects.

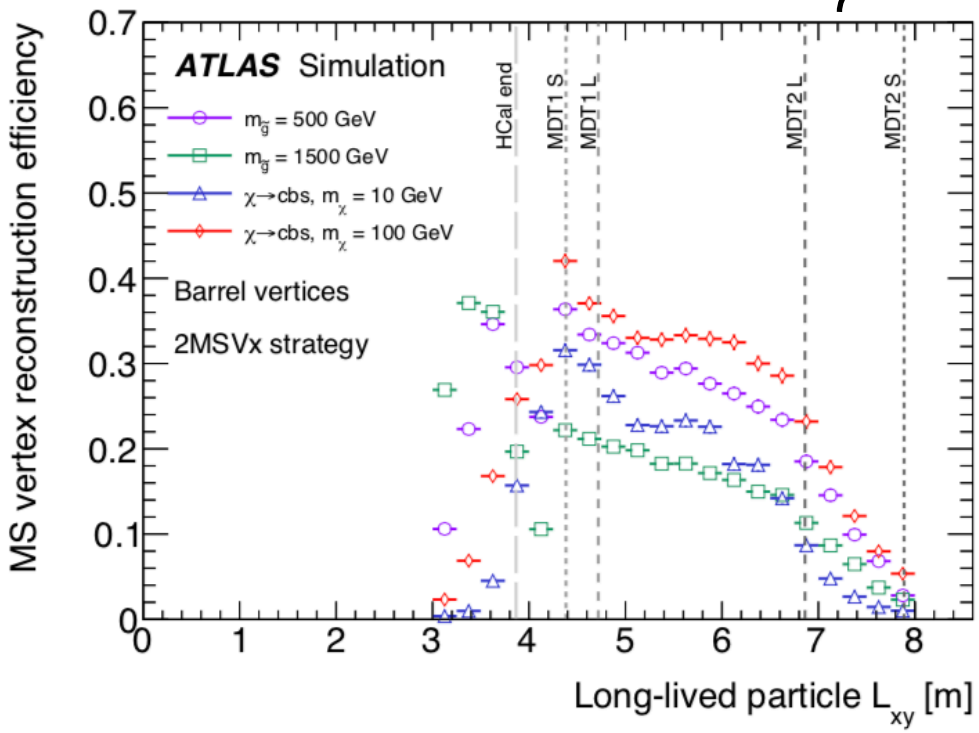
Lifetime extrapolation

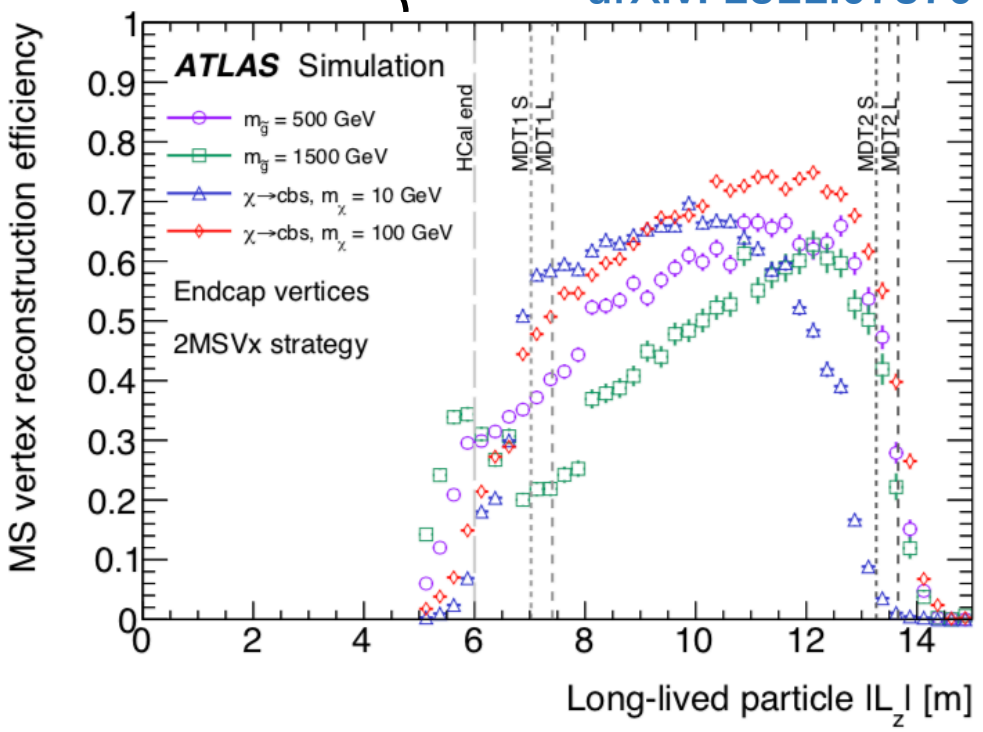
- Toy Monte Carlo Method

- LLP decay position with any τ can be simulated using toy MC from 4-momenta and decay length following $f(t) = e^{-t/\beta\gamma c\tau}$.

- With simulated trigger and vertex reconstruction efficiency, we are able to simulate the signal events.

