Status of deviations from the SM in the Higgs sector

Higgs Hunting 2026

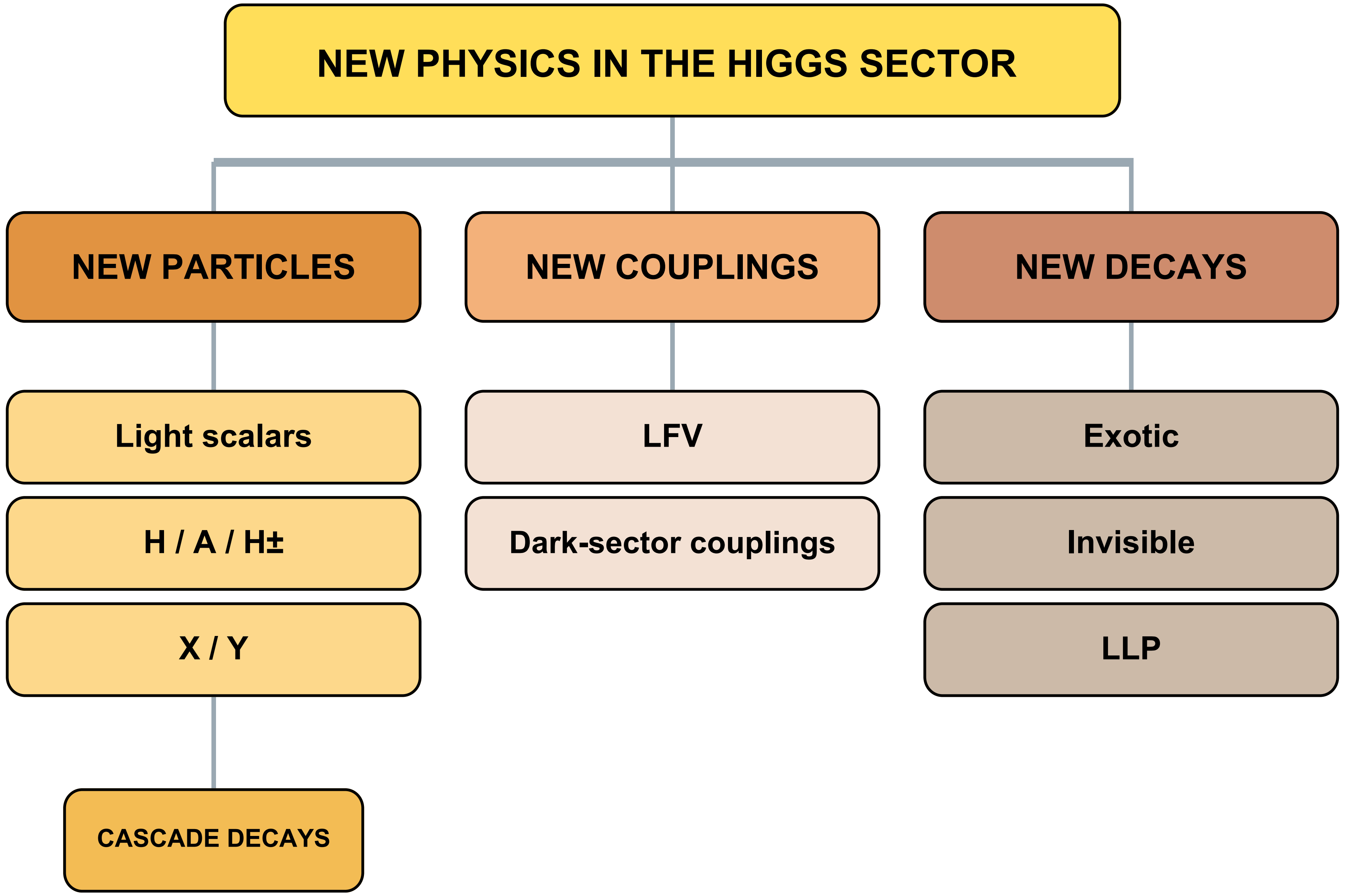
INFN ROMA

Livia Soffi

Based on public results from the ATLAS and CMS Collaborations

Deviations and the extended Higgs sector

- From <u>possible manifestations of new physics</u> to experimentally motivated priorities
  - We start from a map of possibilities — and end with a map of priorities.



