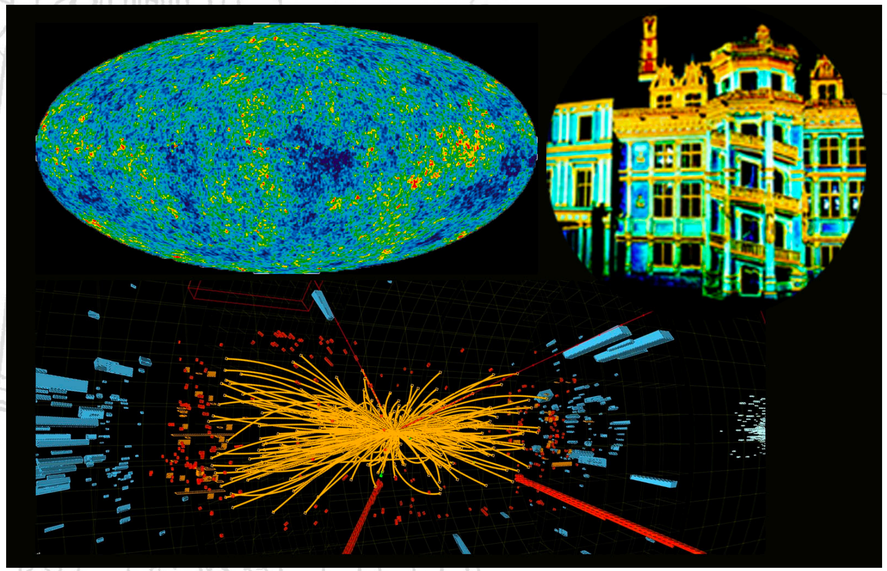


Searches for exotic decays of the Higgs boson as a window to the dark sector with the ATLAS detector

Huacheng Cai
University of Pittsburgh

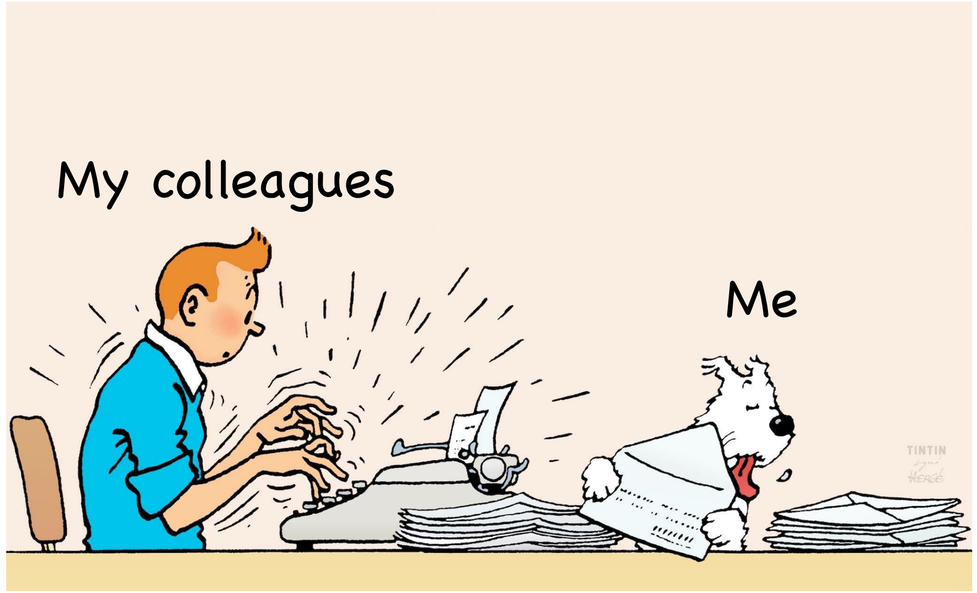
On behalf of the ATLAS collaboration

25th May, 2022
Blois 2022, Loire Valley

University of Pittsburgh

ATLAS EXPERIMENT

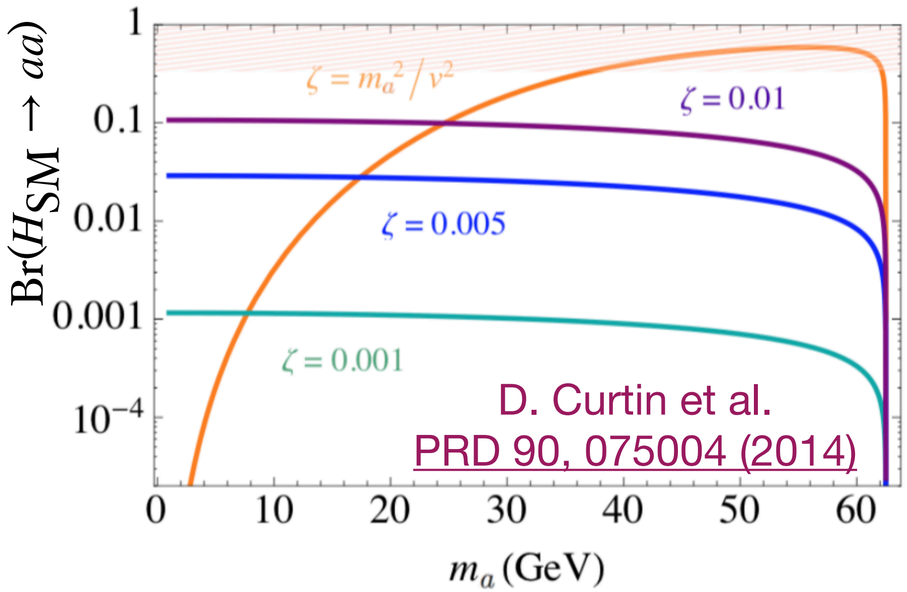
About this talk

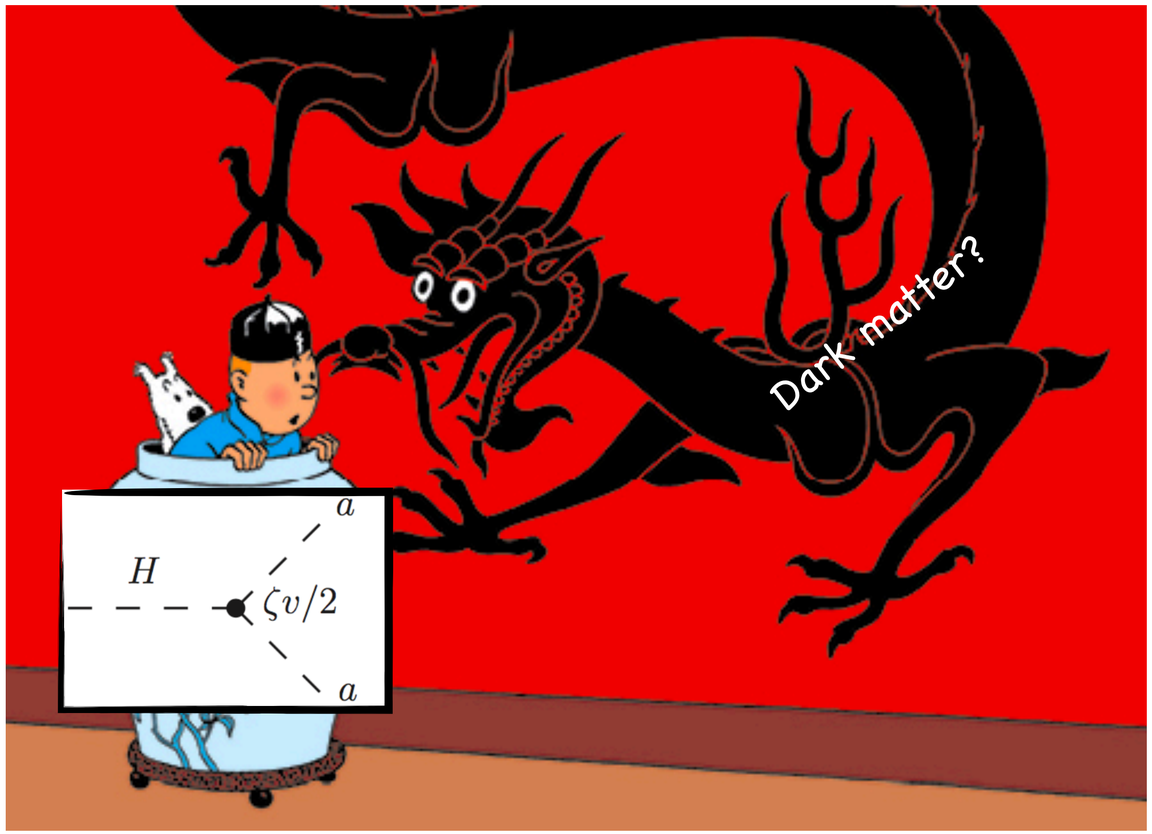


- Searching for **exotic** decays of the Higgs boson.
- Unconventional physics signature in the detector:
  - Collimated, non-isolated objects.
  - Non-prompt, displaced vertex.
  - Detector effects and misidentified objects require data-driven background estimation.
  - Non-collision background.
- All the analyses mentioned today use full Run2 dataset of $\sqrt{s} = 13\text{TeV}$ between 2015-2018, recorded by ATLAS detector, corresponding to 139fb^{-1}.
  - Time limited, just focus on the most recent results…

Something hidden behind the SM Higgs?

- A hidden sector that can decay to SM through interaction with the SM Higgs boson.
- Simple example: two-Higgs-doublet plus singlet model (2HDM+S).
  - Can affect the decay of 125 GeV Higgs if mass range in 0 to $\frac{m_h}{2}$.
  - Four types of coupling to SM fermions, just as 2HDM.
  - Candidate of dark matter mediator.