arXiv: 1811.07370



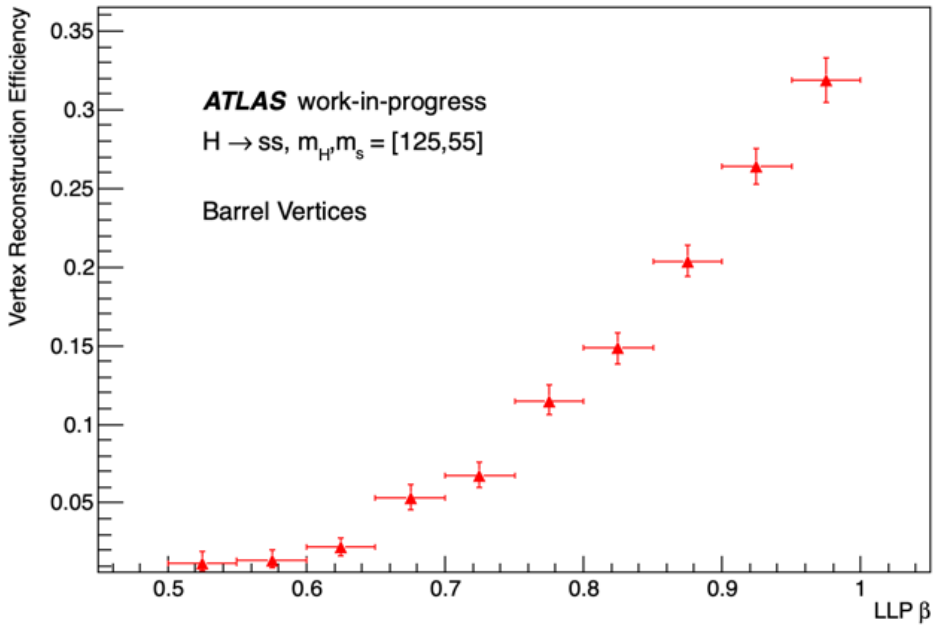


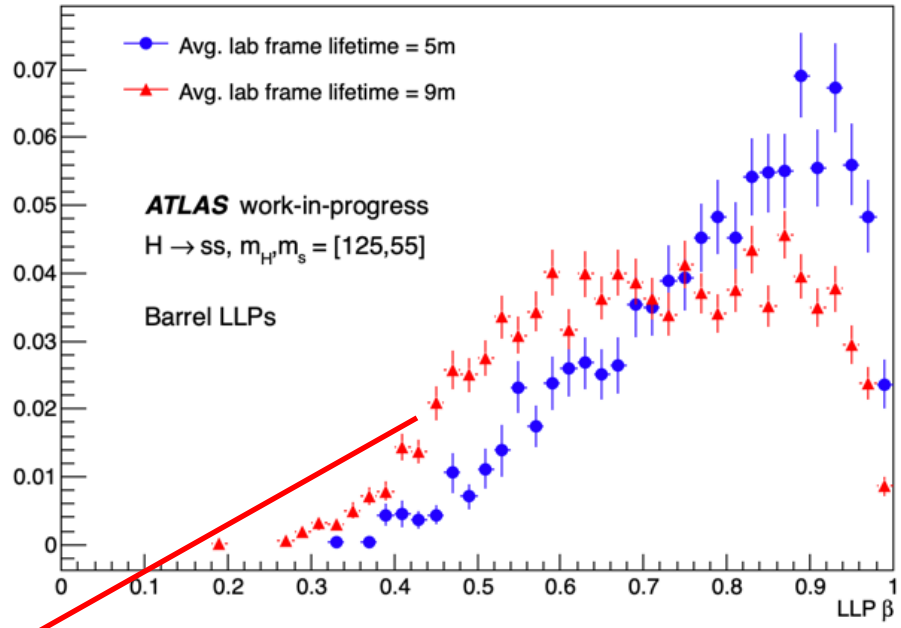
Lifetime extrapolation

- A possible defect in toy Monte Carlo Method

  One set of vertex reconstruction efficiencies are used for all the lifetime values.

Problematic for heavy LLPs



