Recent results on LLPs from displaced vertices in ATLAS

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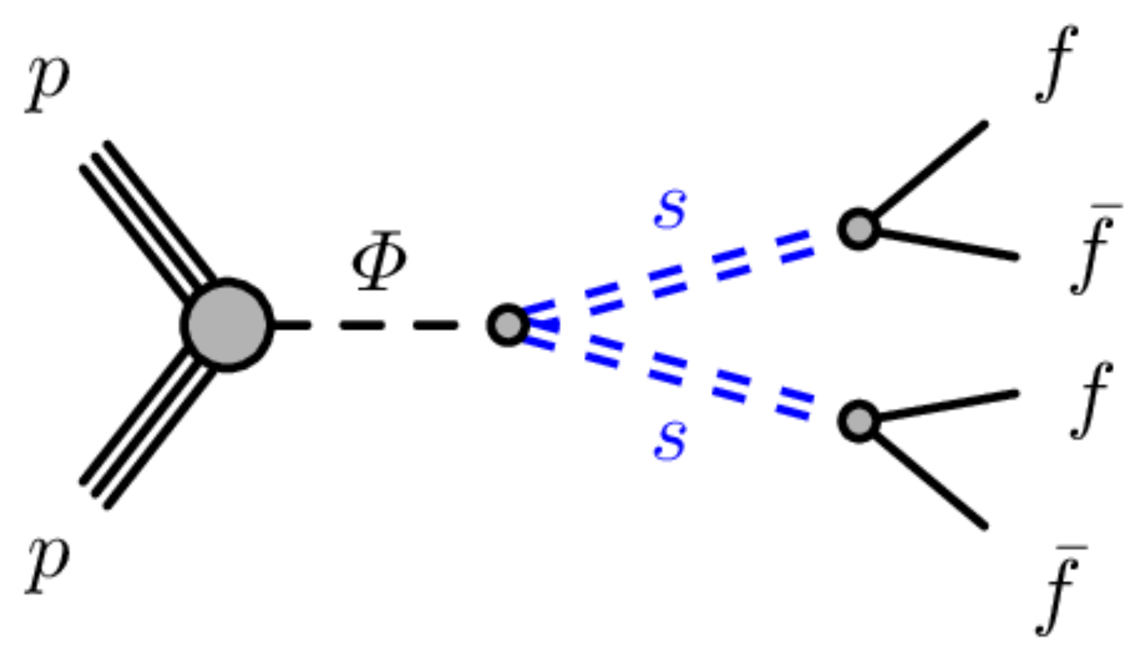
Displaced vertices

LLPs are predicted by various BSM theories, including supersymmetry, hidden sectors, and dark matter models:

- mass scale is unknown and are very difficult to probe at particle colliders, often lead to unconventional signatures!
- complement traditional searches for prompt decays by providing sensitivity to different lifetimes and decay modes
- the challenge of detecting LLPs drives the development of innovative tracking and detection techniques

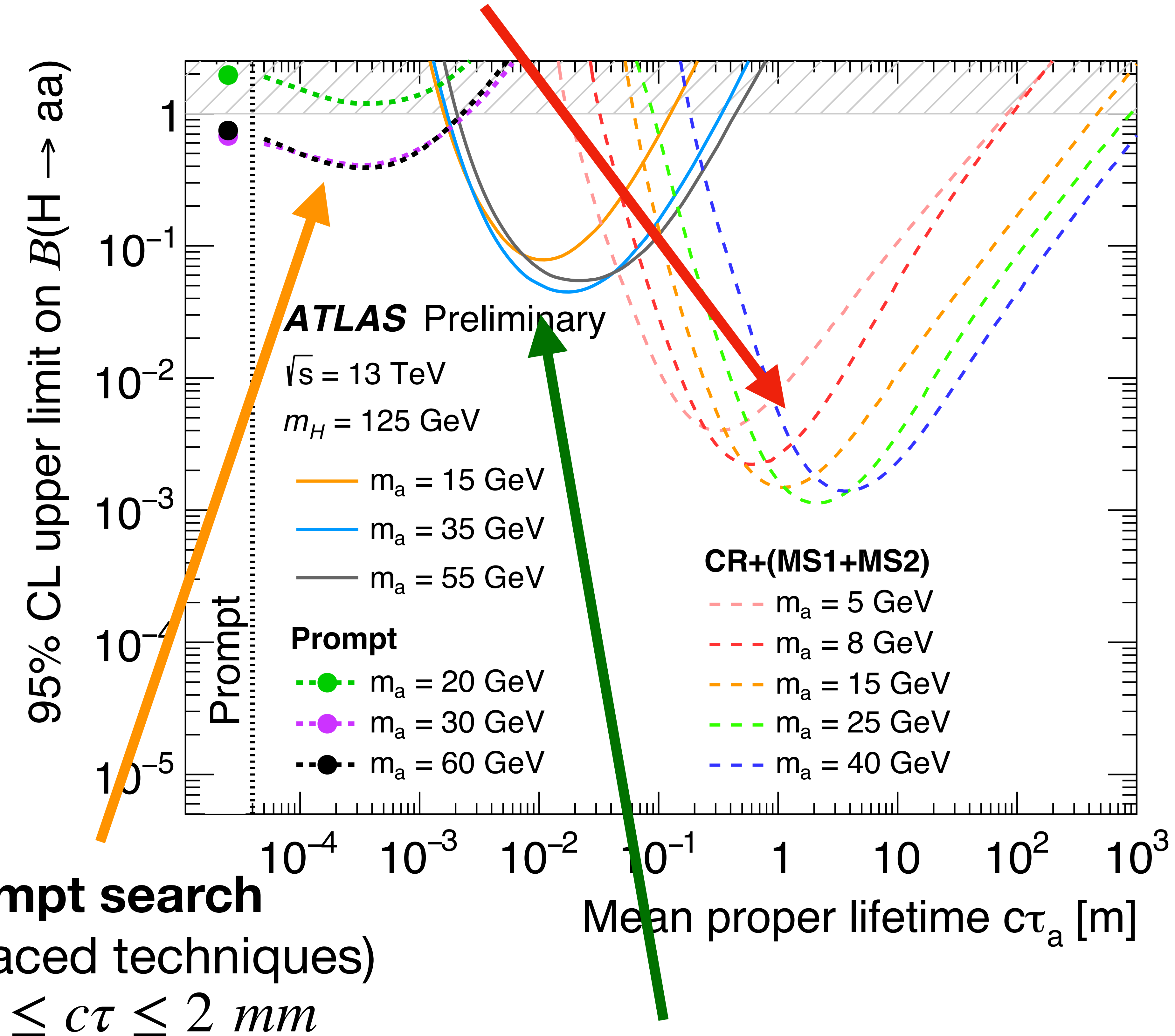
$$\kappa H^2 S^2 + \mu H^2 S$$



Higgs portal and mixing with ‘dark’ scalars

For scalar masses above 10 GeV —> bb decay mode favoured

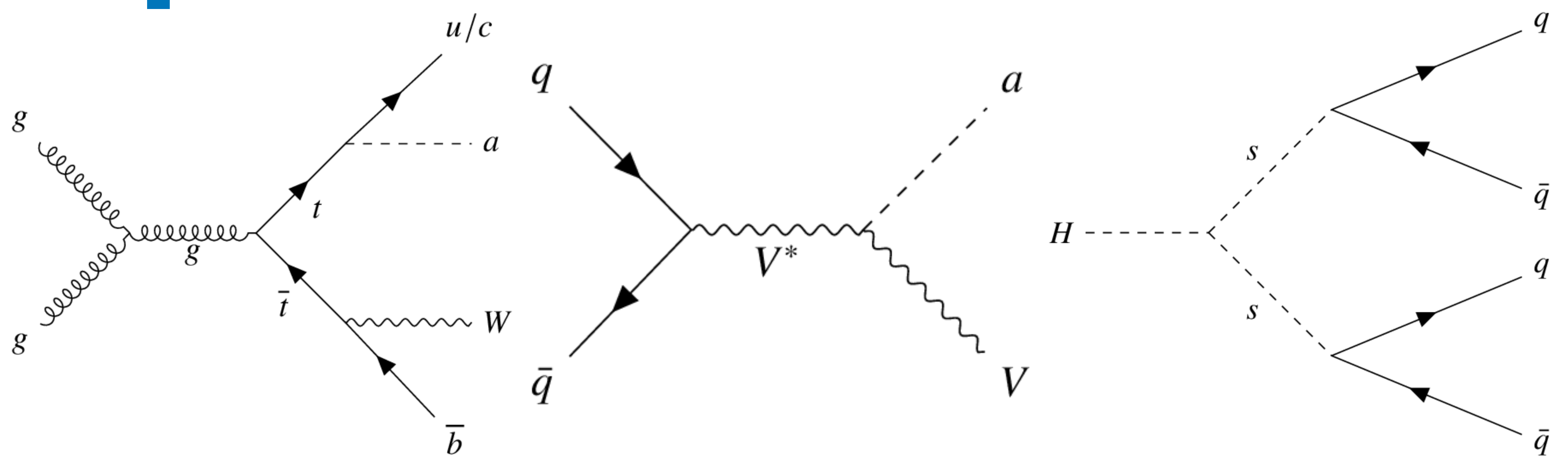
Dedicated searches
in calorimeter: $0.1 \leq c\tau \leq 10\ m$
in muon system: $c\tau \leq 100\ m$
EPJC 79 (2019) 481



Prompt search
(no displaced techniques)
$50\ \mu m \leq c\tau \leq 2\ mm$
JHEP 10 (2018) 031