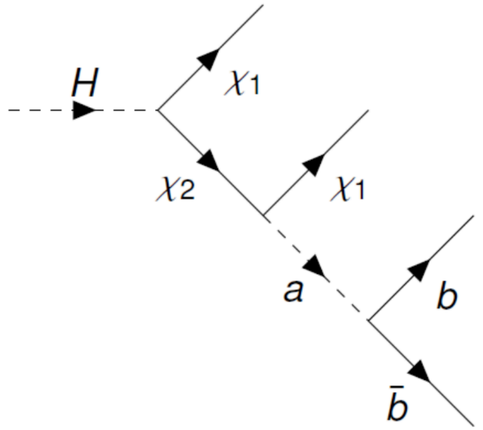


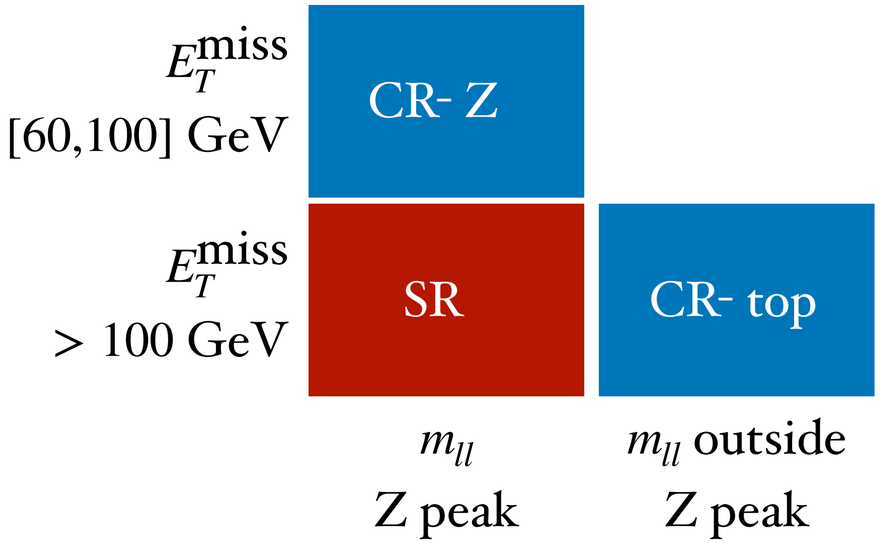


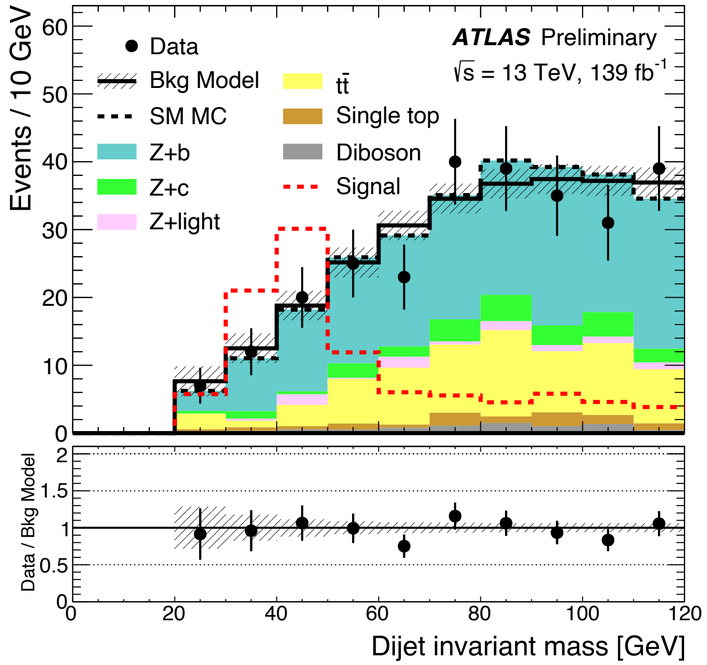
Higgs to $bb + E_T^{miss}$

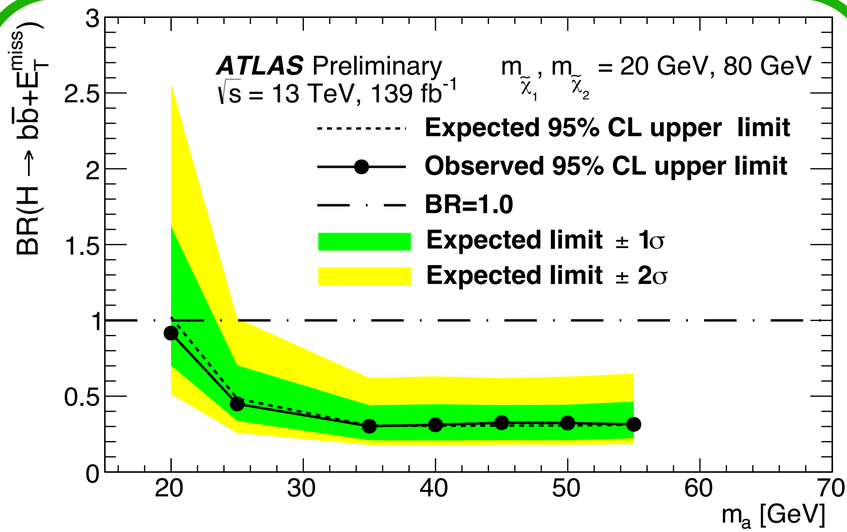
JHEP 01 (2022) 063

- Targeting the phase space near the Peccei-Quinn (PQ) symmetry limit (NMSSM).
- Focus on the ZH associated production.
  - Where Z decays to a pair of electrons or muons.
- Select events with OS/SS lepton pair, large E_T^{miss} and at least one b-tagged jet.
- Search in the m_{jj} spectrum to see if any excess over the bkg. estimation.







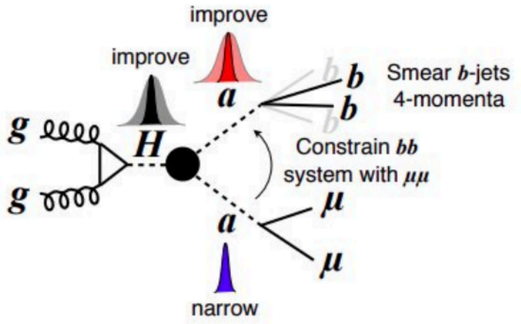


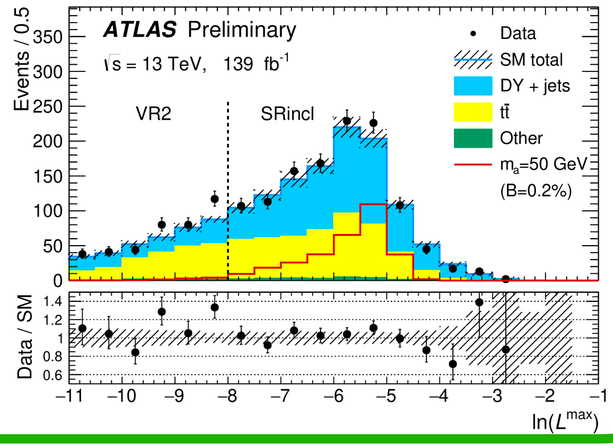
Branching ratio limit set for different (χ_1, χ_2) combinations.

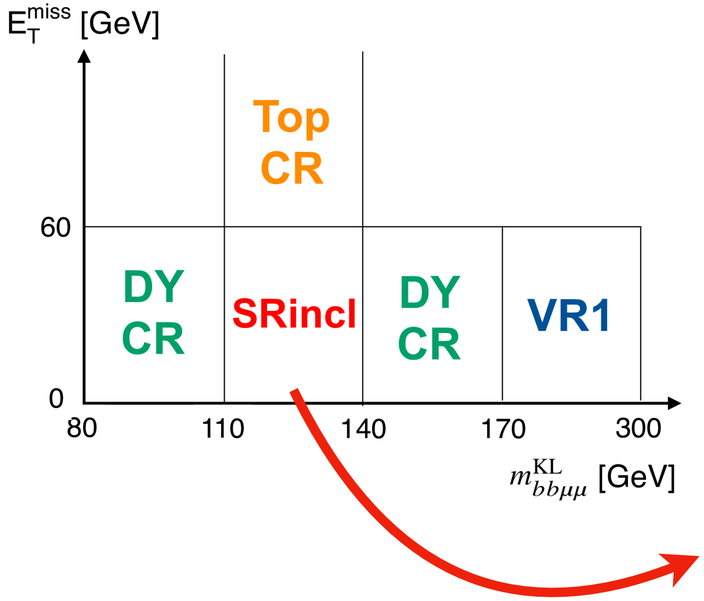
Higgs to $bb\mu\mu$

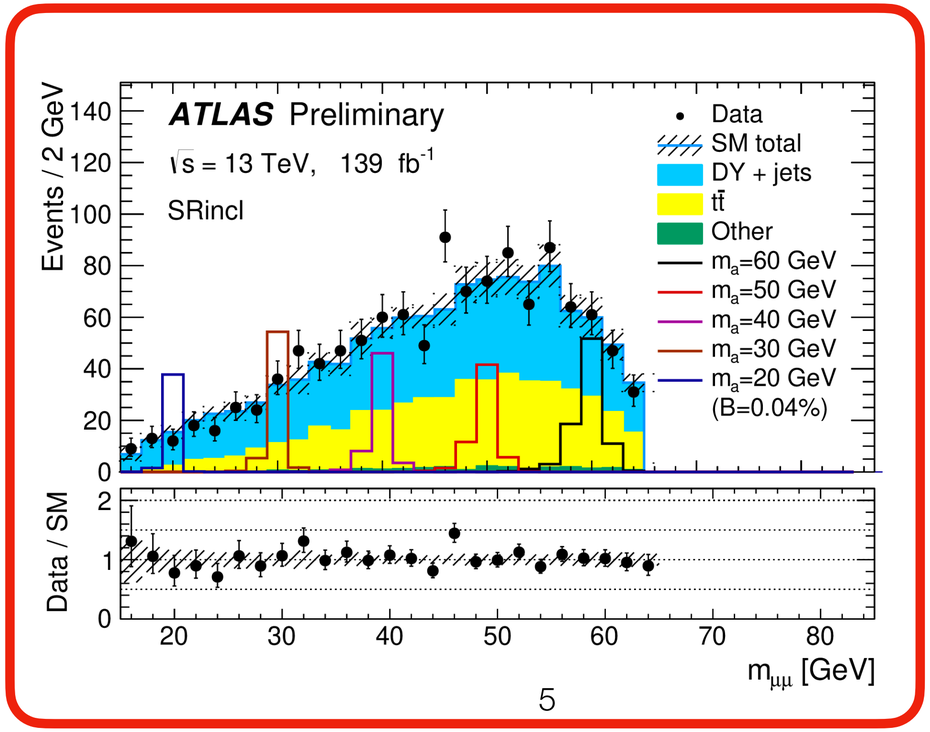
Phys. Rev. D 105 (2022) 012006

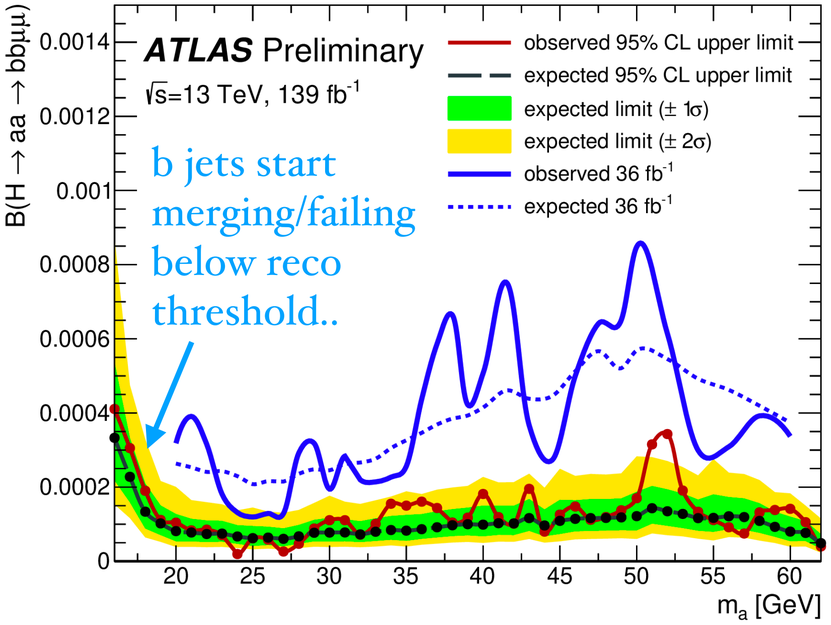
- Benefit from large Br($a \to bb$) and clean $a \to \mu\mu$ signature.
- Constrain m_{bb} and $m_{\mu\mu}$ in a kinematic-likelihood (KL) fit.
  - Cut on $\ln(L^{\max}) > -8$ to select event with $m_{bb} \approx m_{\mu\mu}$.