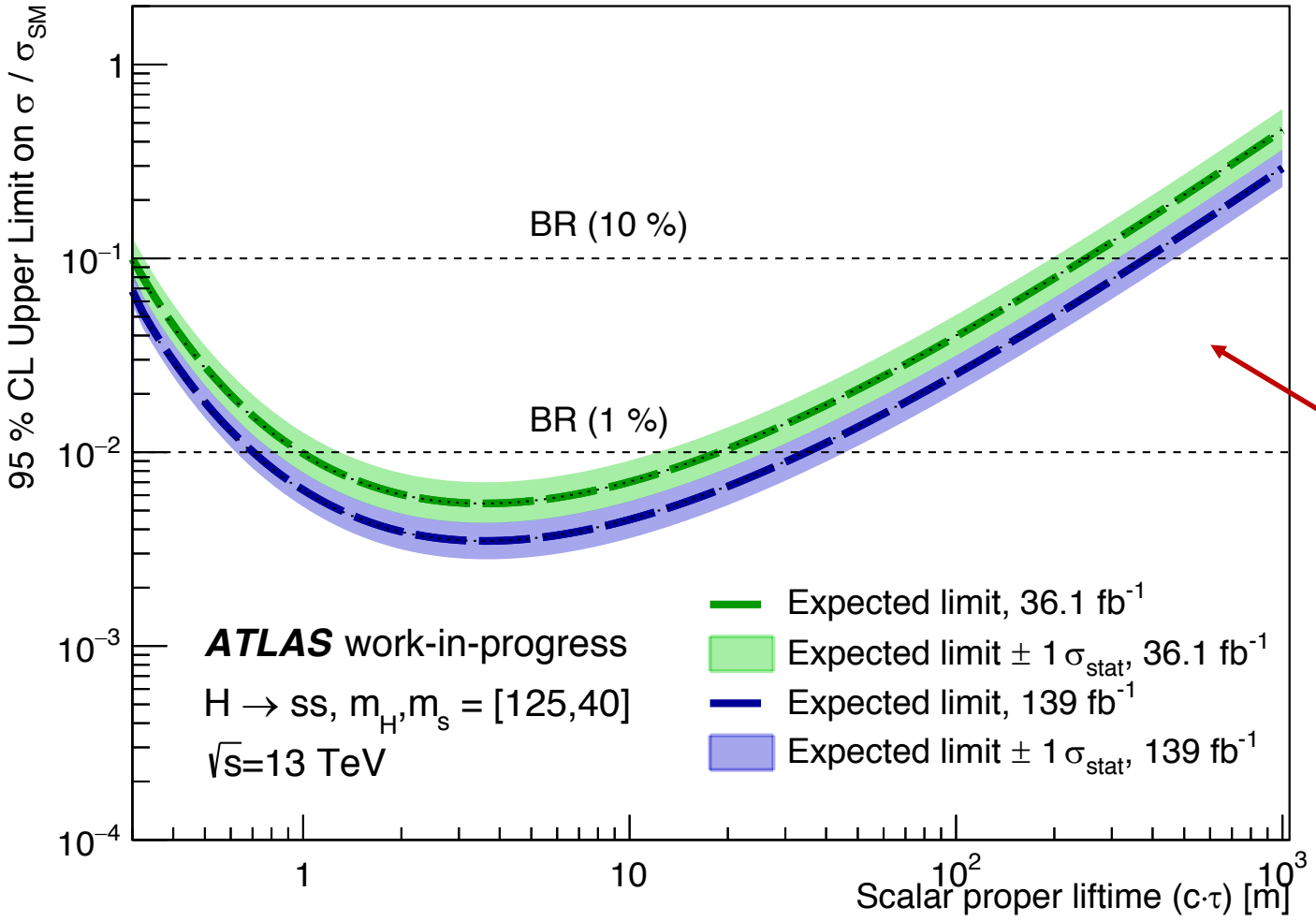


Difference becomes noticeable for heavy LLPs

Lower β means an overall LOWER vertex reconstruction efficiency in MS

Expected limits for the LLP search in MS

- CLs expected limits at 95% CL could be calculated at different luminosity.