ZH,H->4b analysis
Displacement in ID
JHEP 11 (2021) 229

ATLAS search for displaced vertices

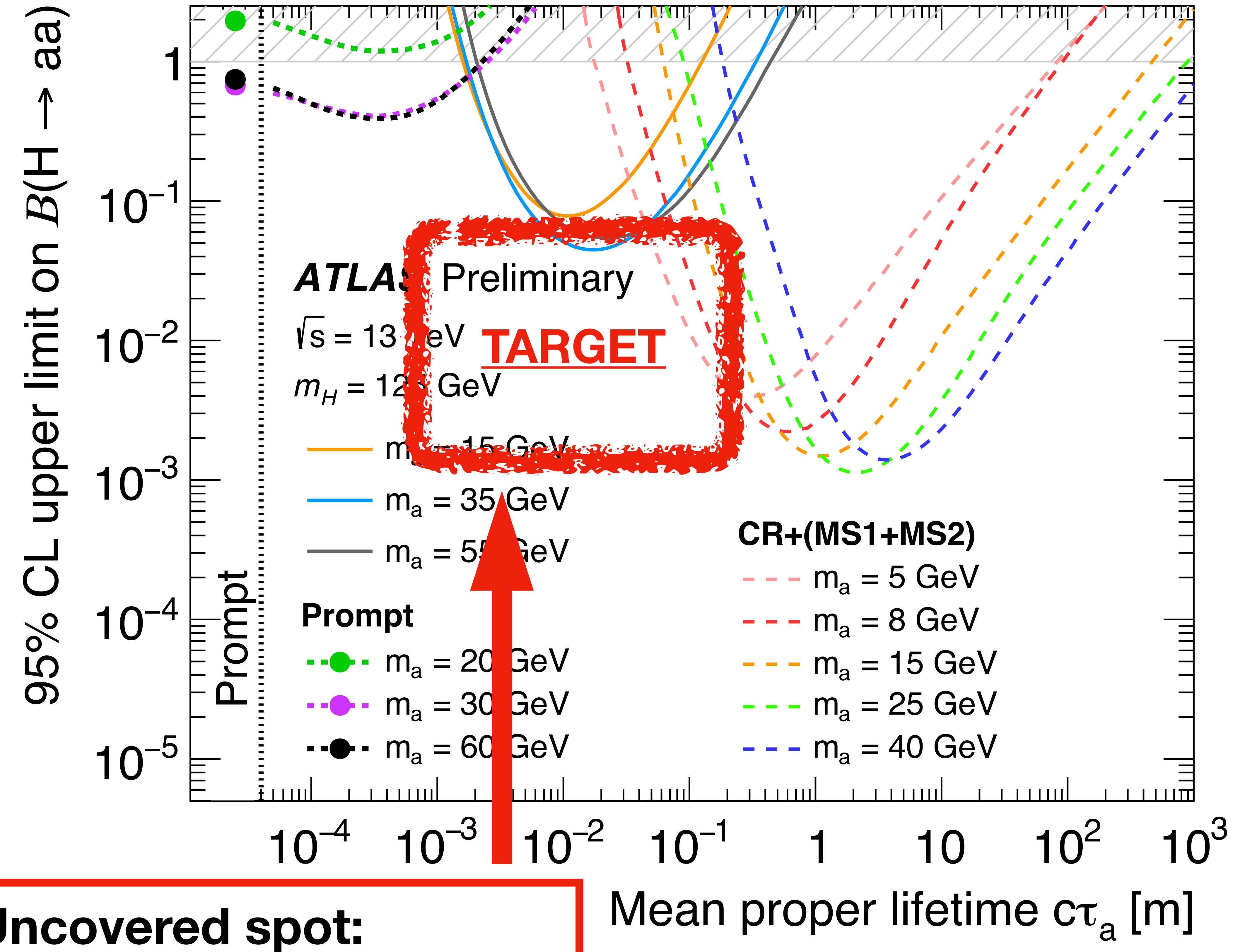


Search for exotic decays of the Higgs boson to pairs of long-lived neutral particles in the inner detector:

- Trigger on VH/VBF Higgs production to probe small lifetimes ctau < 100mm and small masses > 5 GeV

- First ATLAS search to exploit the improved Large Radius Tracking algorithm: O(10) improvement over previous search with same dataset

- First collider search to probe long lived axion-like particle (ALP) in Va non-photon decays and exotic top decay benchmarks



Uncovered spot:
LLP decays inside inner detector

Submitted to PRL: [arXiv:2403.15332]

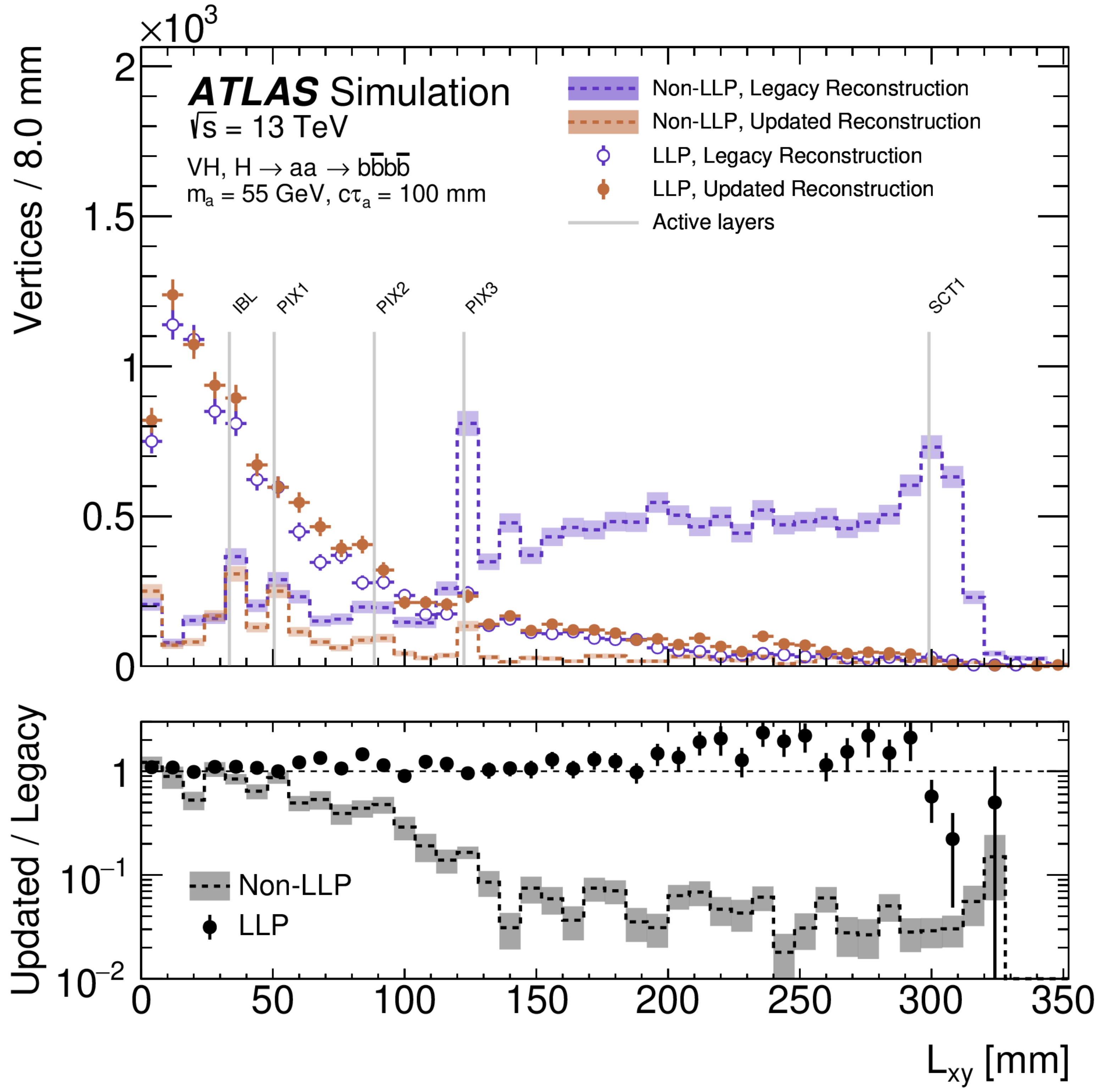
Large Radius Tracking

ATLAS has a **new** special tracking iteration, **the Large Radius Tracking (LRT)**, which has now been made available for every event (in legacy Run-2 it was applied to O(10%) of the events)

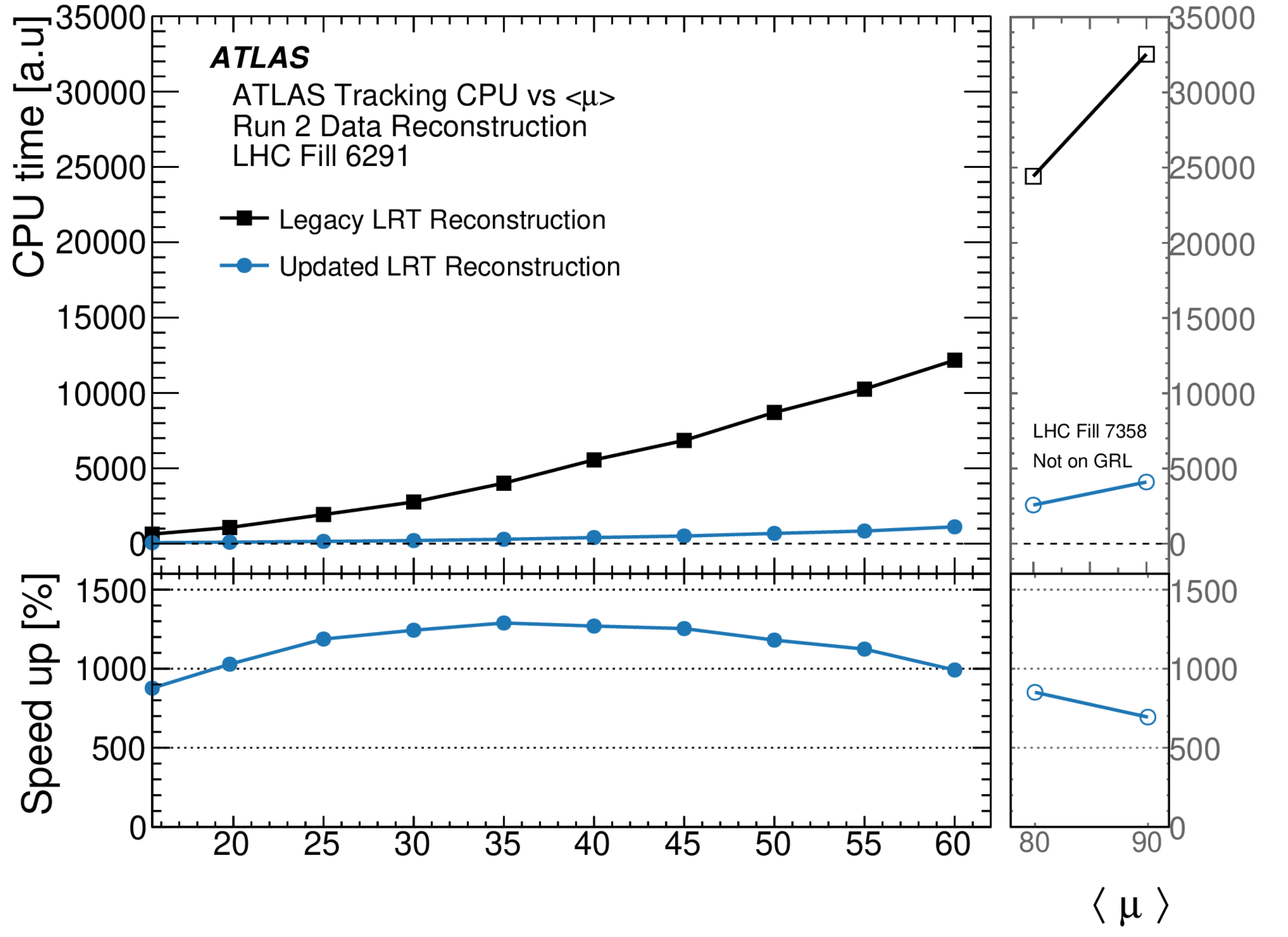
- Run on unused hits with LLP focused tracking cuts
- Optimised for neutral LLP decays
- Huge gain in CPU time and disk space consumption allows to run LRT in ATLAS reconstruction workflow for every event

Extends ATLAS standard tracking:
- d0: 5 mm —> 300 mm
- z0: 200 mm —> 500 mm

x5 significance impact on displaced vertex searches!!