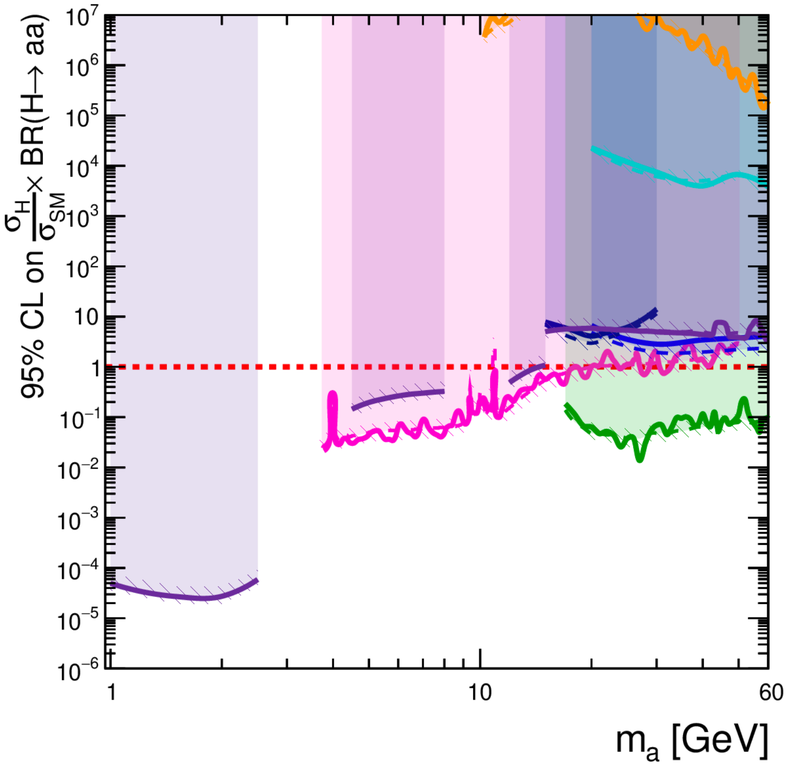


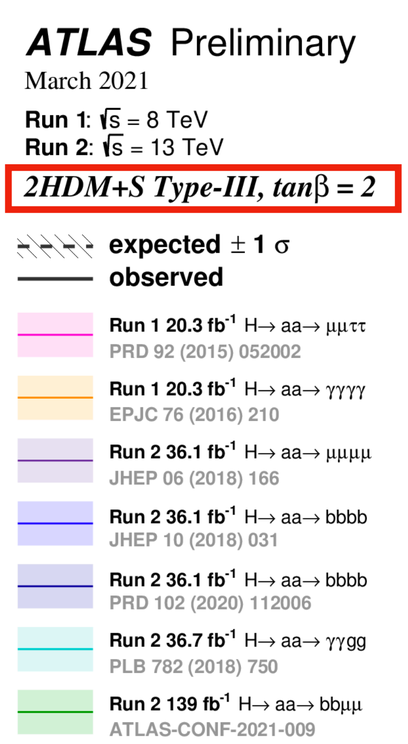


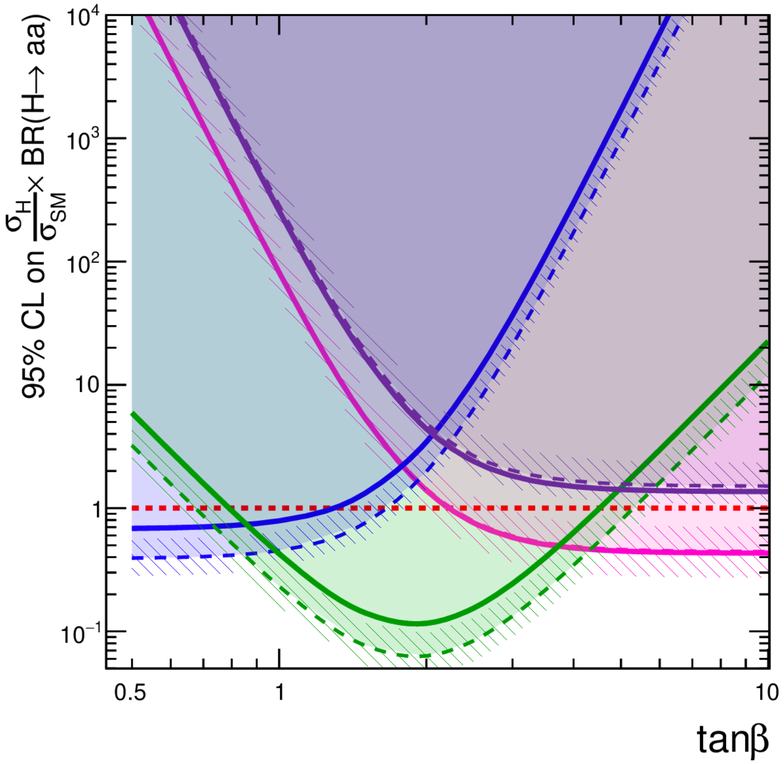


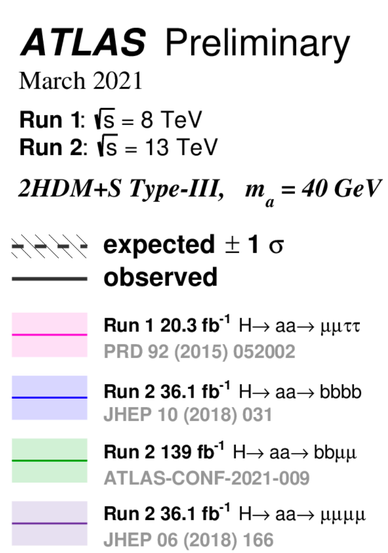
Summary of 2HDM+S

ATL-PHYS-PUB-2021-008





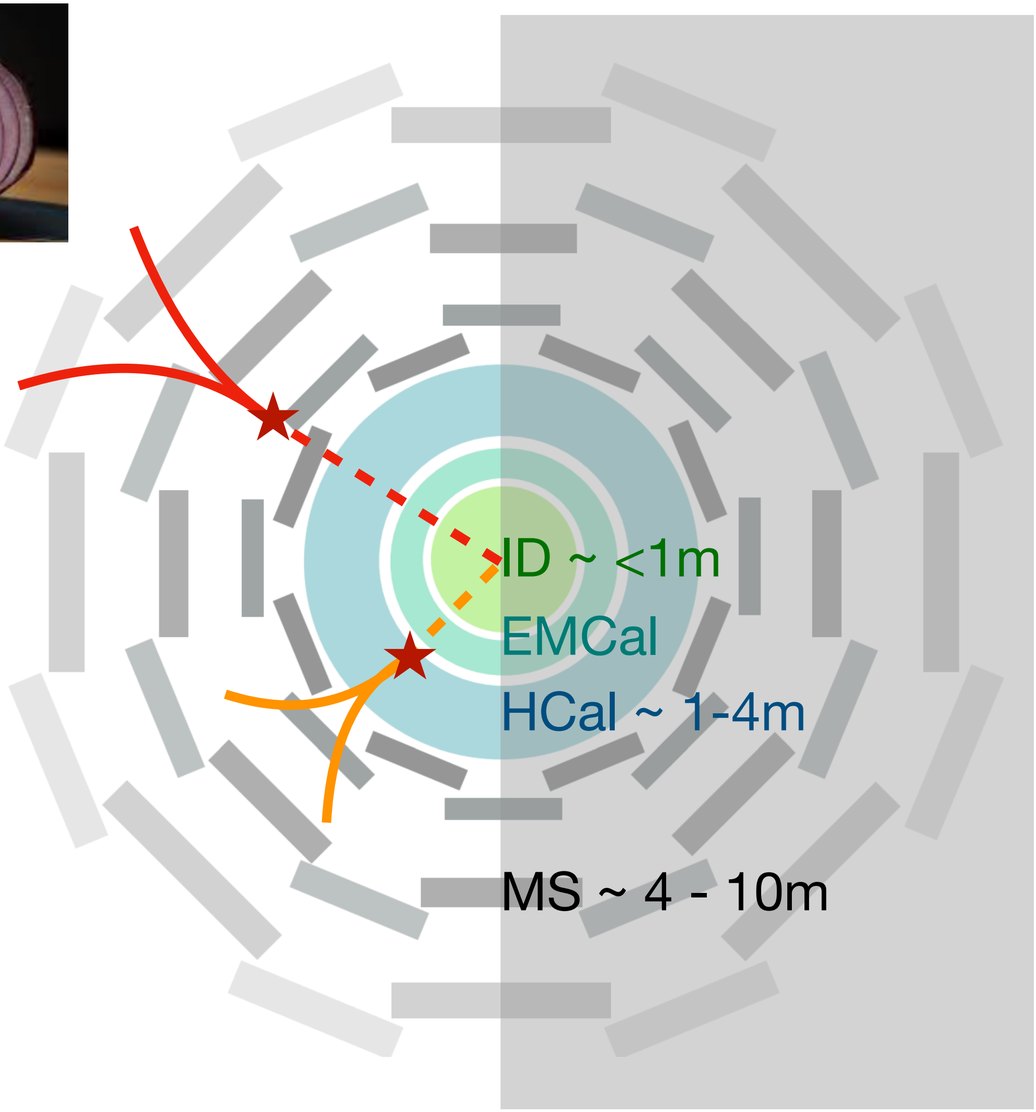


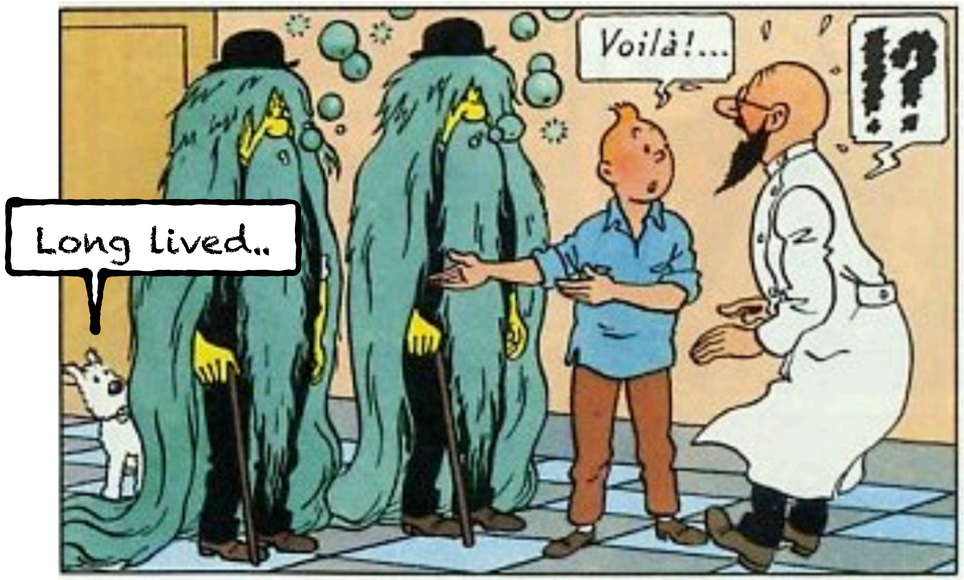


- Model independent limits translated to limits of Br($H \rightarrow aa$) under the assumption of each particular 2HDM+S scenario.
- Exclusion power differs by channels/analyses at different tan β.

What if it's a long lived particle (LLP)?

- No much constraint on the lifetime τ.
- LLP predicted by many BSM models:
  - Including SUSY, little Higgs, extra dimensions..
- Majority of the Run 1 analyses focusing on prompt particles.
  - Lots of work in non-standard reconstruction, trigger alg, etc..