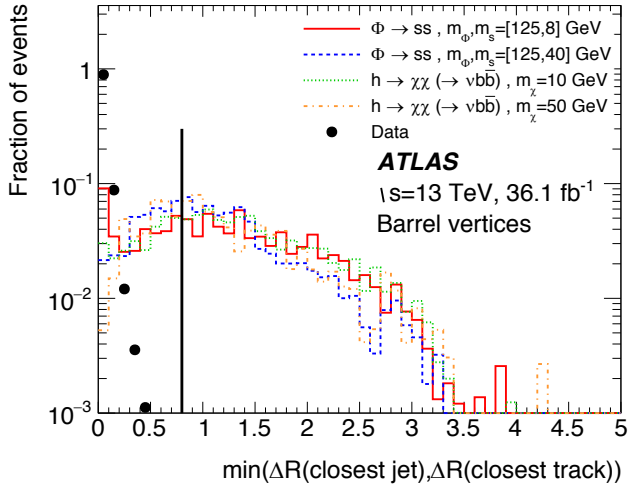


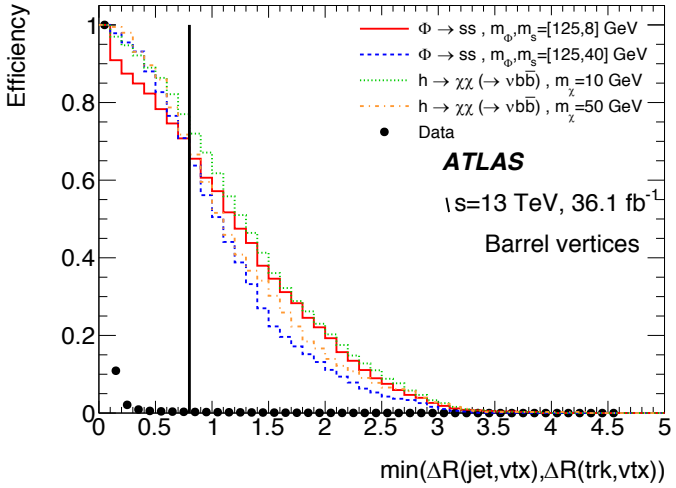
95% CL Limits for H→ss process by requiring only one displaced vertex in the muon spectrometer.

Losing sensitivity due to the decays outside the detector

Looking for new background discriminating variables

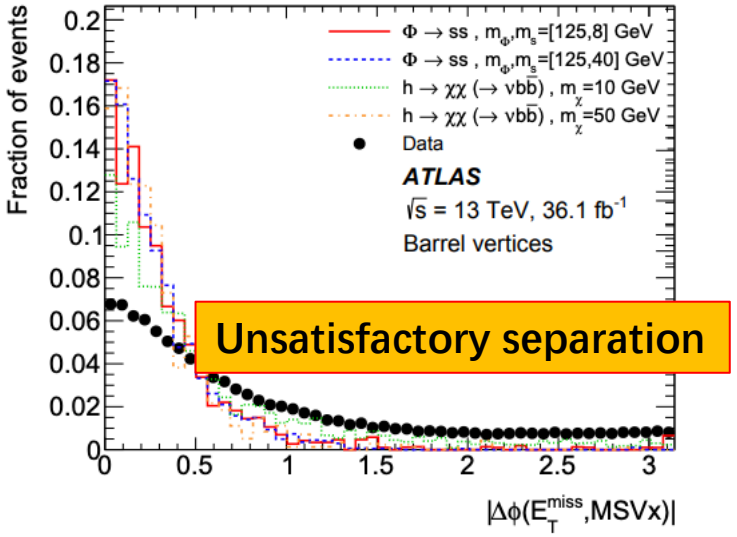
- min(ΔR(closest jet), ΔR(closest track)) is a very good ABCD variable. 😀