x10 fakes reduction w/ LRT
most challenging background for light LLPs in the ID



Huge increase in processing performance
Reduced event-time reconstruction and event size output

[Eur. Phys. J. C 83 (2023) 1081]

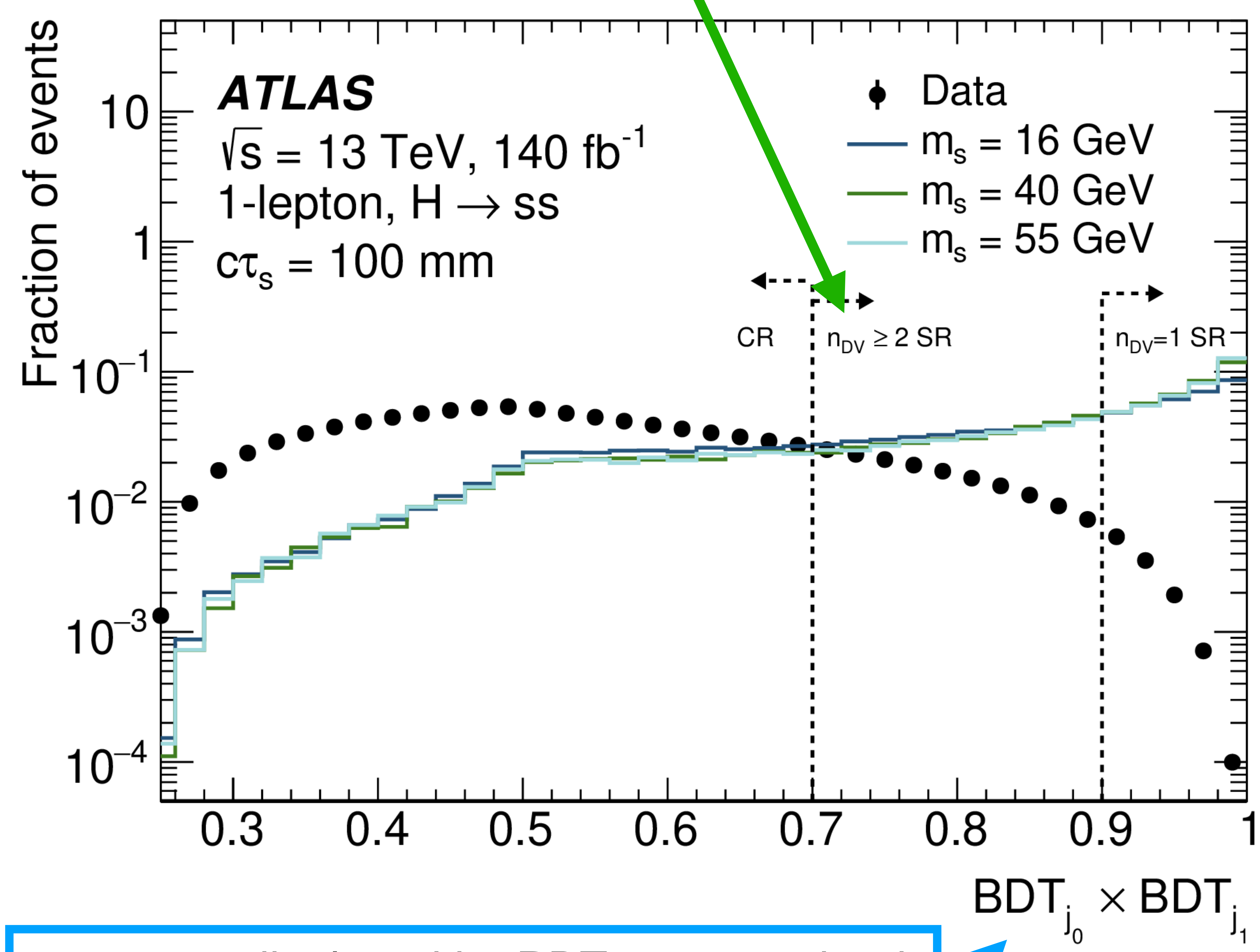
Analysis overview

Signature is characterised by the presence of two or more displaced jets that do not originate at the PV

Three search regions, targeting ZH, WH, and VBF production modes:

- Events with at least 2 displaced jets and at least 1 matched displaced vertex
- Signal (SR) and control region (CR) based on BDT discriminant output and number of DVs
- Data-driven background estimation of the hadronic jets main background, based on per-jet vertex matching probability maps
- Material veto used to reject secondary vertices from material interactions

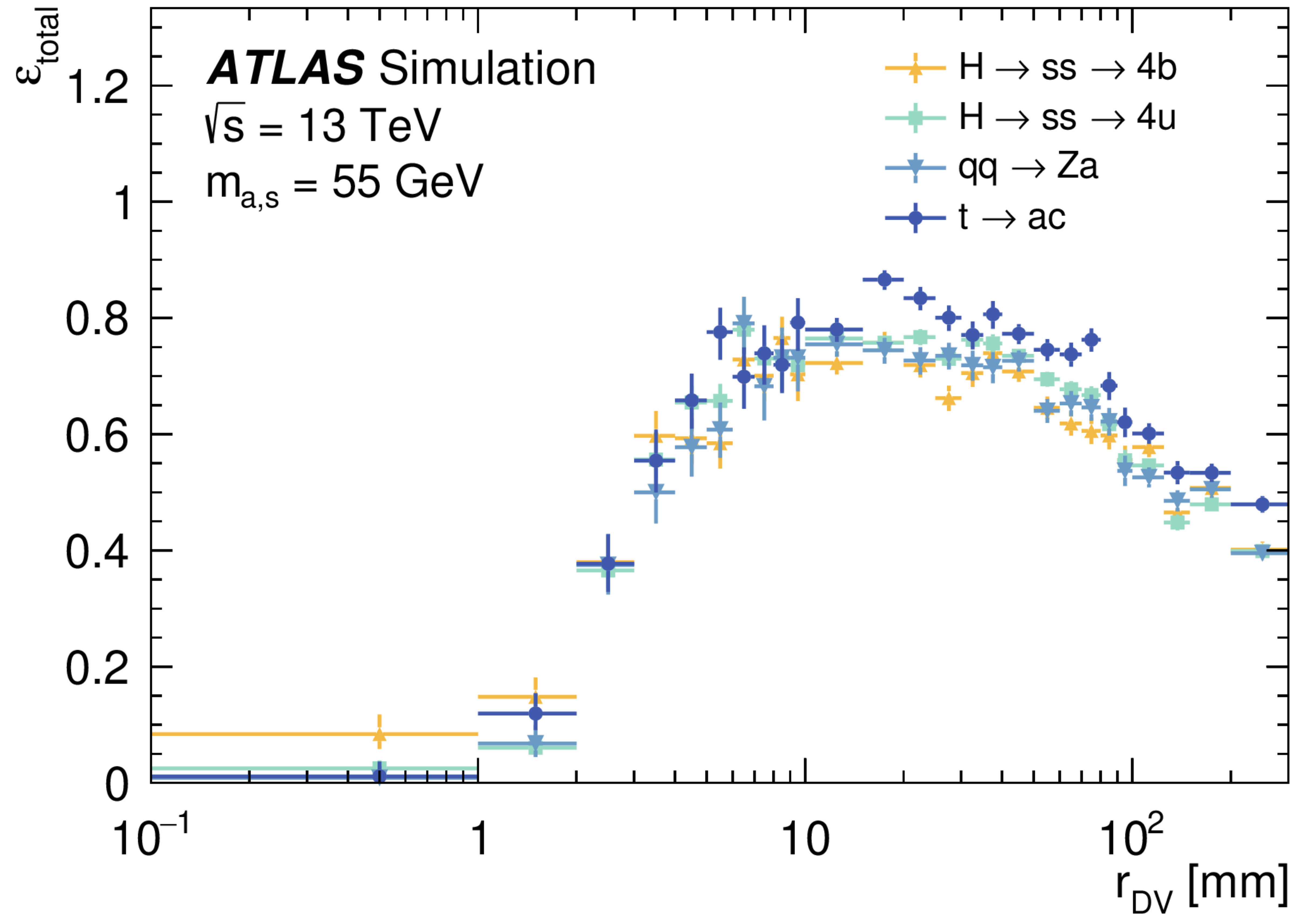
Number of displaced vertices (nDV)

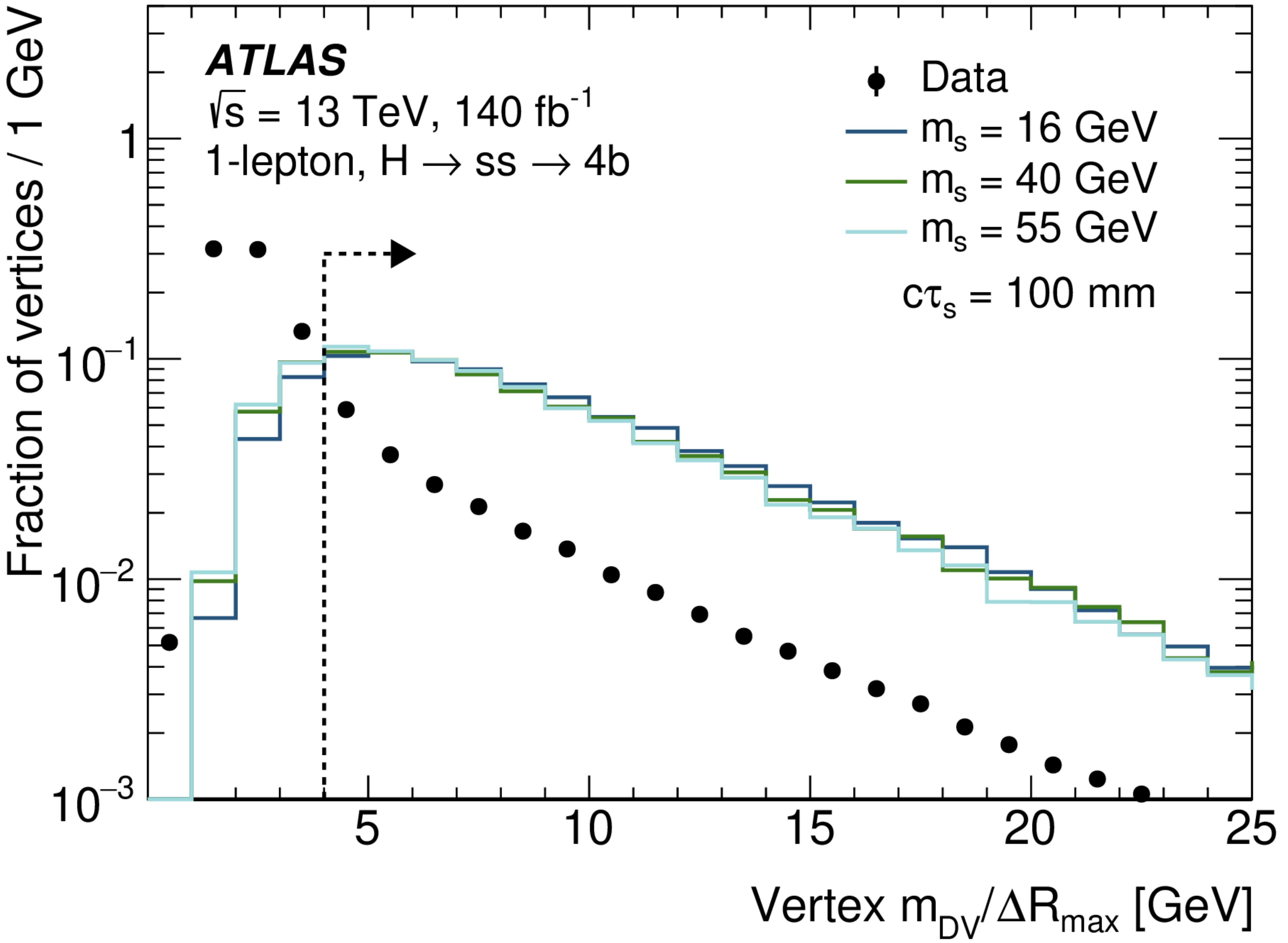


prompt vs displaced jet BDT tagger trained on track variables associated to the jet