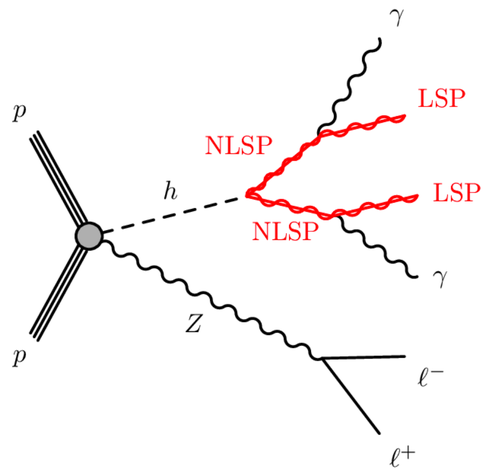


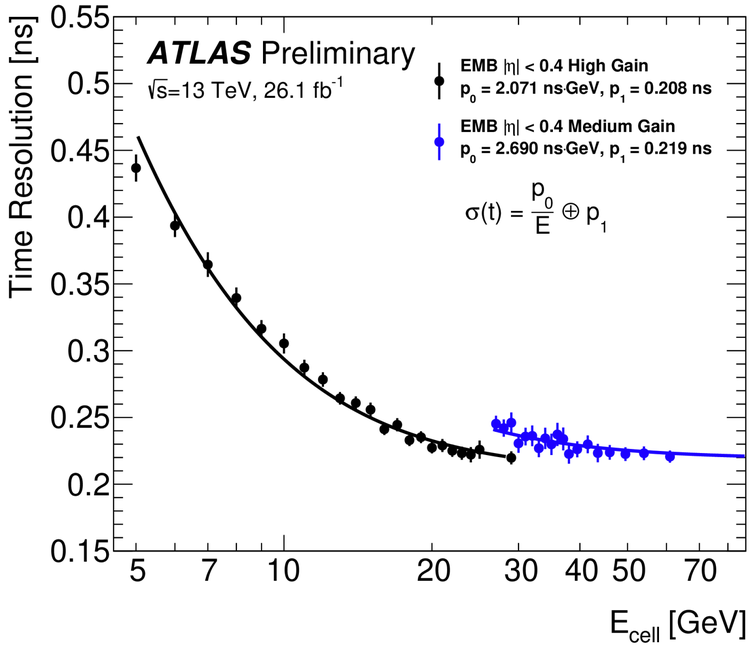


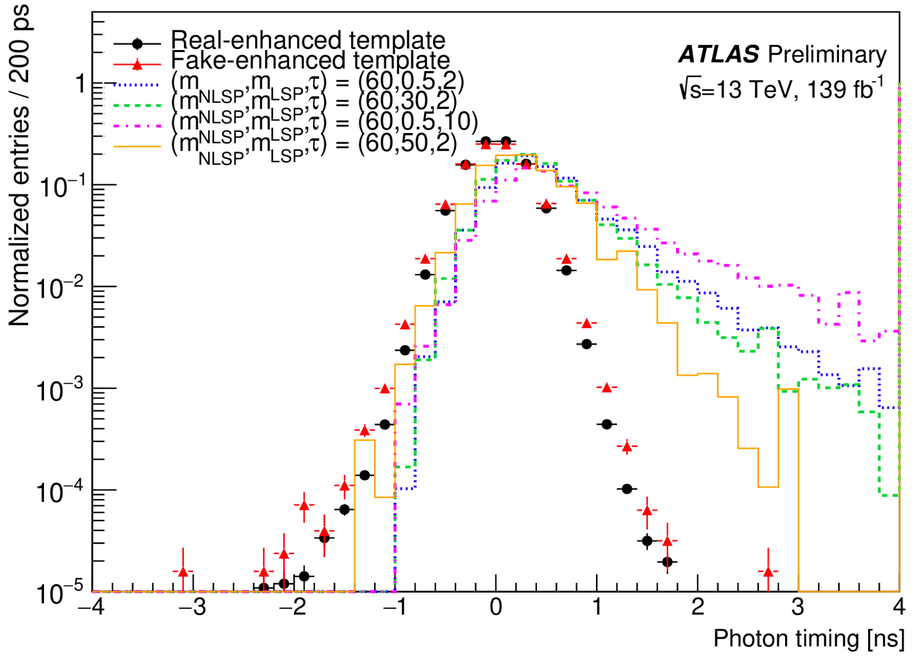
Displaced photons

ATLAS-CONF-2022-017

- Targeting model: Higgs decay to a pair of NLSP(long lived), each decays into a γ + LSP.
- Using the ATLAS EMCal (Liquid Argon calorimeter) to measure precisely the arrival time and trajectory of the photons.
  - Calibrated by $Z \rightarrow ee$ events recorded in 2018, for 2 different gain selections in LAr.
  - Excellent timing resolution in LAr calorimeter!
- Background: mixture of photon(real) and jets(fake), mixture factor fitted as a nuisance parameter.

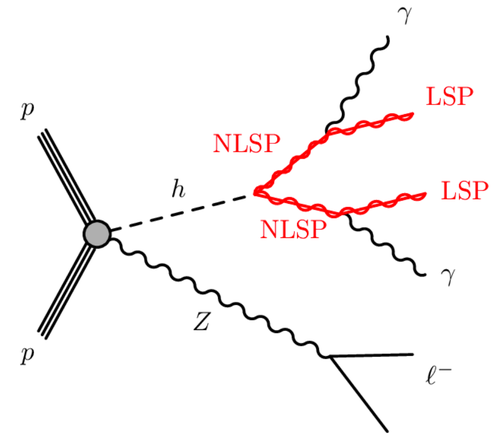




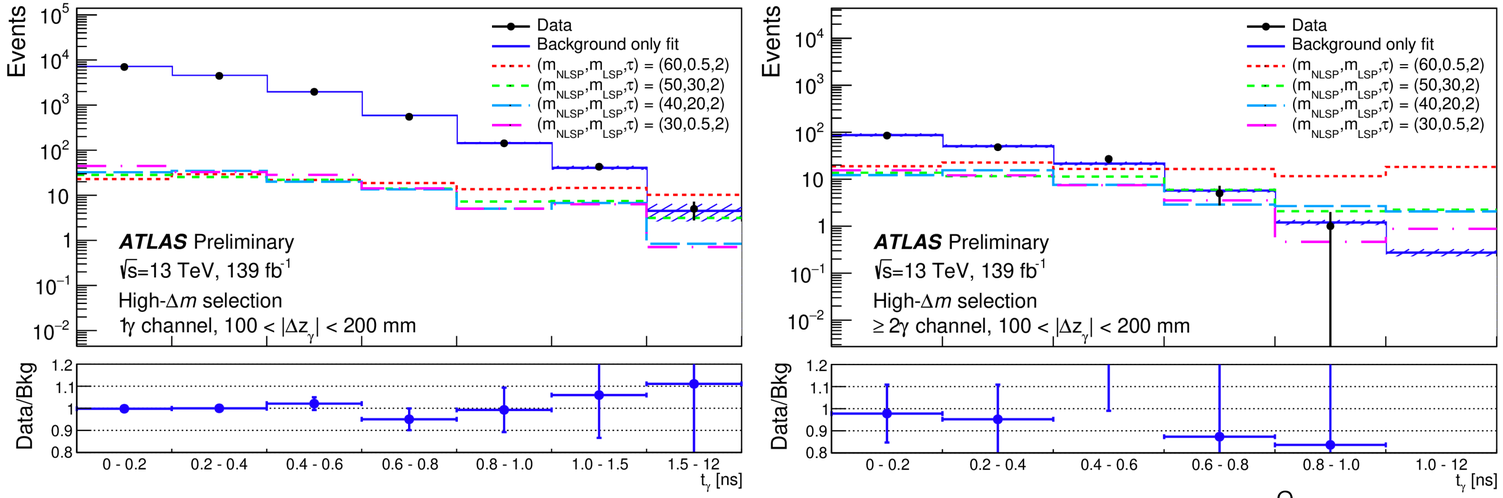


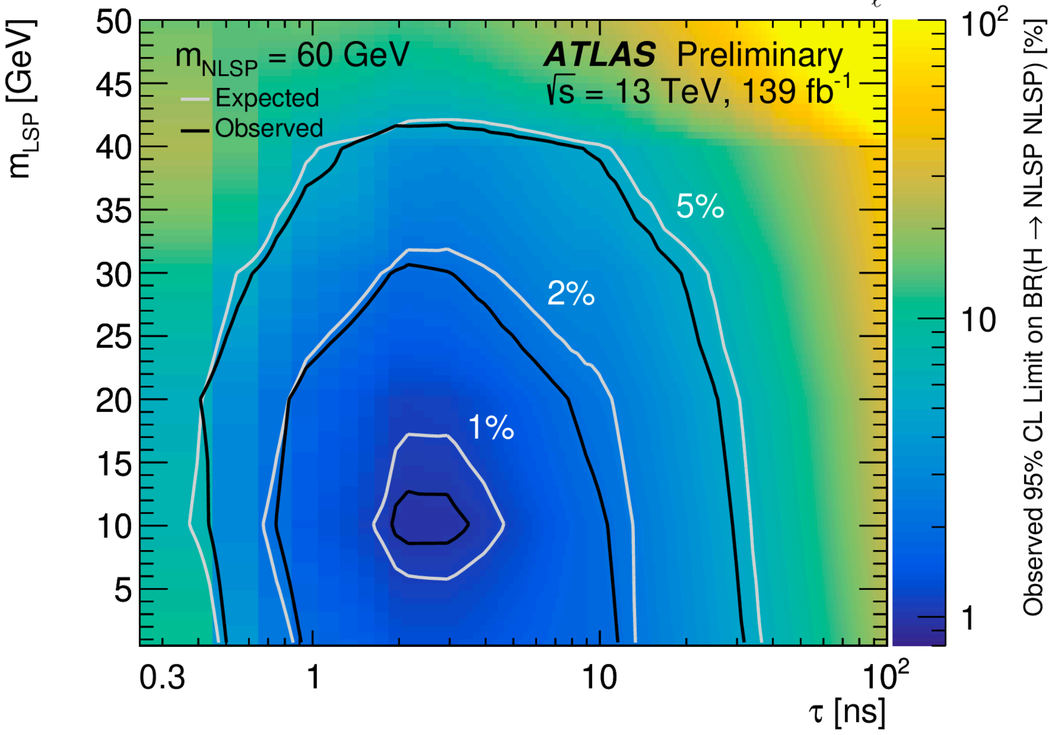
Displaced photons

- Signal regions: 1γ and $\geq 2\gamma$, low or high Δm between LSP and NLSP candidate.
  - Better sensitivity of $\geq 2\gamma$ with lower background.
  - Further sliced by different pointing parameter $|\Delta z_\gamma|$.
- Final discrimination: arrival timing of the photon.



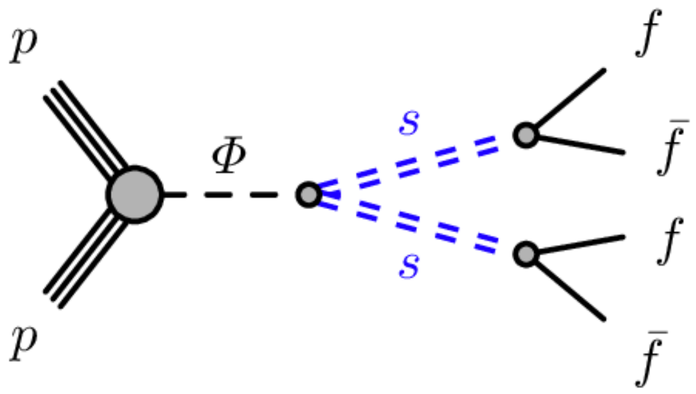
Region	Requirements	Expected	Observed	σ^{95}_{vis} [fb]
1γ	$1.5 < t_\gamma < 12$ ns, $\lvert\Delta z_\gamma\rvert > 300$ mm	3.8 ± 1.6	4	0.042
$\geq 2\gamma$	$1.0 < t_\gamma < 12$ ns, $\lvert\Delta z_\gamma\rvert > 300$ mm	0.28 ± 0.04	0	0.022
$\geq 1\gamma$		4.1 ± 1.7	4	0.041