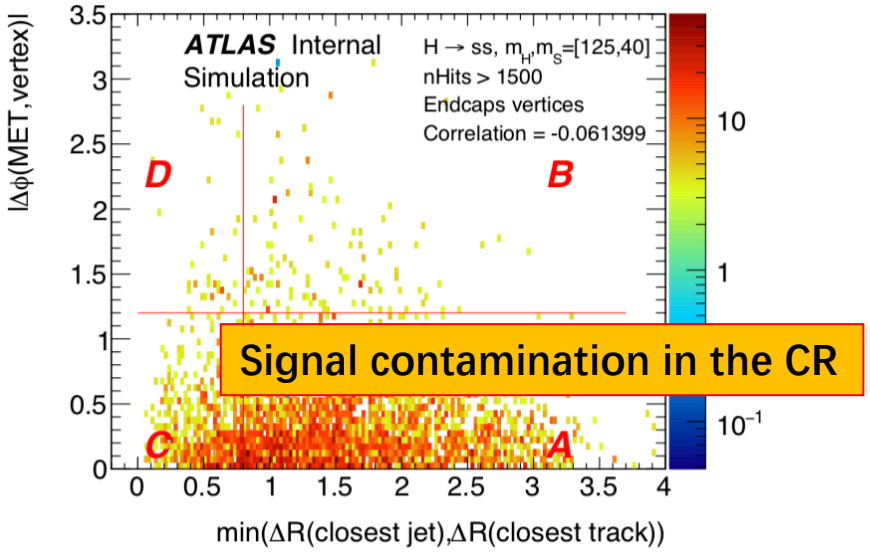




arXiv: 1811.07370

- Δϕ(MET, MSVertex) used in the 1 vertex + MET analysis has several cons there: ☹