ATLAS & CMS

Categories containing at least one retained feature (> 2.4 sigma local^^)	Final states with a retained feature
★ Light scalar resonances	$\gamma\gamma$; $\tau\tau$
★ Heavy neutral / scalar pairs	$\gamma\gamma$, VV, $\tau\tau$, bb, tt/tb, e/μ, merged jets
★ Charged Higgs / LFV	eμ, eτ/$\mu\tau$, cb and WZ/WW
★ A→XH cascades	Zbb, ZWW, Ztt and Zhh→Z4b
★ X→YH / HH	$\gamma\gamma$bb, $\gamma\gamma\tau\tau$, 4b/bb$\tau\tau$, VV and 4ℓ
★ Exotic H125 decays	Z$\gamma\gamma$, 4ℓ, $\mu\mu\tau\tau$, 4b/6b and bb$\mu\mu$

^^https://indico.cern.ch/event/1651921/

- The deviations are one output of a **much broader programme of searches** for new particles, couplings, and decays.

LHC Beyond the Standard Model Working Group

The public inventory at a glance

Repository

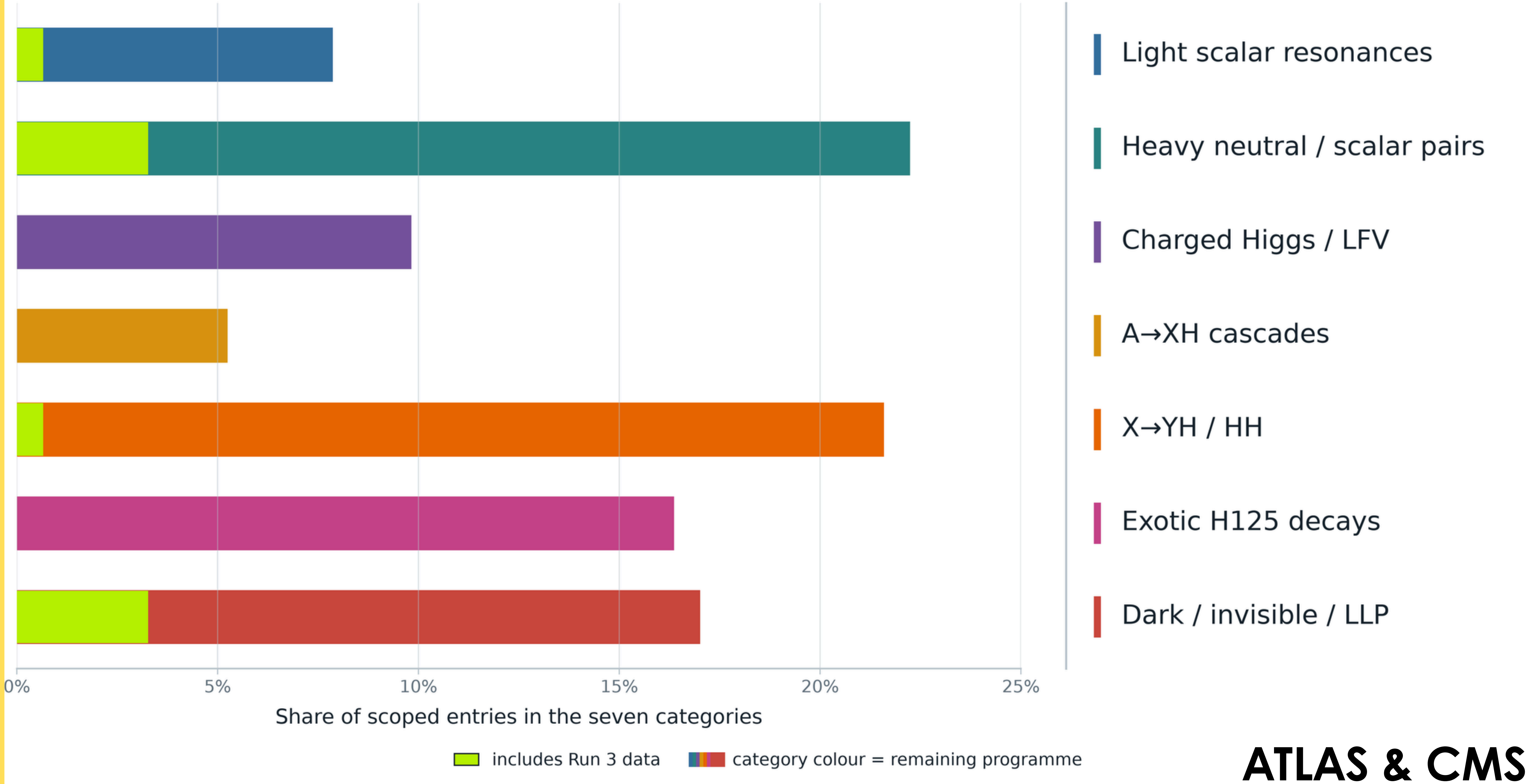
179

scoped analysis entries

174

unique public references

== plots produced for this talk