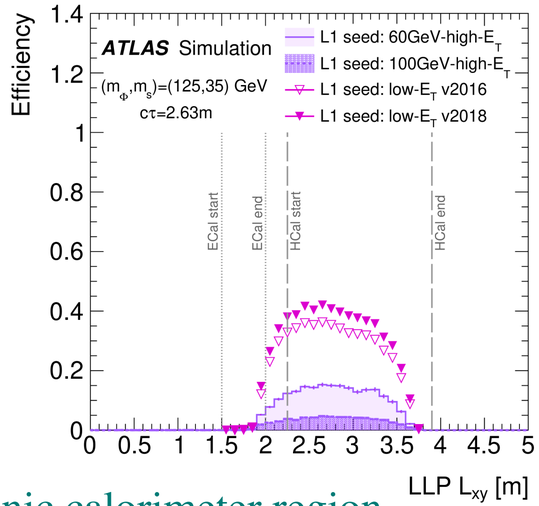


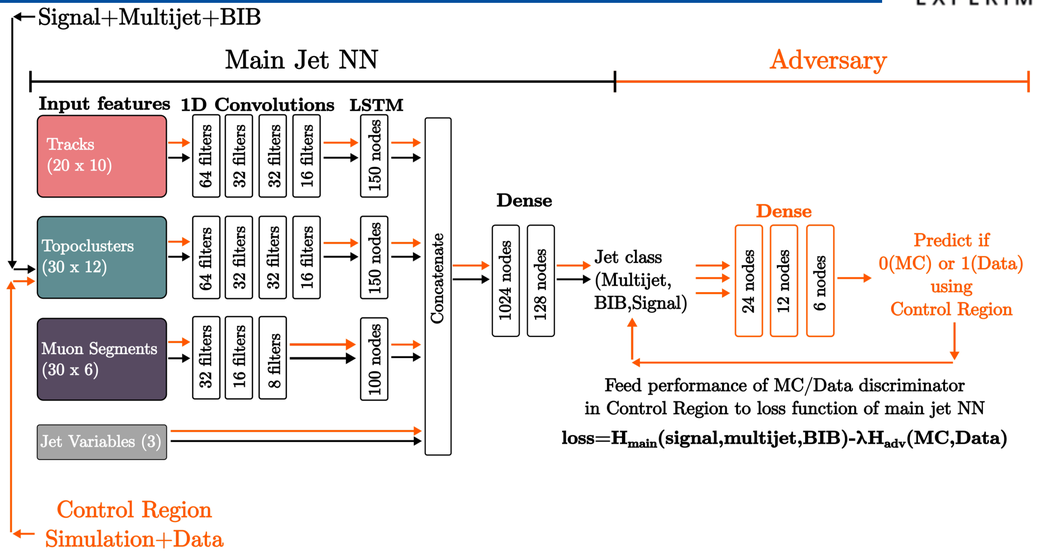


Displaced jets in HCal region

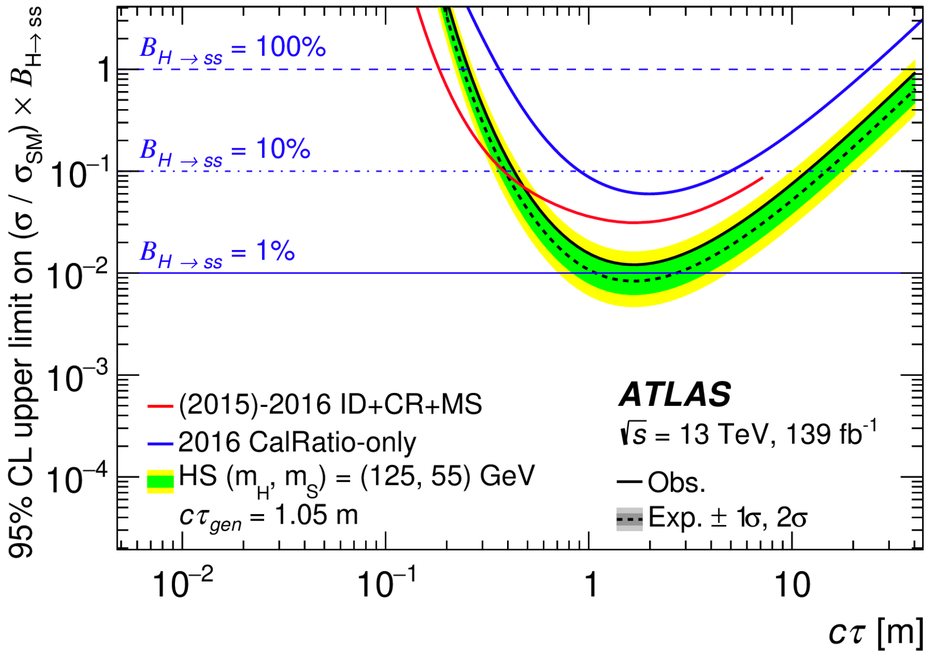
arXiv: 2203.01009





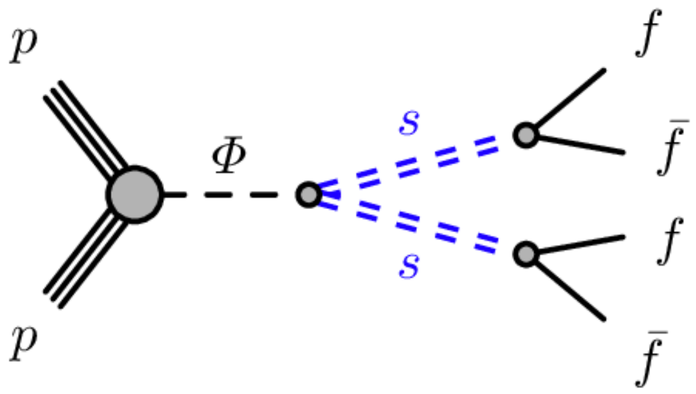


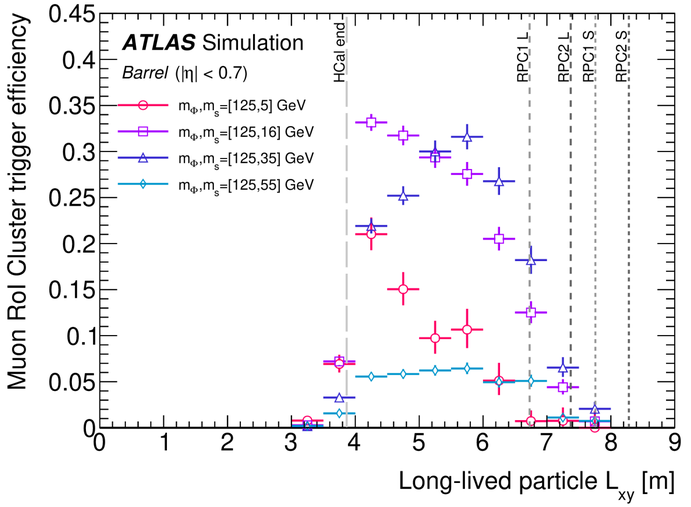
- Targeting LLP decaying to jets within the hadronic calorimeter region.
  - Using custom triggers for neutral particles into jets in the HCal.
- Dominant background: SM multijet events.
  - Using a fully data-driven ABCD method to estimate the yield.
    - Per-jet NN feeds into the event level BDT, as one of the discriminators for ABCD method.
    - Second discriminator is ΔR between jet and tracks.
- Secondary background: non-collision background (cosmic ray, beam-induced background).
  - Adversarial neural network trained to identify displaced jets, mitigating effects from potential mis-modelling in the final systematics.

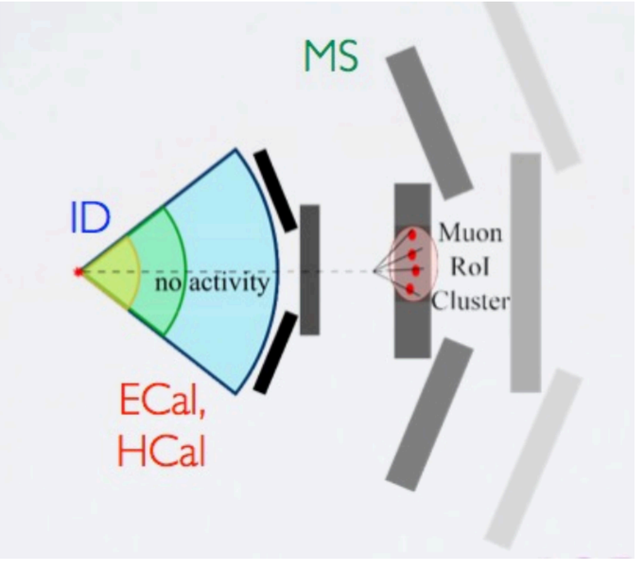


Displaced jets in MS region

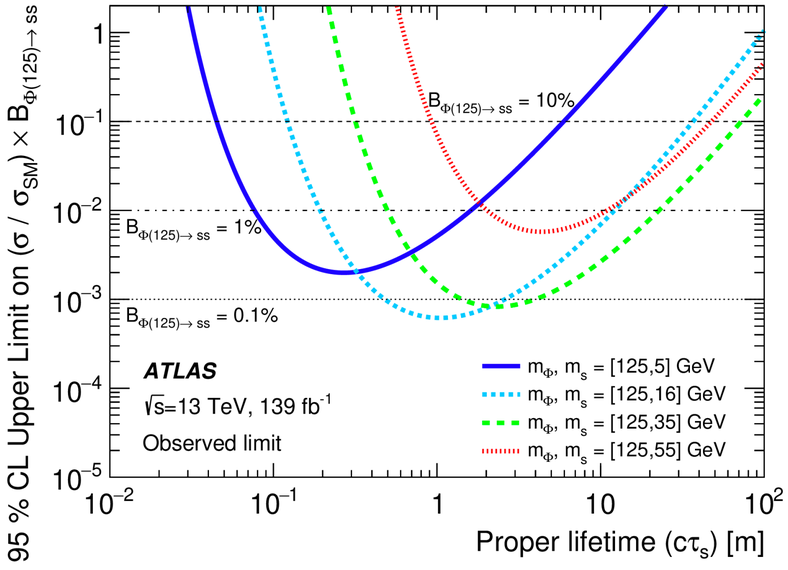
arXiv:2203.00587







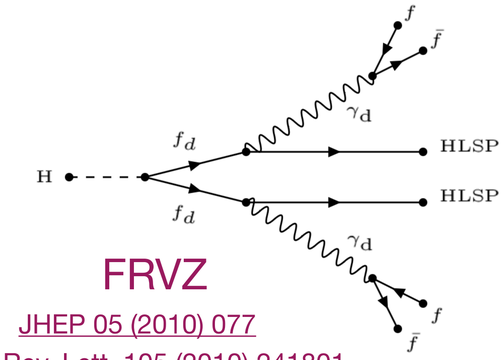
- Targeting LLP decaying to jets within the muon spectrometers.
  - In the muon RoI Cluster trigger, makes clusters of RoIs resulting from the hadronic decay products.
- Requiring two displaced MS vertices.
  - Reconstructed by a custom vertex reco algorithm.
  - Significantly reduce most of the background.
  - Further reduction via requiring the $\Delta R \geq 1.0$ between two DVs.
- Residual background estimated by a fully DD method.



Displaced collimated DPJs

ATLAS-CONF-2022-001

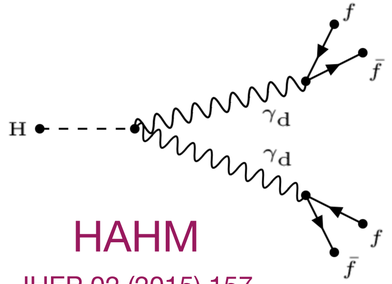
- Select events with collimated dark photon jets(DPJ) reconstructed in calorimeter or MS.
  - SRs designed for different caloDPJ and μDPJ multiplicities (2-0, 1-1, 0-2).
- Focus on ggF/*WH* production mode.
- Different taggers used for each type of background.
  - DNN for cosmics, convolutional NN for BIB and QCD.
- Fully data-driven ABCD method is used for background estimation.