Displaced DVs and jets

The reconstructed DVs are required to uniquely match the displaced jets in the event





efficiency of the displaced vertex reconstruction algorithm

ratio of DV mass and the max distance between tracks

Background estimation

Per-jet vertex matching probability for a data-driven background estimate

Exploit the control regions to parametrise the background by deriving a per-jet probability map which quanitfies the likelihood that a given jet is matched to a DV as a function of:

- BDT score
- pT
- Jet b-tagging score

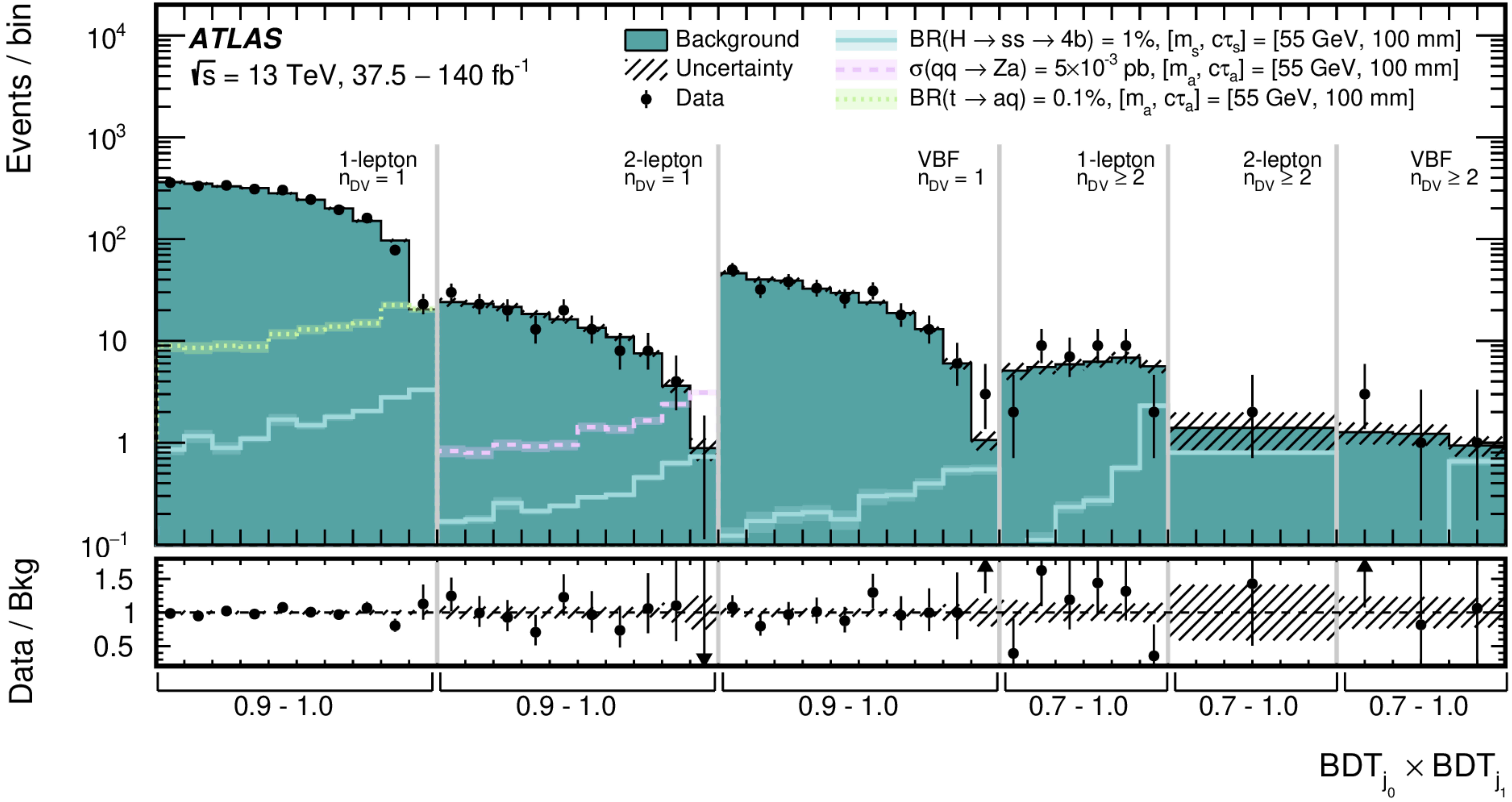
Per-event probability is then computed from a multinomial distribution based on the jets in the event:

$$P(1\ \mathrm{DV})_{\mathrm{event}} = \sum_{i=1}^{n_{\mathrm{jet}}} P(1\ \mathrm{DV}|j_i)_{\mathrm{jet}} \times \prod_{k\neq i} \left(1 - P(1\ \mathrm{DV}|j_k)_{\mathrm{jet}}\right) \qquad P(2\ \mathrm{DV})_{\mathrm{event}} = 1 - P(1\ \mathrm{DV})_{\mathrm{event}} - P(0\ \mathrm{DV})_{\mathrm{event}}$$

Applied as per-event weight to predict background distribution in 1DV and 2DV SRs

Results

No excess over background estimate observed



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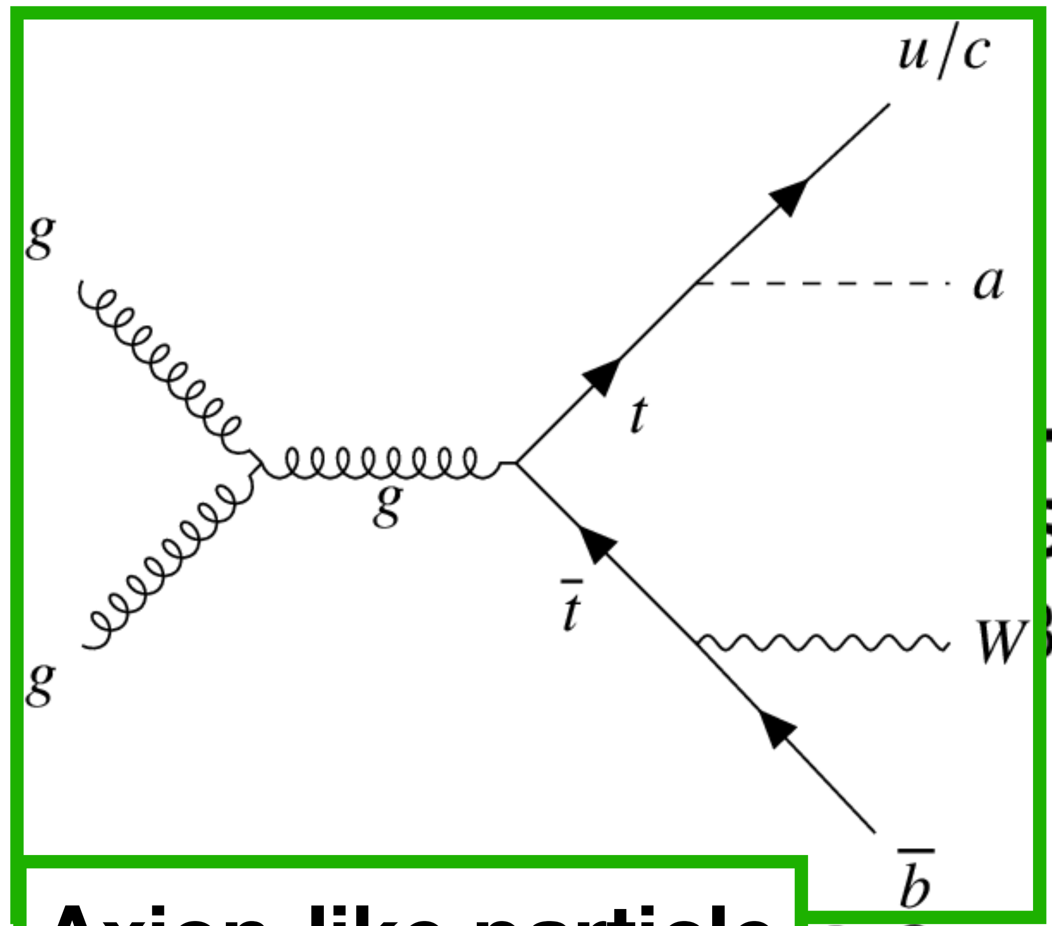
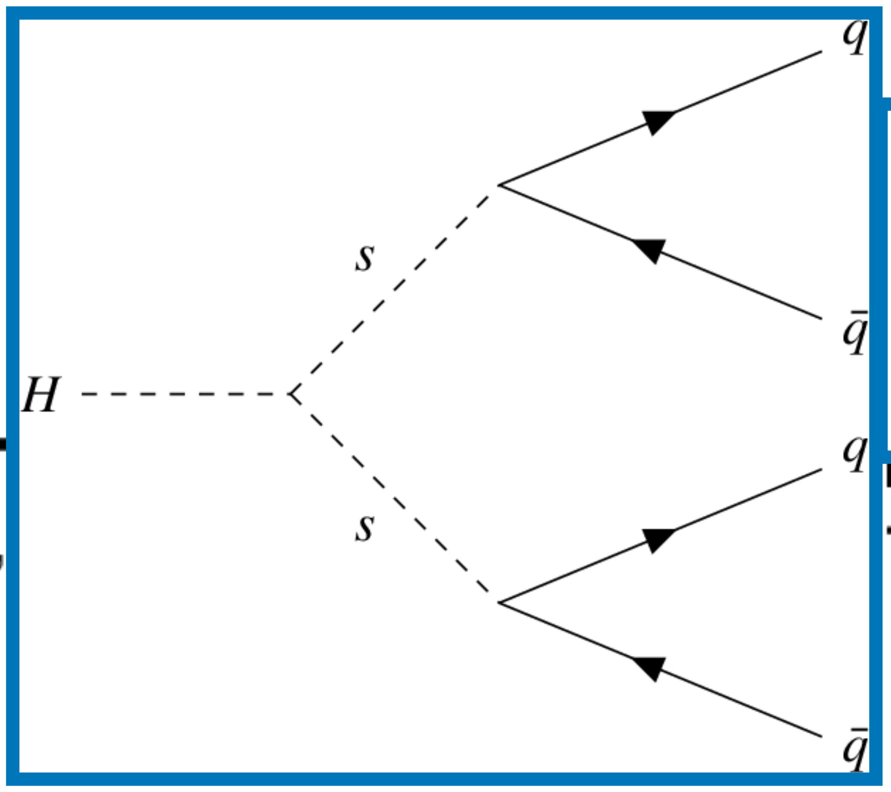
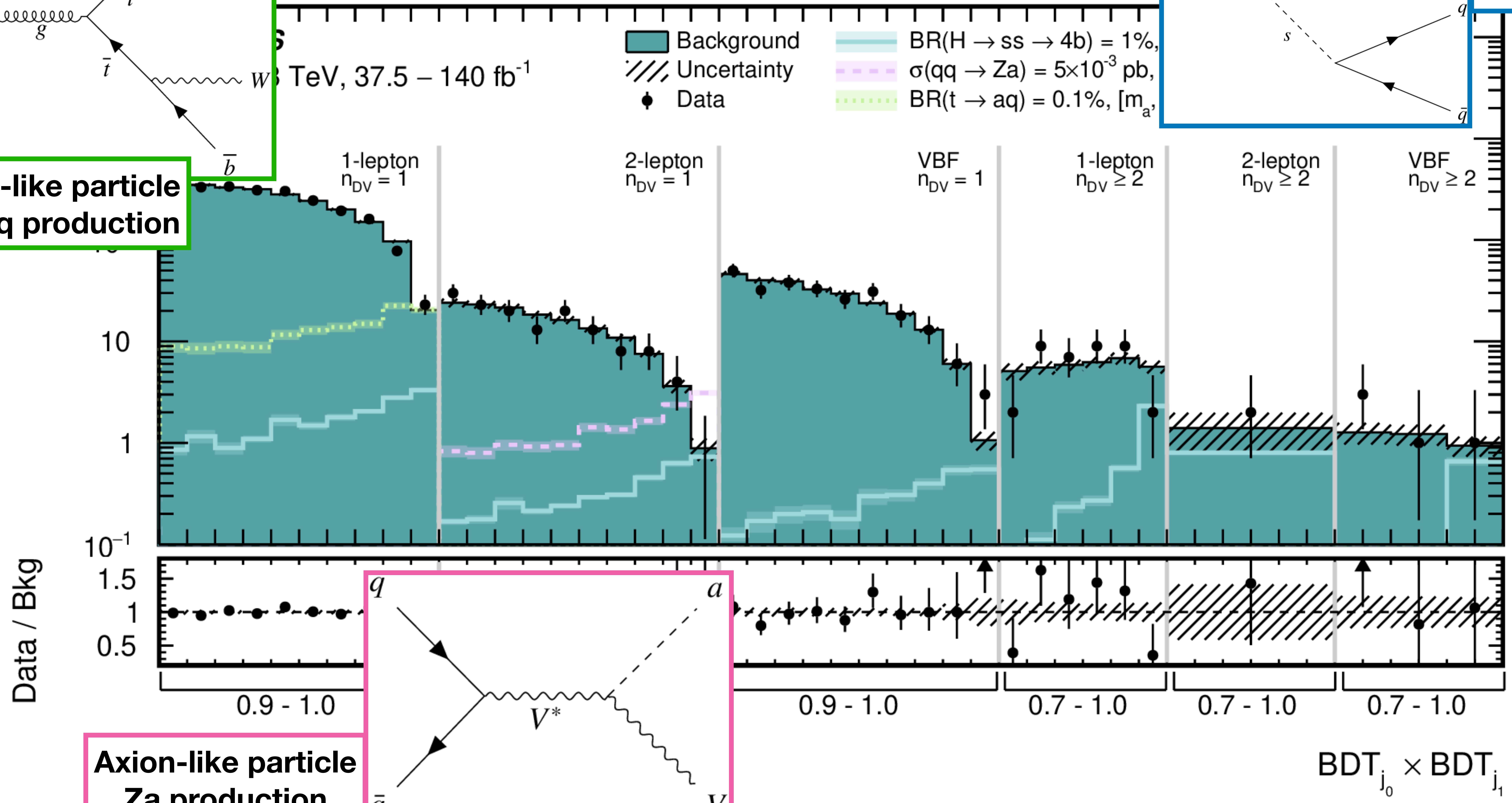