ATLAS & CMS

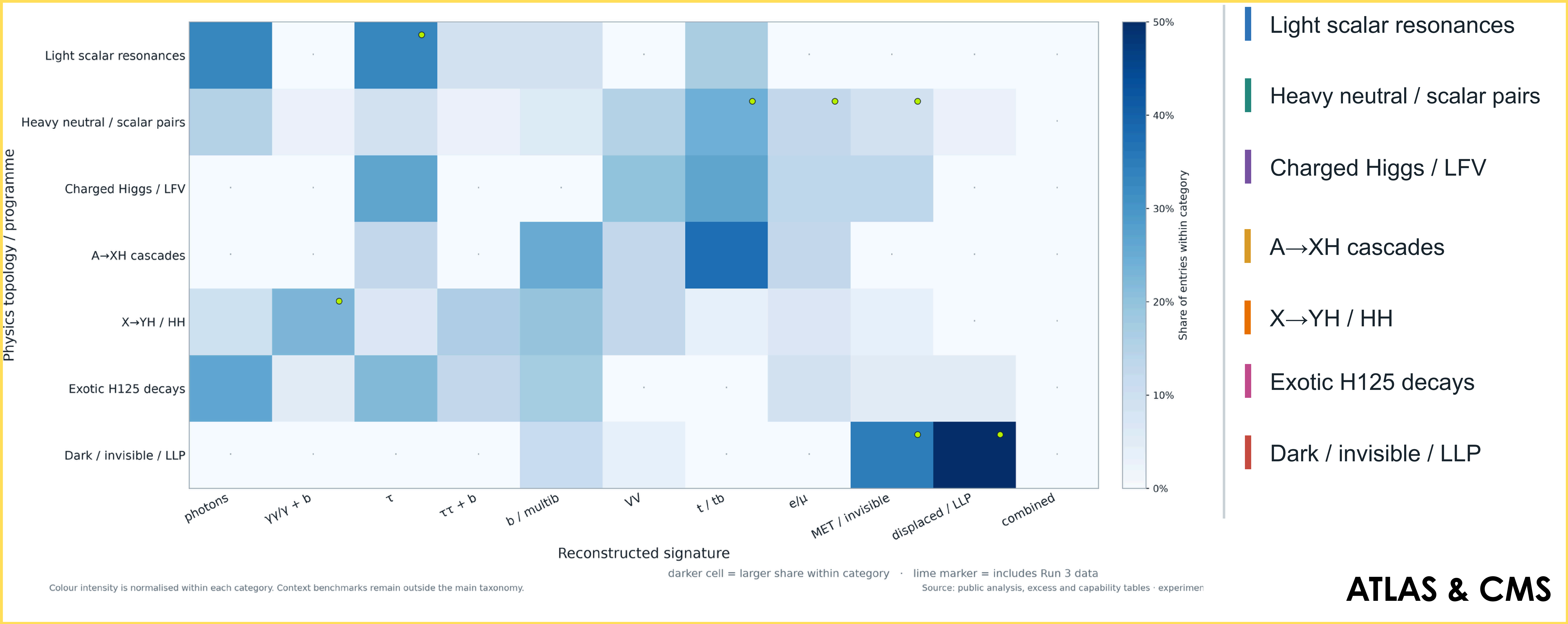
98 CMS · 80 ATLAS LHC entries + one LEP

19 entries include Run 3 data

164/179 have an identified cross-experiment relation

42 unique references contain at least one observed local deviation above 2.4σ

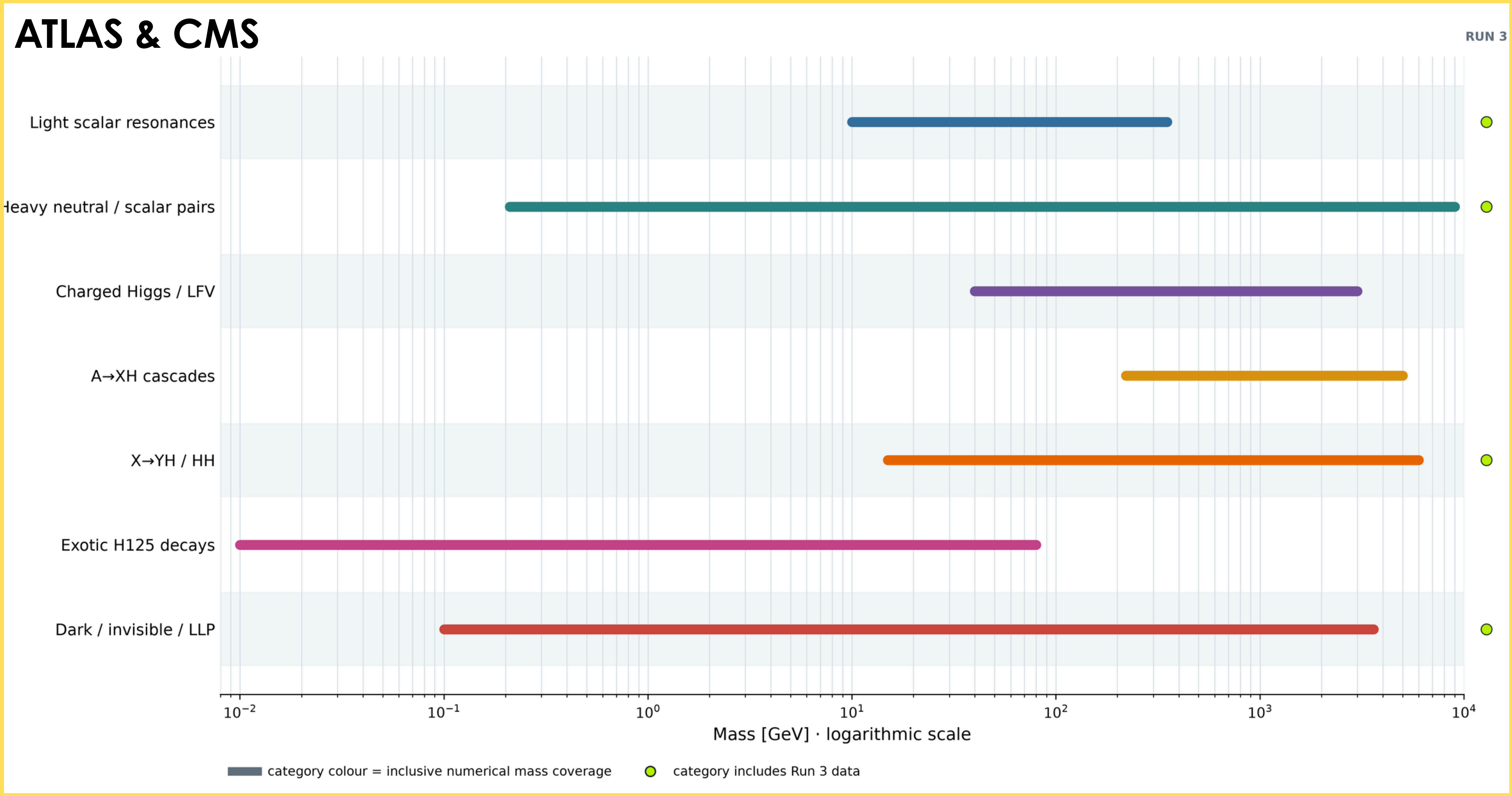
Shared experimental signatures



- The categories organise the search programme; the reconstructed signatures **connect** them **experimentally**.