FRVZ

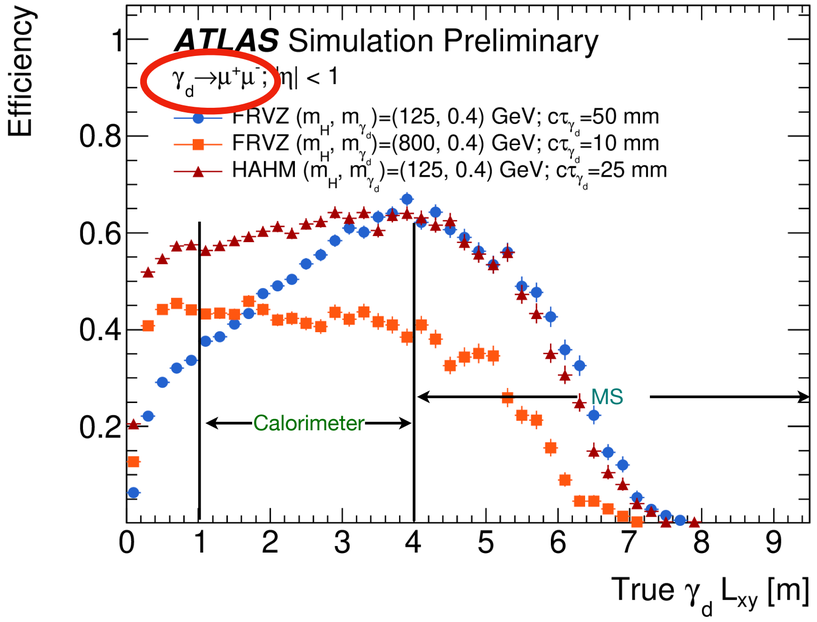
JHEP 05 (2010) 077

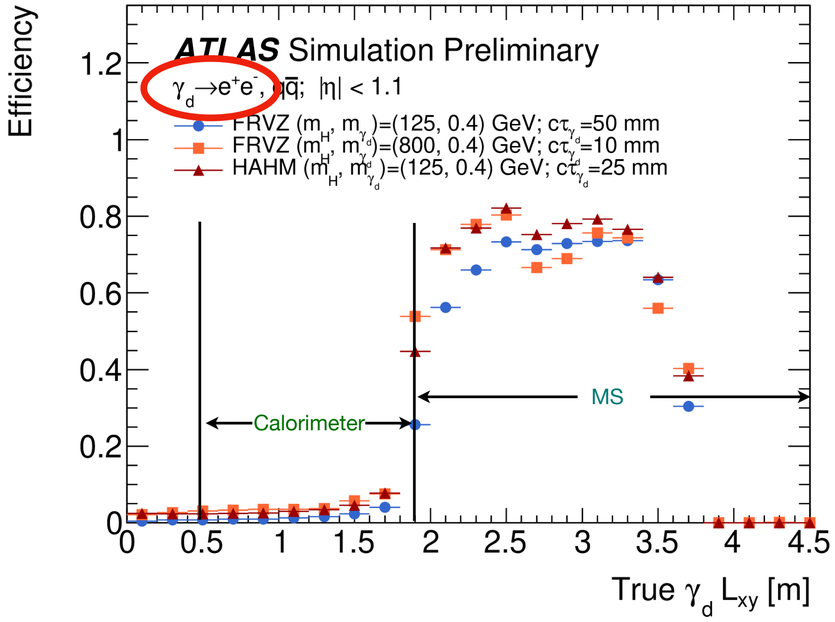
Phys. Rev. Lett. 105 (2010) 241801



HAHM

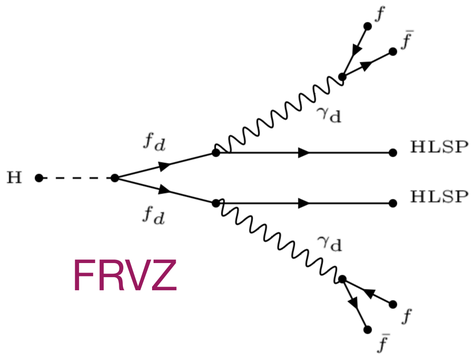
JHEP 02 (2015) 157



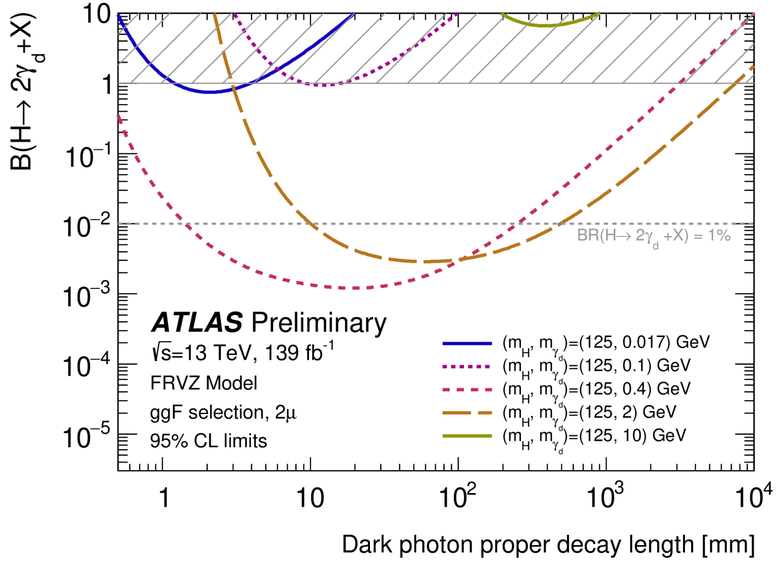


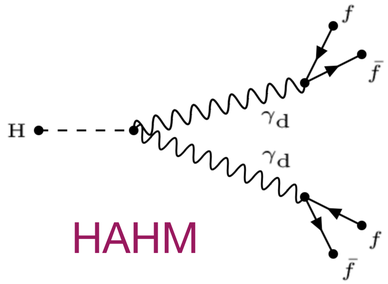
Displaced collimated DPJs

ATLAS-CONF-2022-001



FRVZ





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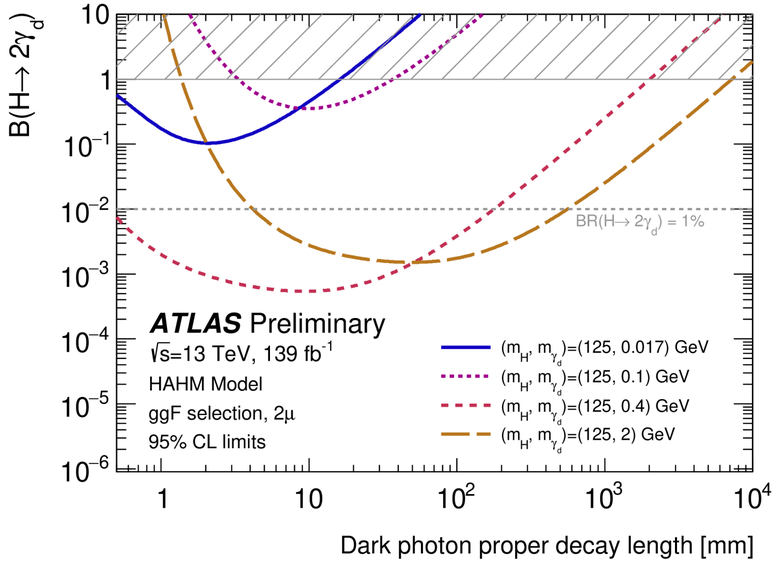
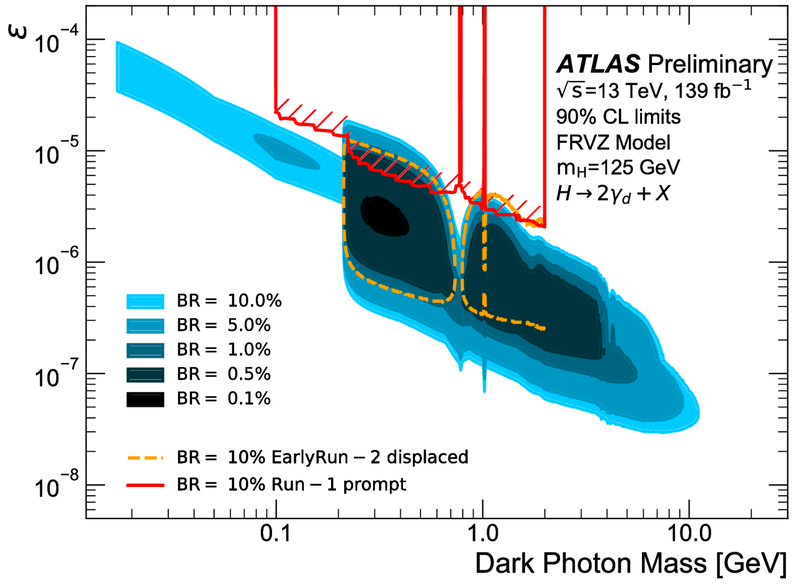
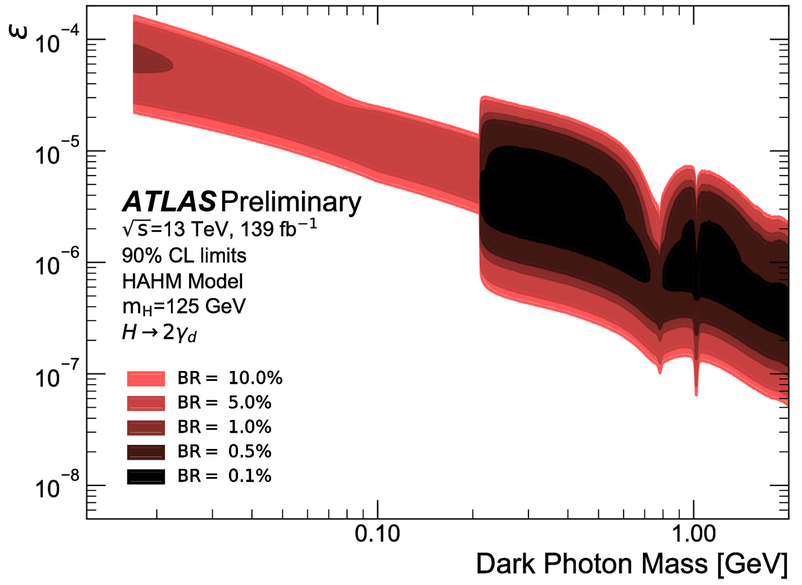
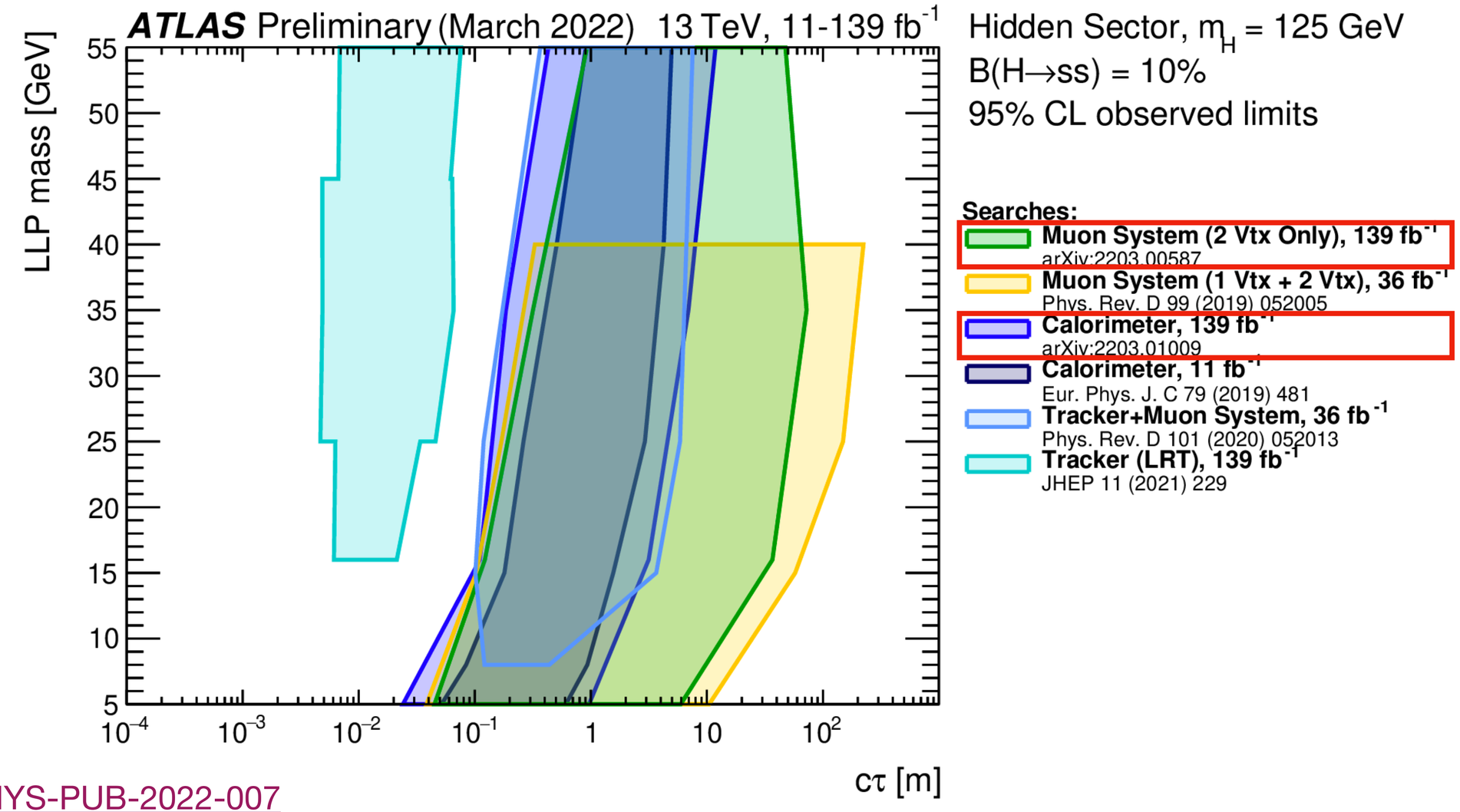