Axion-like particle t—>aq production

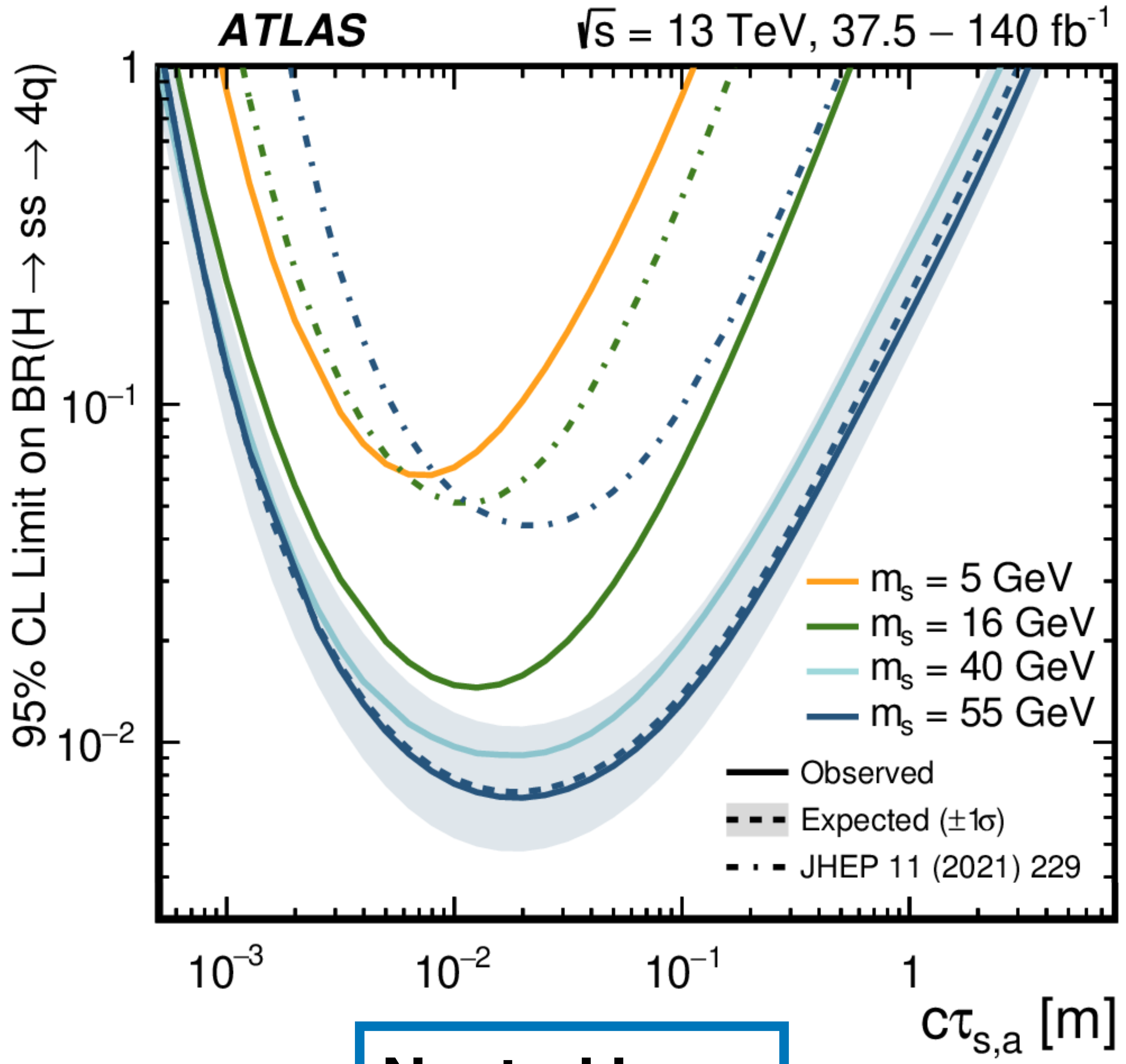


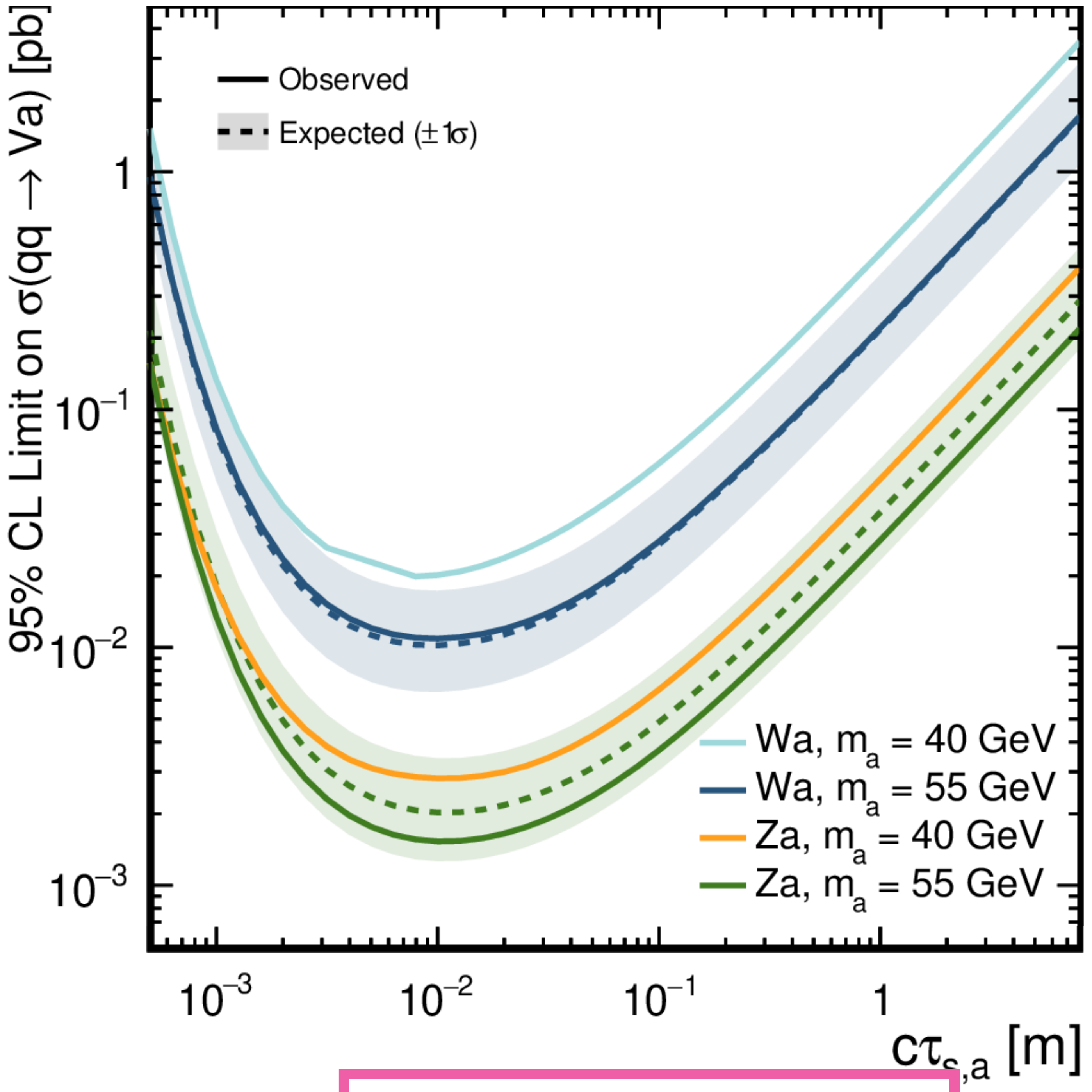
Neutral long-lived scalar

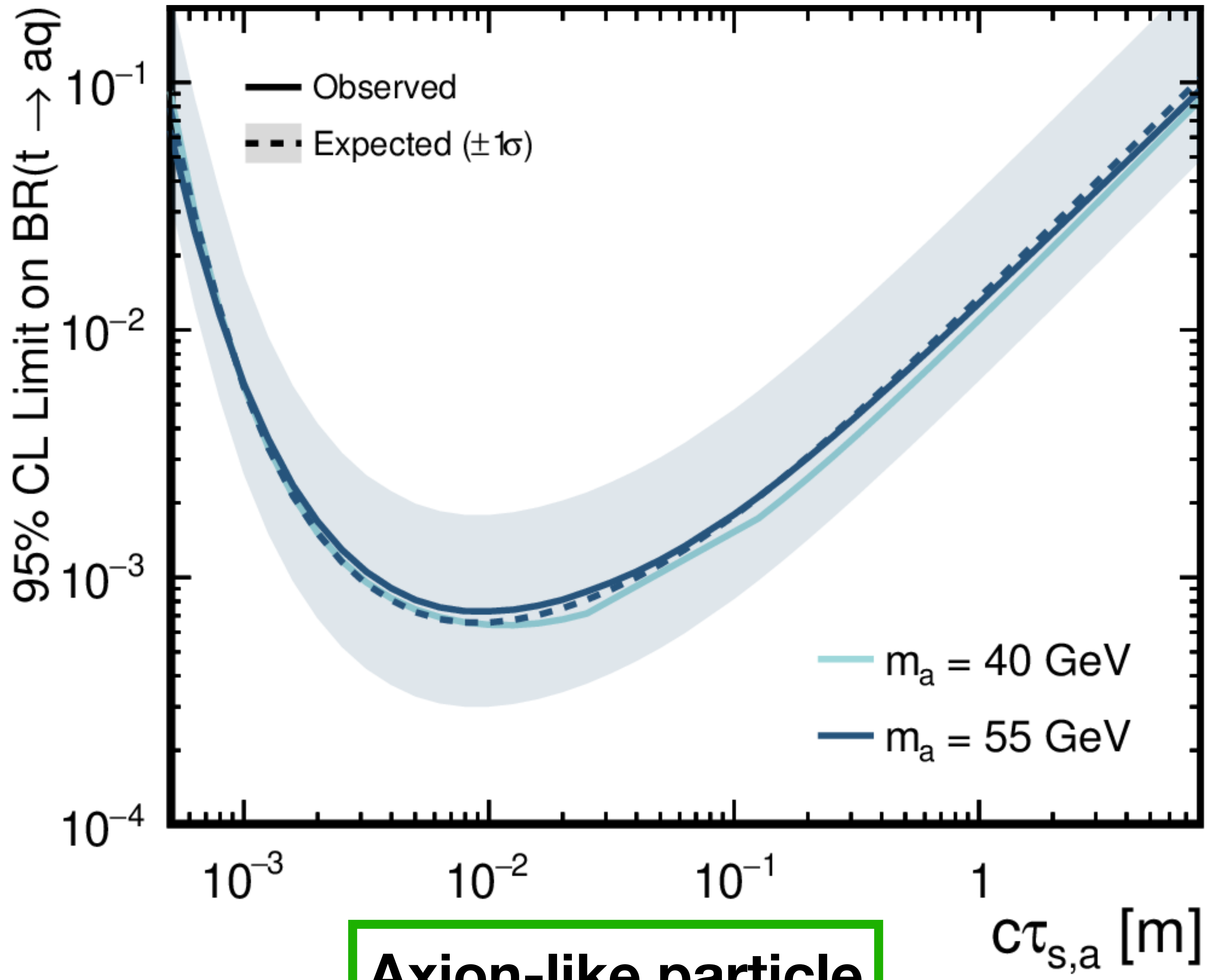


Axion-like particle Za production

Observed limits