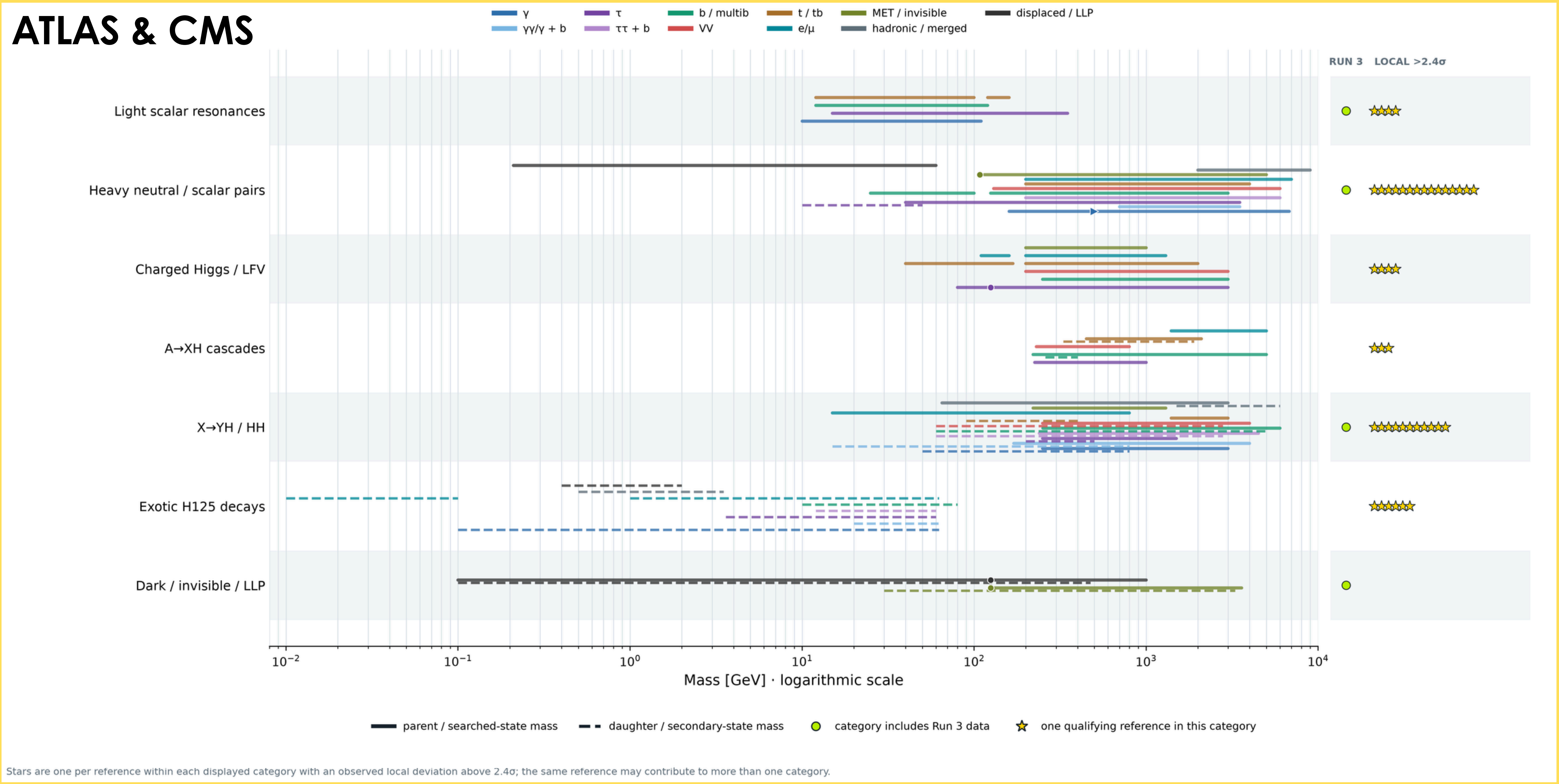
A programme spanning five orders of magnitude

- The **extended Higgs programme** spans sub-GeV daughters, electroweak-scale states, and multi-TeV parents.



A programme spanning five orders of magnitude

- The inclusive envelopes resolve into **distinct experimental signatures**; the stars only flag the presence of a retained local deviation (above 2.4 σ local).



When should a deviation influence the search programme?

- Mass proximity alone is a **prompt for a cross-check**, not evidence of a shared signal.

1

Global context

How much does the look-elsewhere effect reduce the local feature?