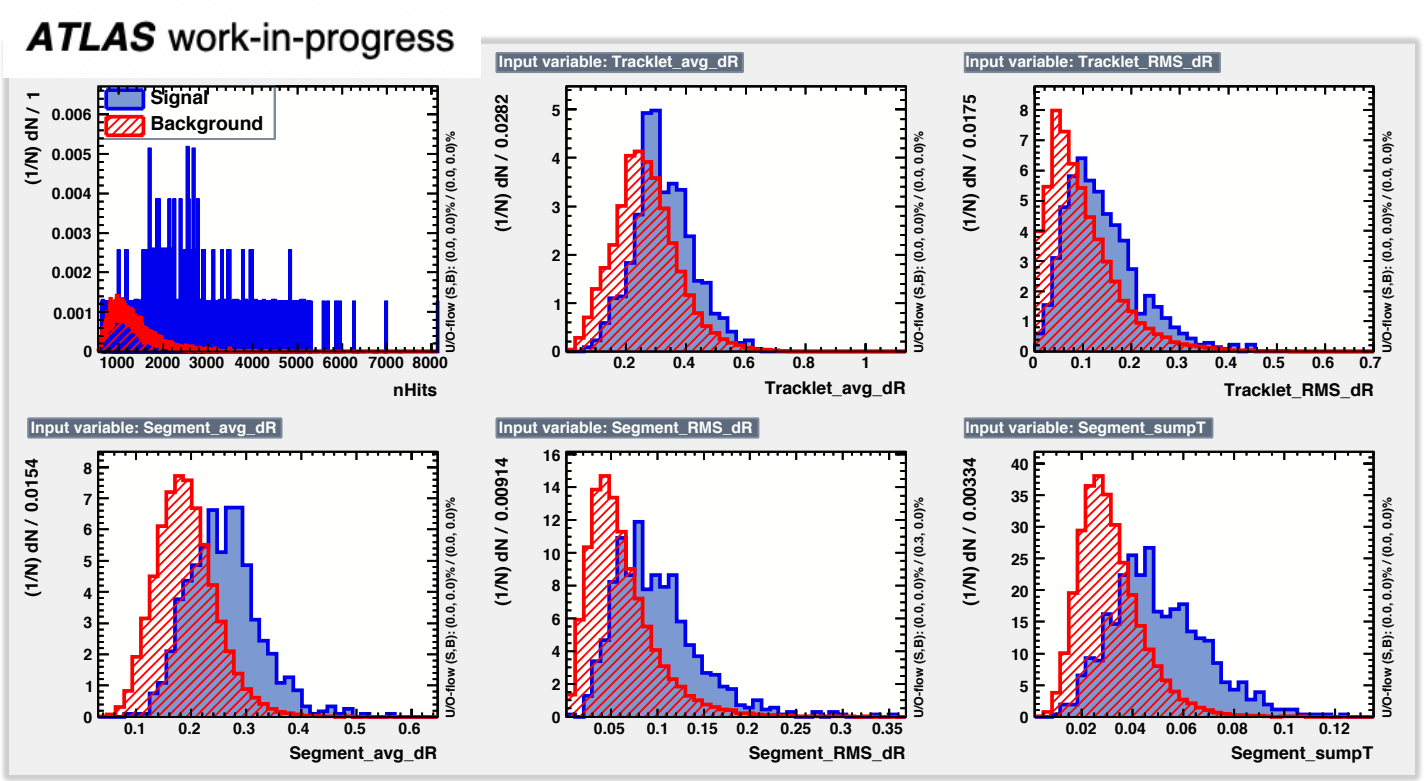




Looking for new background discriminating variables

- New variables should have small correlation with min(ΔR(closest jet), ΔR(closest track)). Variables that are not closely related to jet or track may be good candidates, like:
  - MDT, RPC, TGC hits
  - Tracklet related variables
  - Muon segment related variables
  - …

These will be considered as inputs for BDT



A preliminary list used for MVA:

- nHits
- Tracklet_avg_dR
- Tracklet_RMS_dR
- Segment_avg_dR
- Segment_RMS_dR
- Segment_sumpT
- …

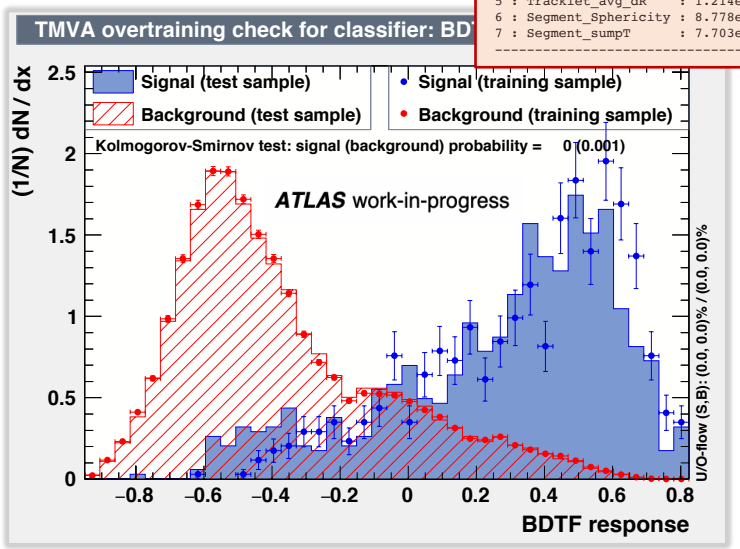
Thanks to Cristiano Alpigiani for the MVA plots!

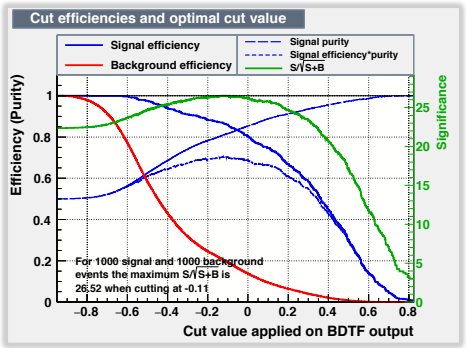
Looking for new background discriminating variables

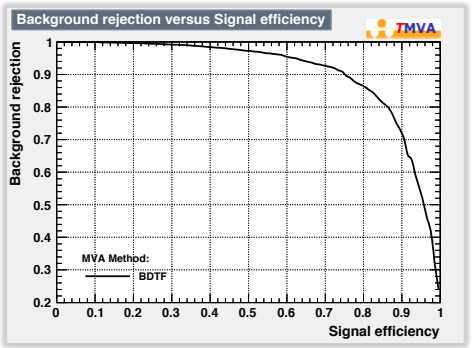
- Preliminary BDT results (mH =125, mS = 40)