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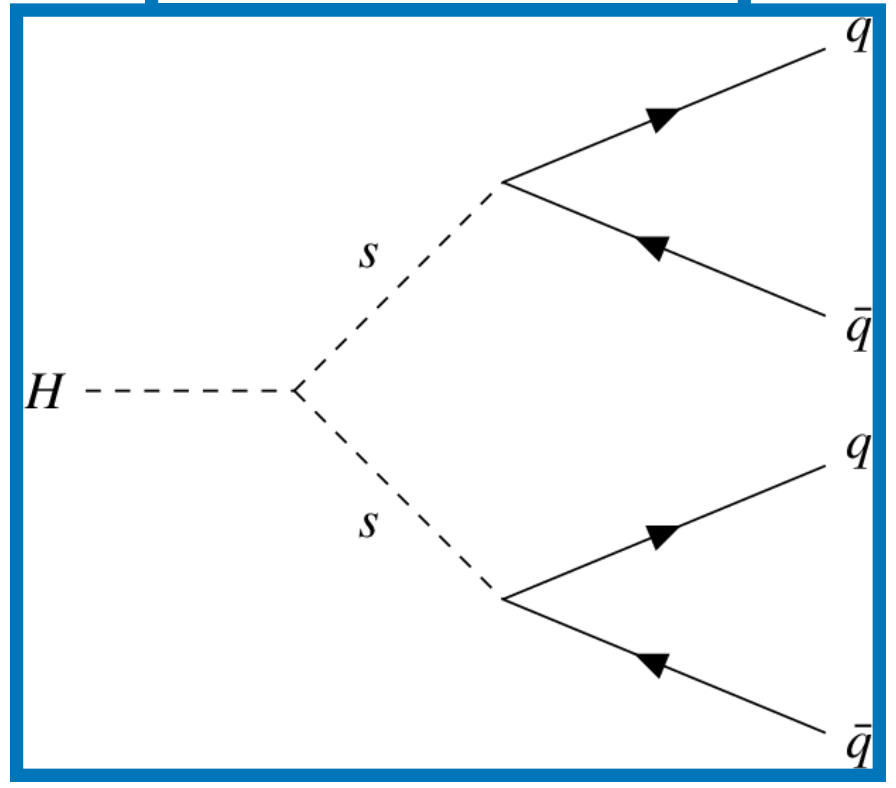

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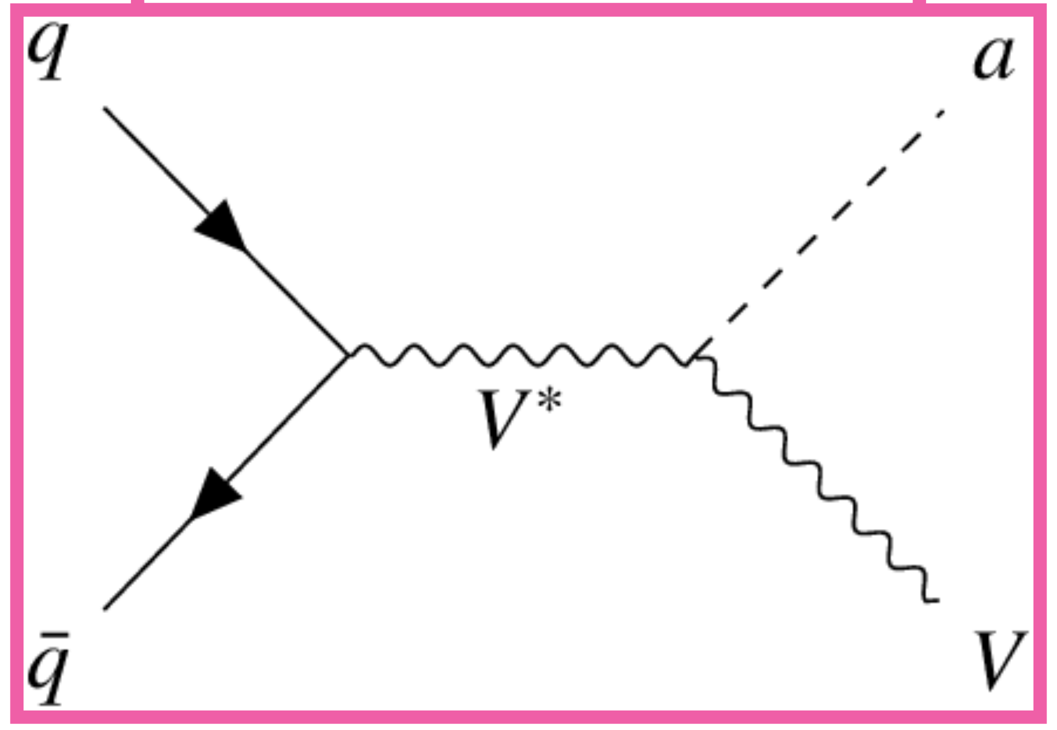
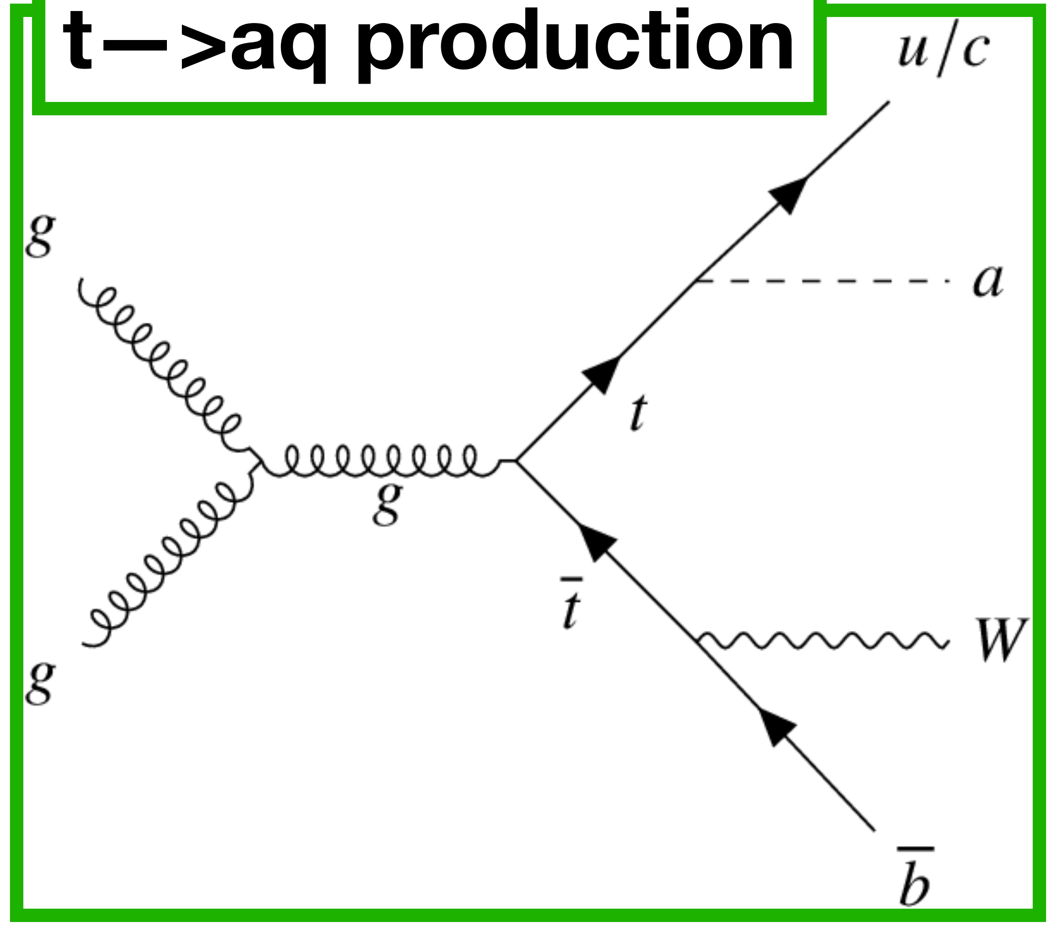