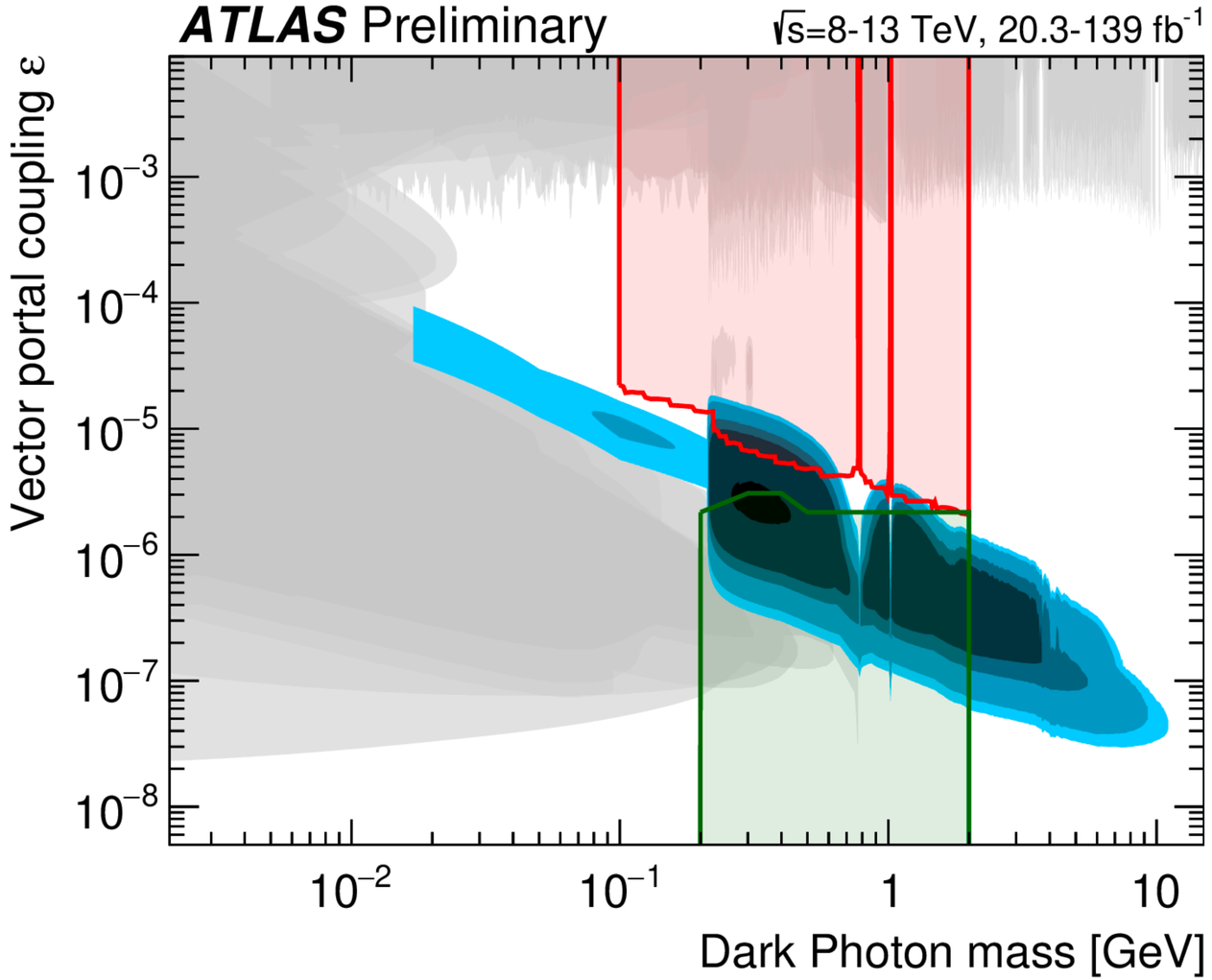


Summary of searches with displaced vertices



ATL-PHYS-PUB-2022-007

Summary of searches for dark photons



FRVZ Model

$H \to 2\gamma_d + X$

m_H = 125 GeV

90% CL observed limits

Displaced (139 fb^{-1})
ATLAS-CONF-2022-001
- BR=10%
- BR=5%
- BR=1%
- BR=0.5%
- BR=0.1%

Prompt (20.3 fb^{-1})
JHEP 02 (2016) 062
- BR=10%

Monojet (139 fb^{-1})
ATL-PHYS-PUB-2021-020
- BR=50%

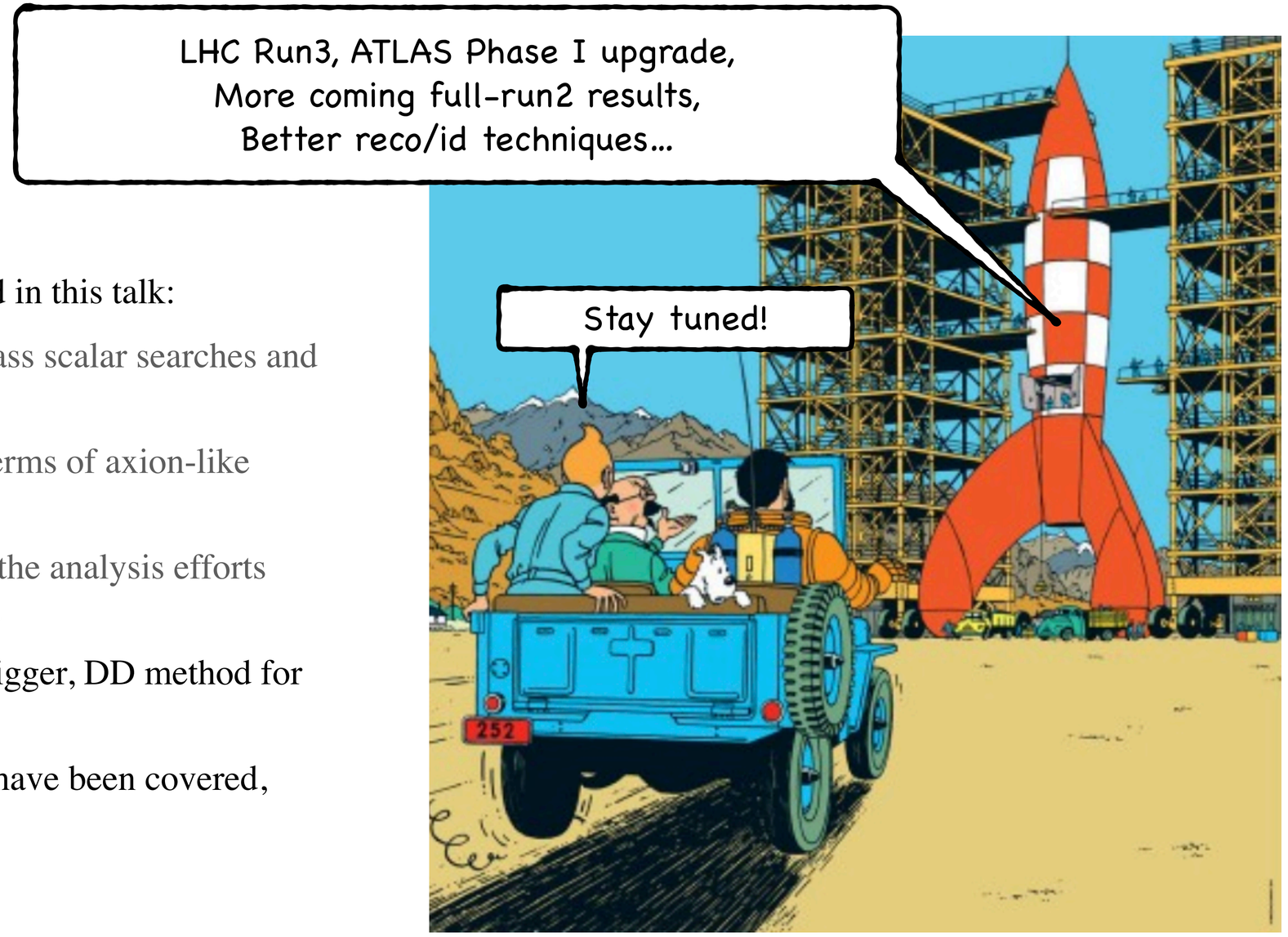
Non-ATLAS searches
JHEP 06 (2018) 004
- Vector-Portal-only limits

Complementarity between the prompt and long-lived:
search for a very long-lived particle decays out of the detector.
[ATL-PHYS-PUB-2021-020]
recast

ATL-PHYS-PUB-2022-007

Conclusions and looking forward..

- Many more BSM Higgs searches not presented in this talk:
  - Such as BSM di-Higgs resonances, low-mass scalar searches and etc.
  - These searches can also be interpreted in terms of axion-like particles (ALPs).
  - Due to the limited time, only small part of the analysis efforts mentioned. See more results here and here.
- Using many techniques such as ML, custom trigger, DD method for optimisation.
- A large parameter space of mass and life time have been covered, much better sensitivity achieved.
  - Still no sign of new physics yet…



Questions?


ANY QUESTIONS?
UH OH, I HAVE A QUESTION.
SHOULD I ASK IT? WHAT IF HE ALREADY ANSWERED IT? IS IT A DUMB QUESTION? AM I GOING TO EMBARRASS MYSELF IN FRONT OF EVERYONE?
MAYBE I SHOULD WAIT UNTIL AFTER THE TALK. DO I REALLY NEED TO ASK IT IN PUBLIC? BUT WHAT IF I'M NOT THE ONLY ONE? SHOULD I DO IT???
YES, CECILIA?
CAN I TAKE THE LEFT OVER COOKIES HOME?
JORGE CHAM © 2013
WWW.PHDCOMICS.COM

Backup slides: Higgs to 4μ

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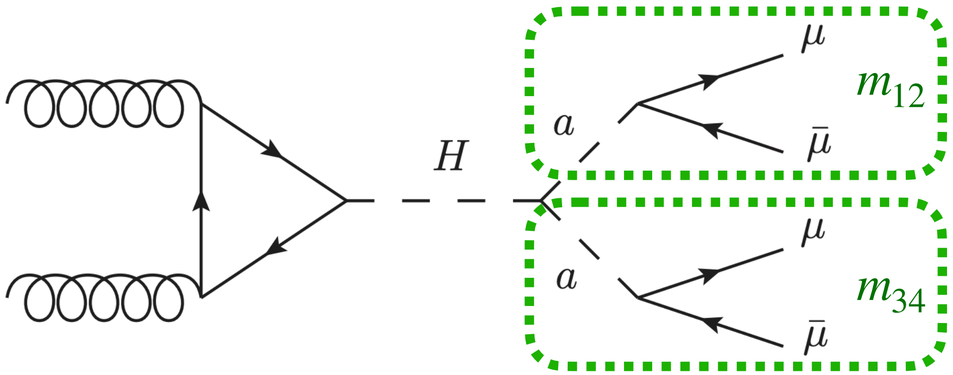
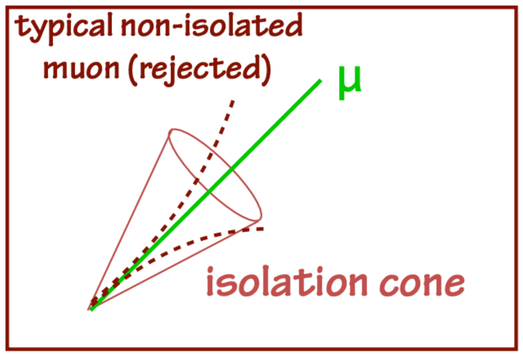
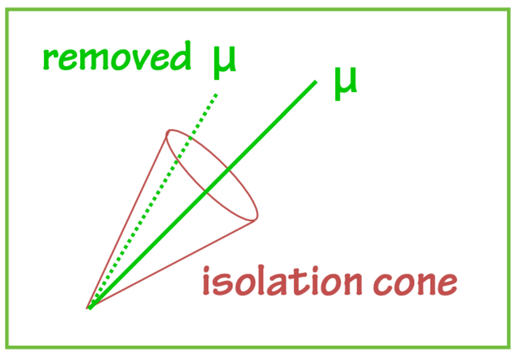
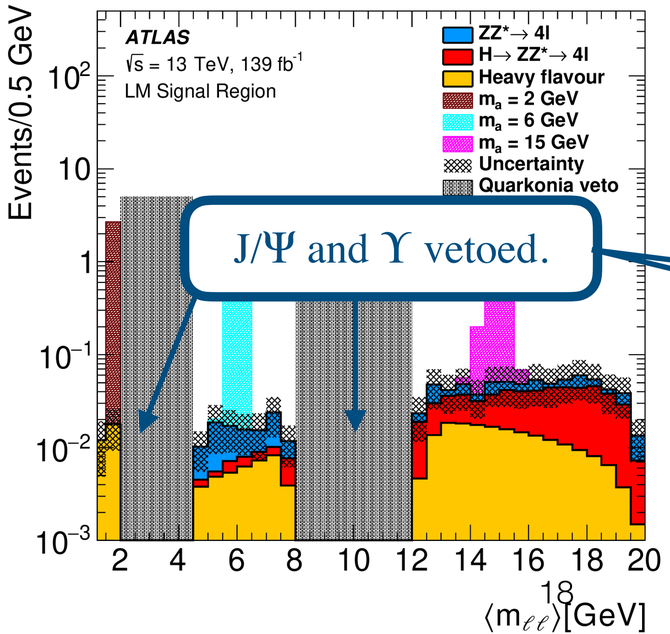
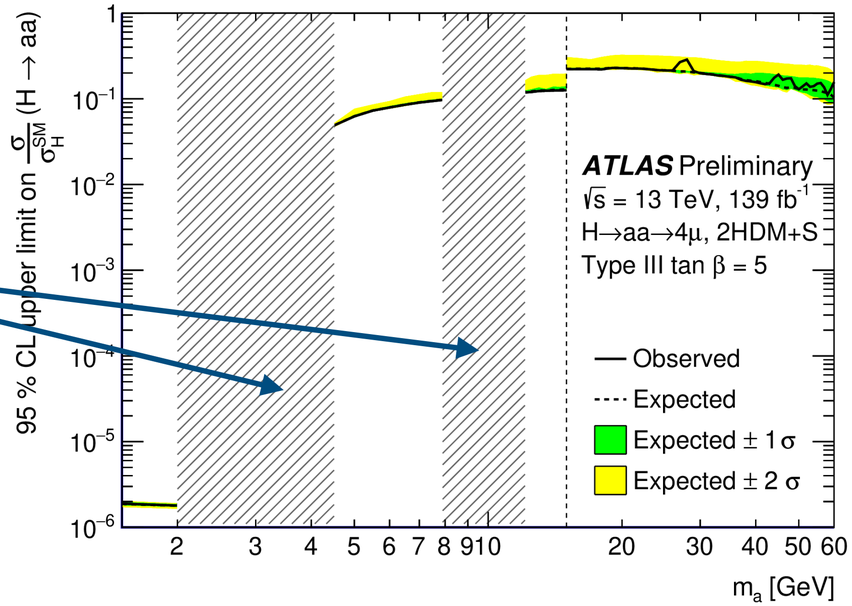