Barrel

Rank	Variable	Var Importance
1	nHits	2.216e-01
2	Segment_avg_dR	1.957e-01
3	Segment_RMS_dR	1.730e-01
4	Tracklet_RMS_dR	1.234e-01
5	Tracklet_avg_dR	1.214e-01
6	Segment_Sphericity	8.778e-02
7	Segment_sumpT	7.703e-02

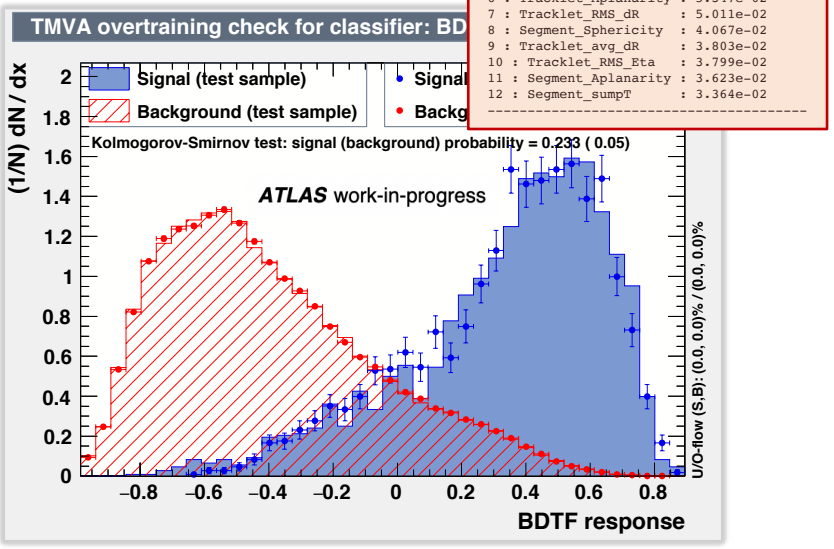


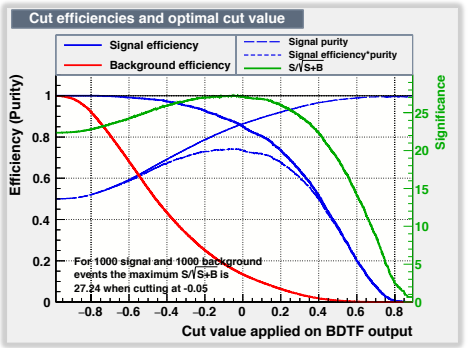


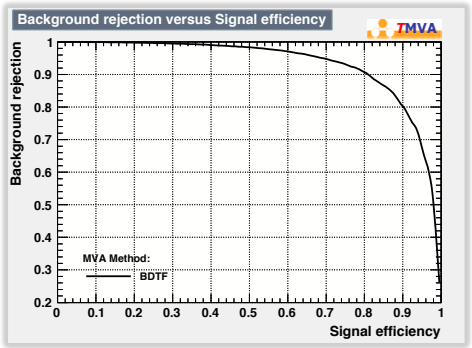


Endcaps

Rank	Variable	Var Importance
1	Segment_meanpT	2.871e-01
2	nHits	1.445e-01
3	Segment_RMS_dR	1.195e-01
4	Segment_RMS_Eta	9.717e-02
5	Segment_avg_dEta	6.164e-02
6	Tracklet_Aplanarity	5.347e-02
7	Tracklet_RMS_dR	5.011e-02
8	Segment_Sphericity	4.067e-02
9	Tracklet_avg_dR	3.803e-02
10	Tracklet_RMS_Eta	3.799e-02
11	Segment_Aplanarity	3.623e-02
12	Segment_sumpT	3.364e-02







So far, BDT has shown stronger power than $\Delta\phi$(MET, MSVertex). Need further optimization and validation studies.

Summary

- MC study on the Hidden Sector model has been done. Study on other models like Baryogenesis is ongoing…
- We are searching for new powerful background discriminating variables. Optimization of BDT is ongoing…
- The sensitivity of the MS LLP search is expected to increase with increased luminosity and signal efficiency/background rejection.