Axion-like particle t—>aq production



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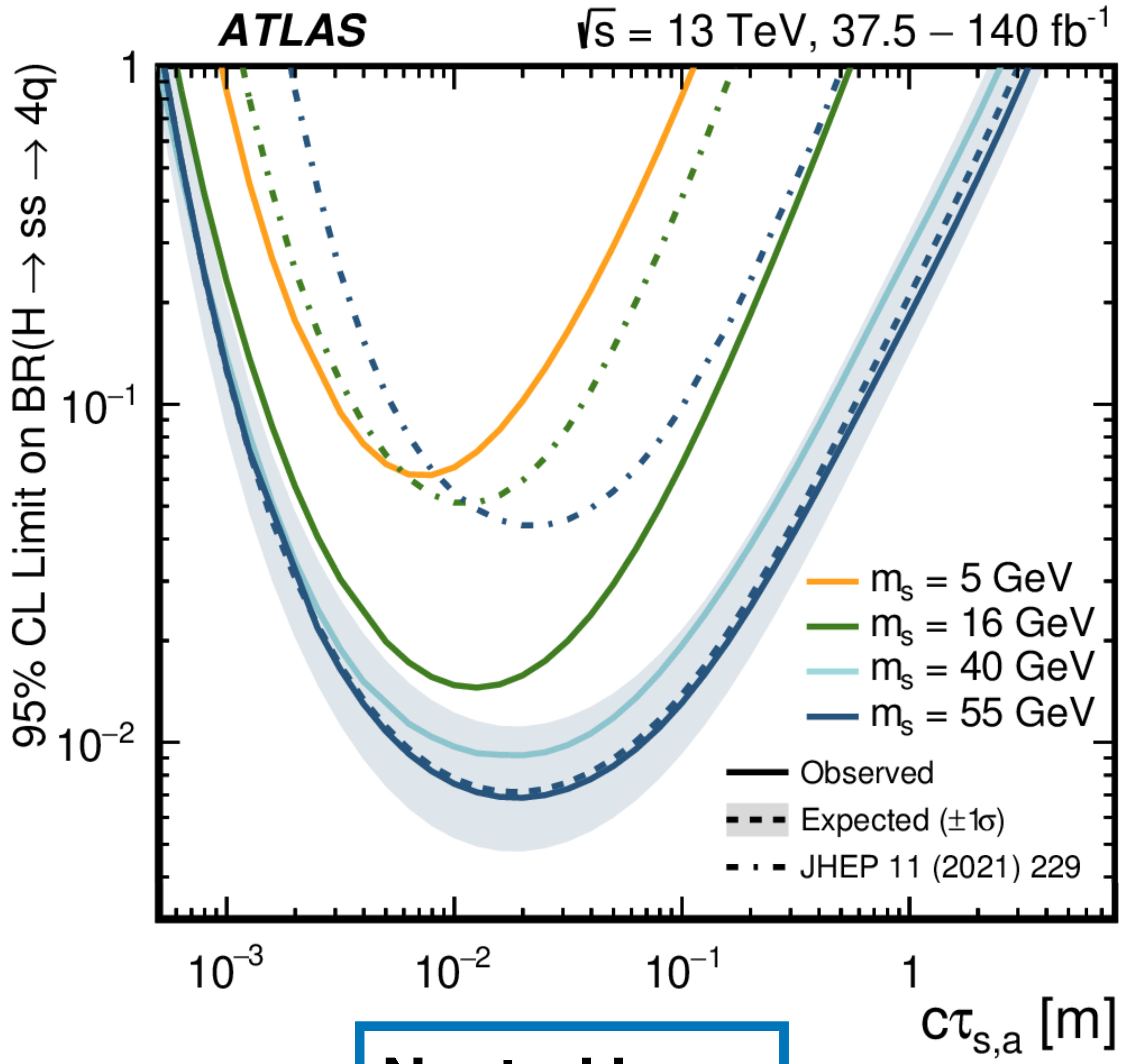

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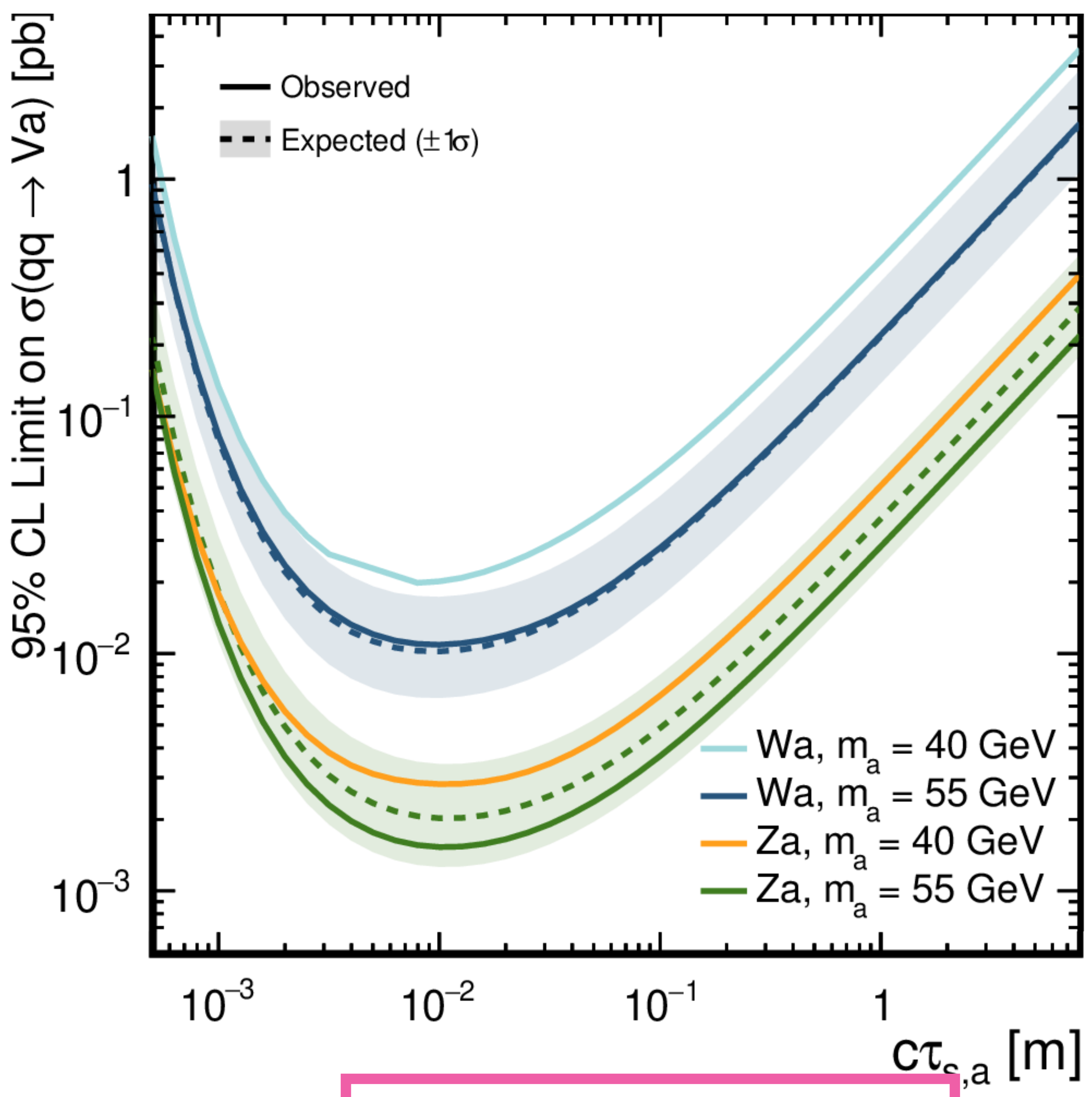