- Targeting a lower m_a, from 1 to 15 GeV.
  - For very low m_a, the two muons almost overlap.
  - Redefine the isolation criteria to account for extra muons in the isolation cone.
- Events selected with dimuon mass compatibility and Higgs mass window.
- Heavy flavour fake background ($b\bar{b}$ double semi-decay to muons) :
  - Estimated by a fully data-driven method using semi-leptonic b enriched template.









Backup slides: Higgs to *bbbb* + displaced vertices

- Using prompt lepton trigger for associated Z.
- Select events with jets exploiting vertices and charged hadron fractions.
  - Using number of displaced vertices as final discrimination, good sensitivity at ≥ 2 DVs.
- Results: 1.30 ± 0.08 (stat.) ± 0.27 (syst.) predicted, with zero data event observed.

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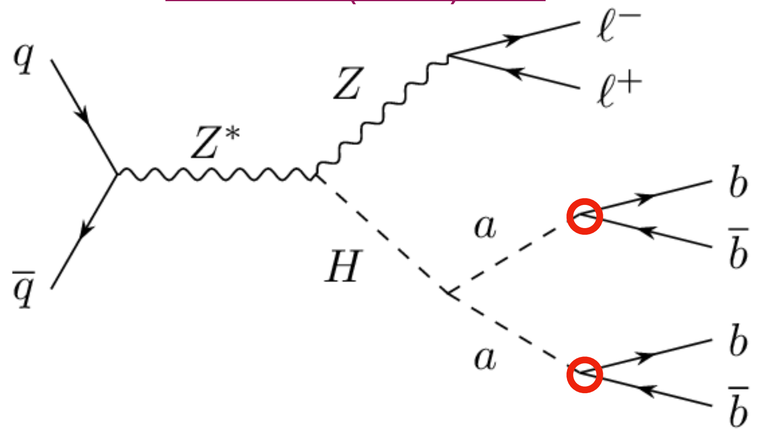
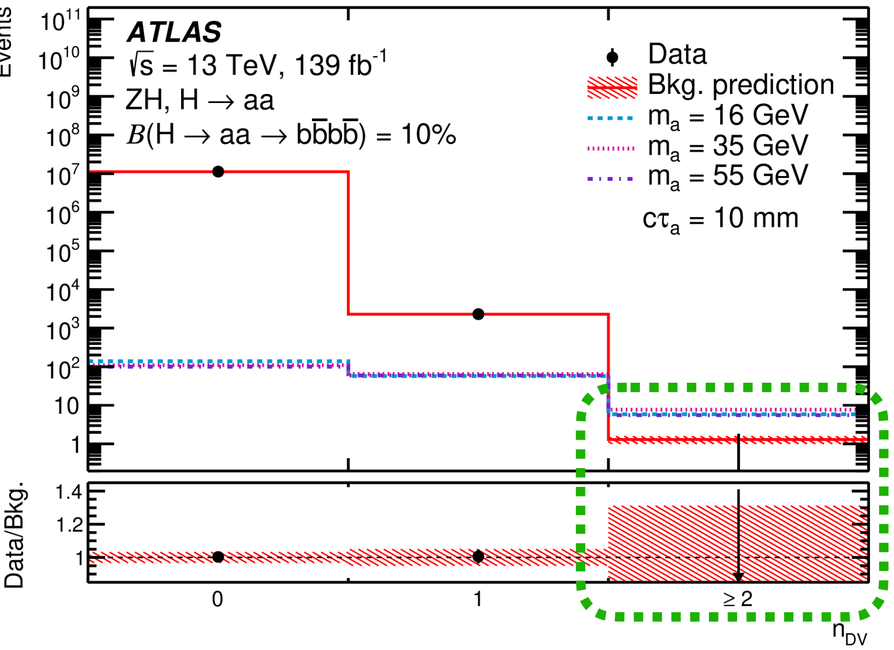
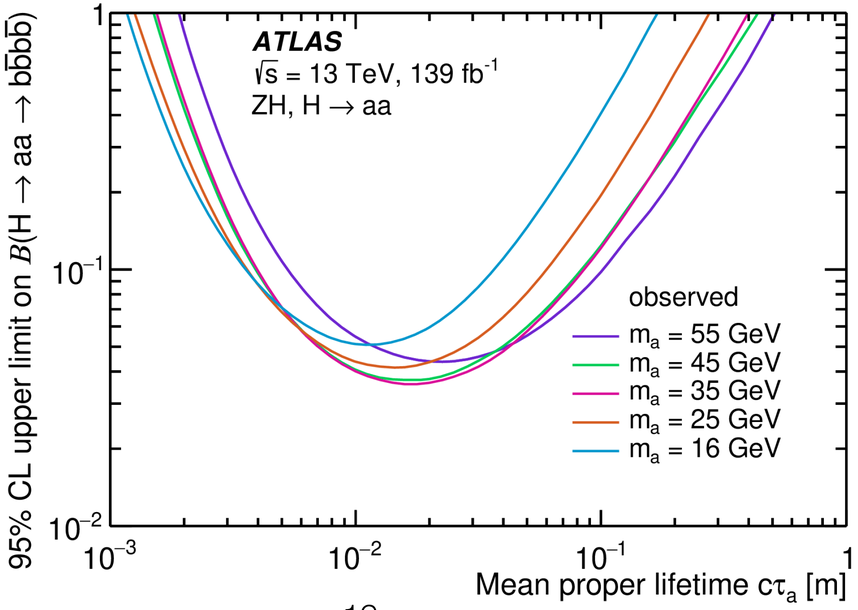
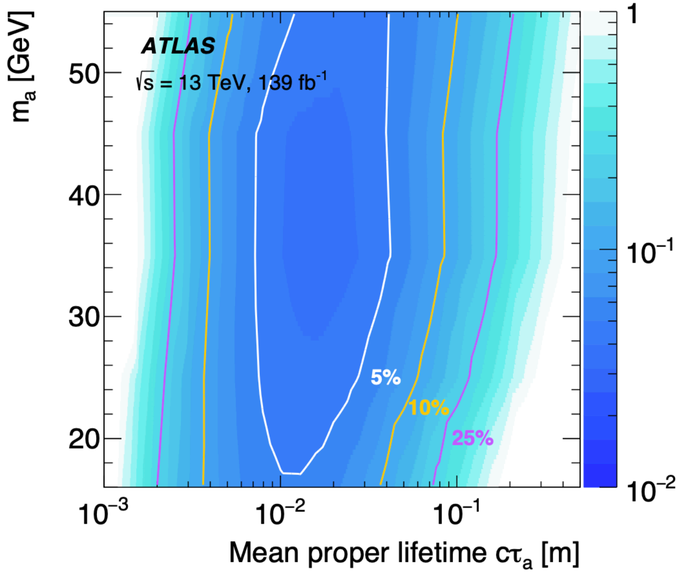
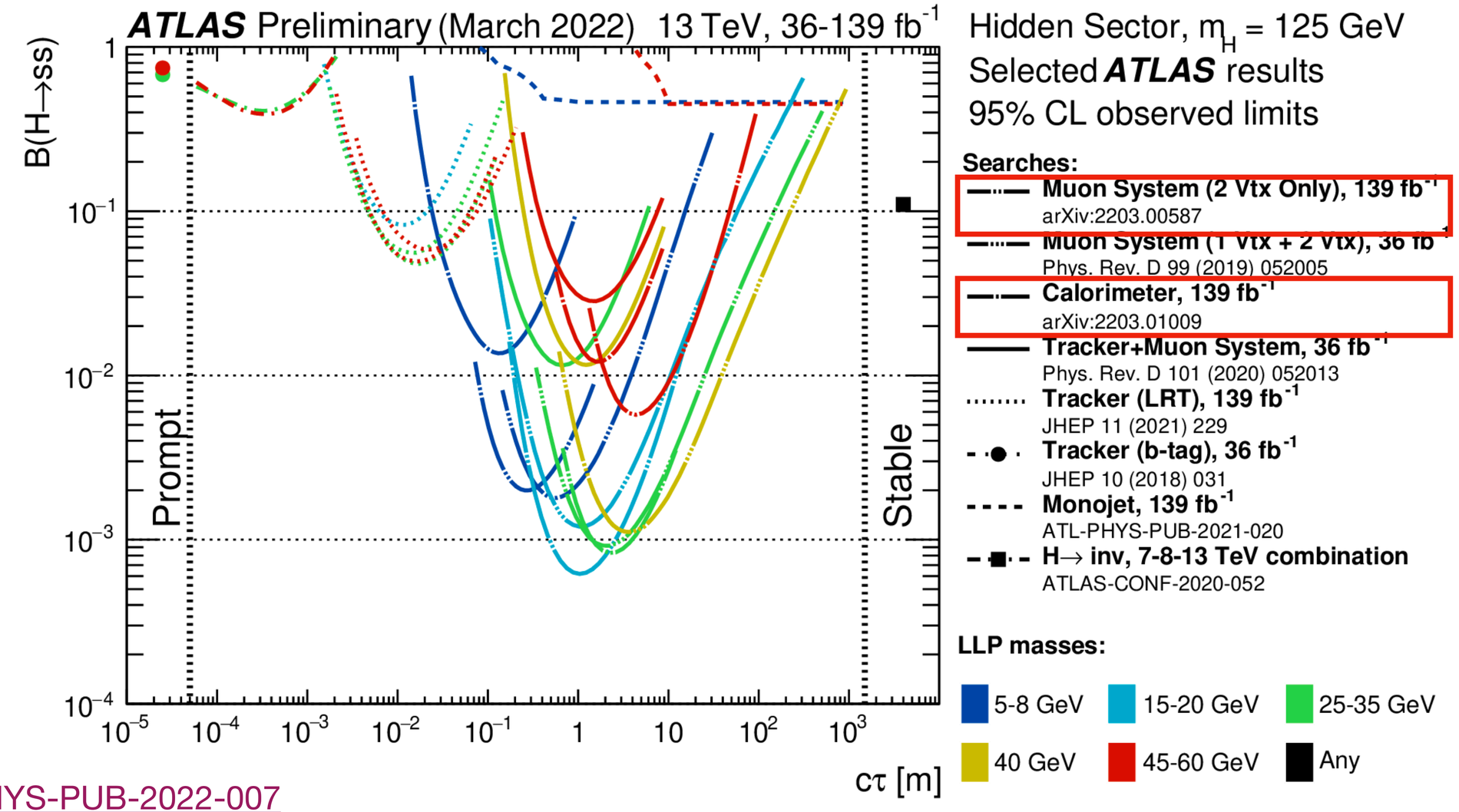








Backup slides: Summary of searches with displaced vertices



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