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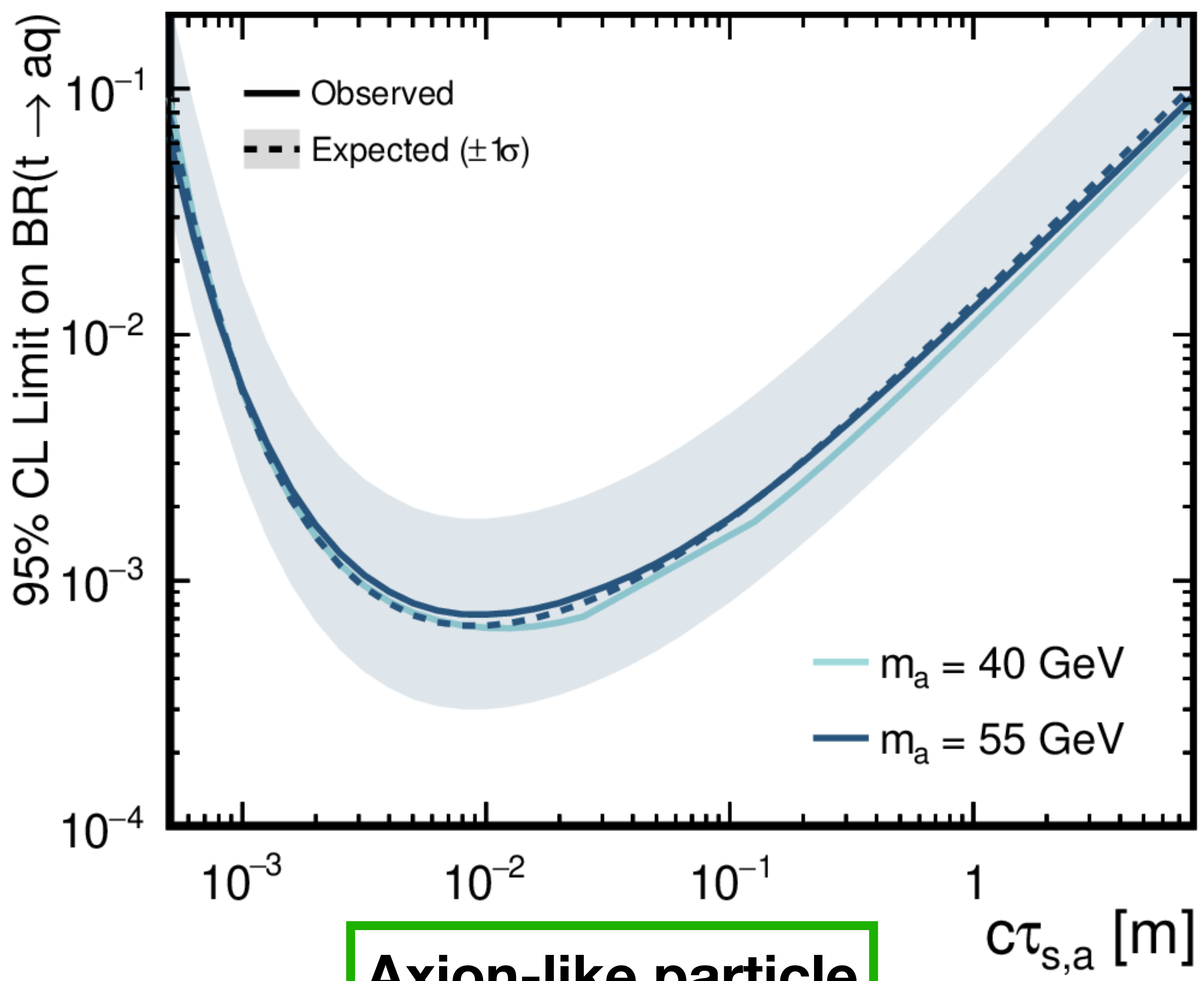


Axion-like particle t—>aq production

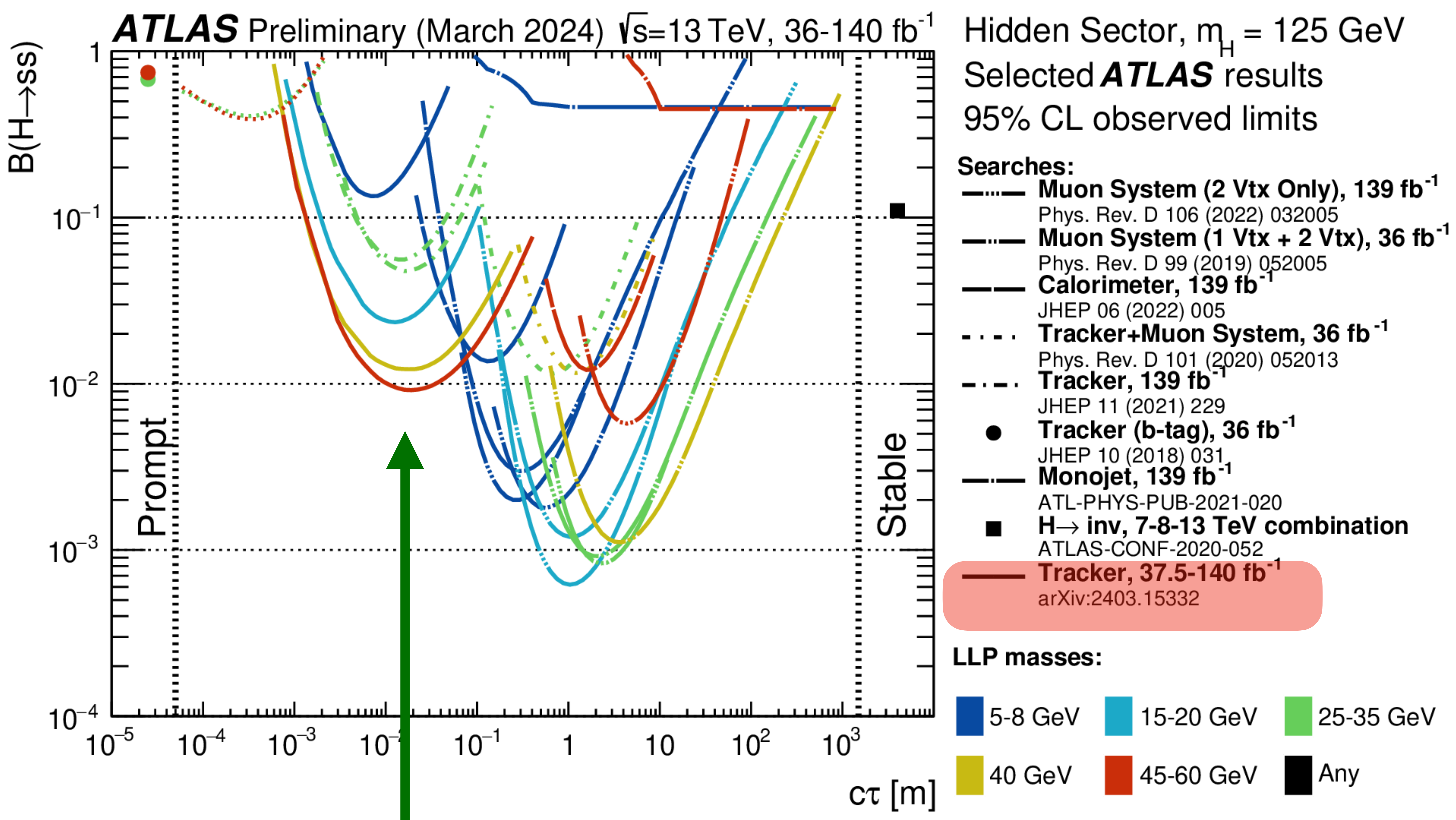
Limits on BR(H → ss) are most stringent to date for ms < 40 GeV and 1 < cτ < 100 mm

First ATLAS limits on long-lived ALP decaying to gluons

First collider search to present limits on BR(t → aq) and long-lived photo-phobic ALP production

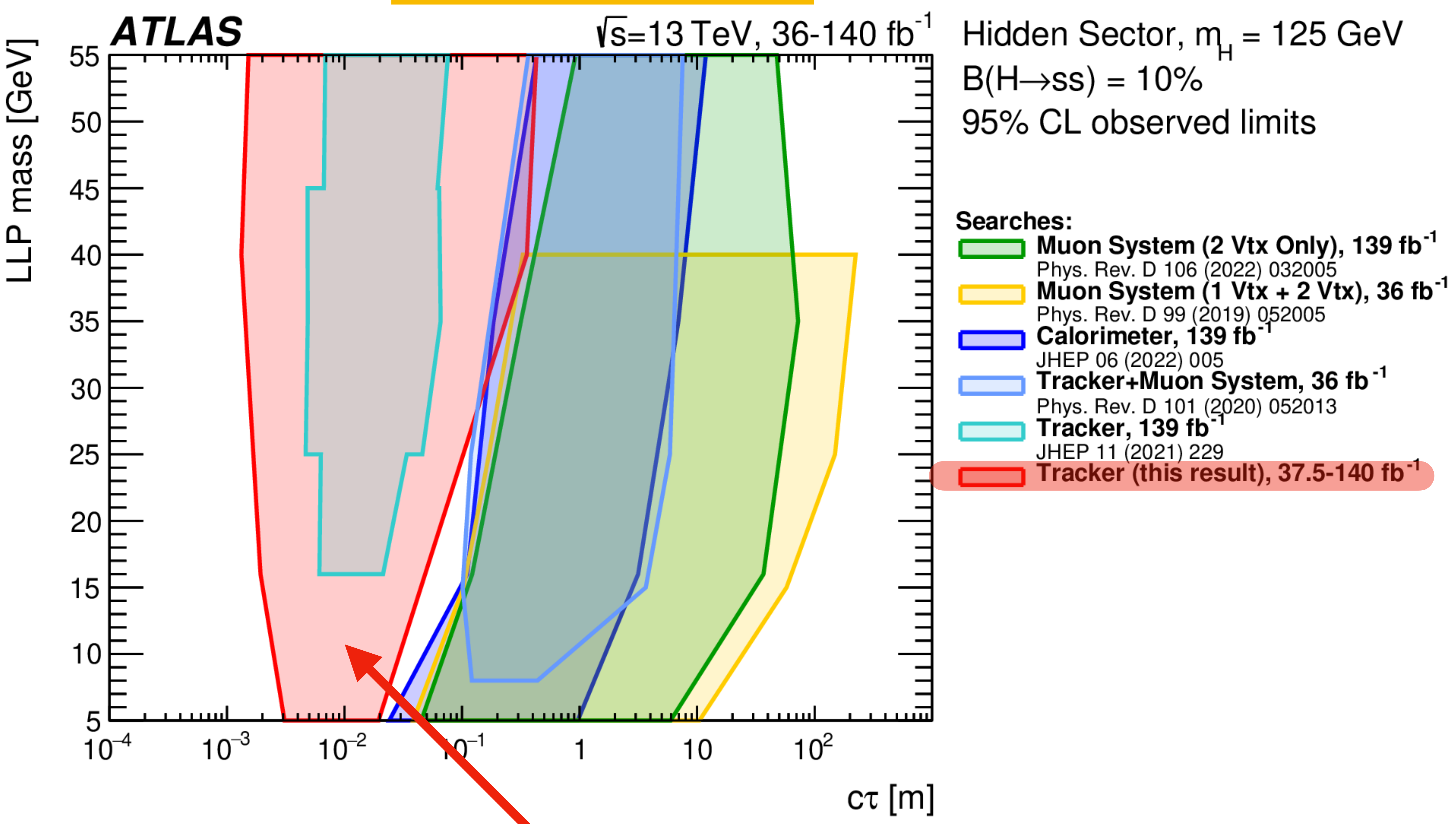
Submitted to PRL: arXiv:2403.15332

The big picture



x10 improvement wrt previous ATLAS limit on same dataset!

ATL-PHYS-PUB-2024-003



Large coverage in mass vs ctau phase space

Conclusions

- New Large Radius Tracking in ATLAS opens up new possibilities for searches involving displaced vertices, enhancing existing searches and enabling new ones
- The first new LRT ATLAS search for displaced vertices in the Inner Detector has been presented, more LRT analyses will come out very soon… stay tuned!
- Great effort in developing new tools and strategies to improve identification and reconstruction of long-lived particles pushing the detectors beyond their limits
- Run-3 and HL-LHC programmes offer a unique opportunity to plan, innovate and create new unconventional searches yet to be explored