2

Internal stability

Does the feature persist across years, categories, and reconstruction choices?

3

Independent test

Can the other experiment test the same mass point and signal hypothesis?

4

Physics coherence

Do other final states imply compatible rates and quantum numbers?

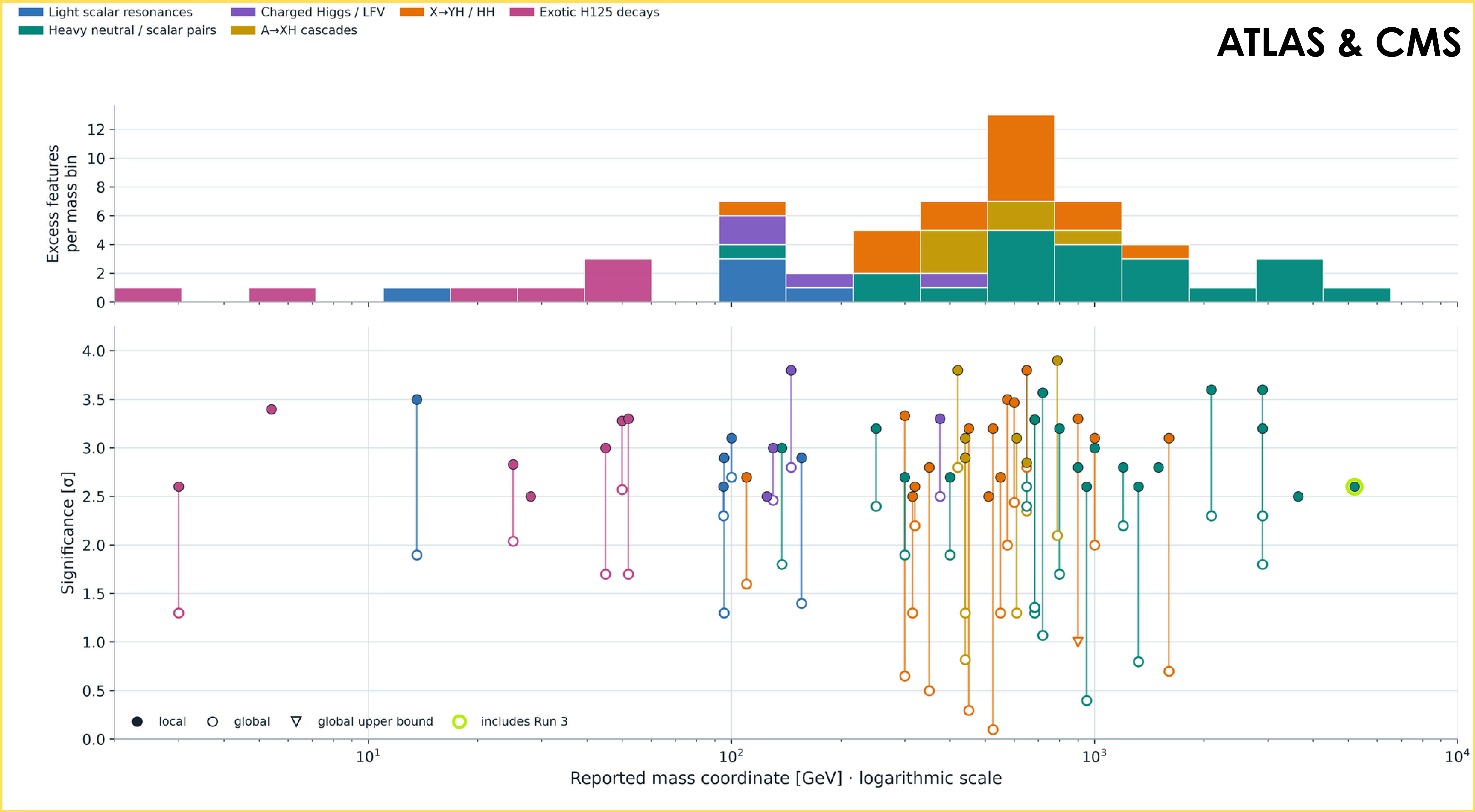
5

Independent new data

Does new data (e.g. Run 3) reproduce the feature with a predefined strategy?

Current excess landscape in the Higgs Sector

- Retained features **spread across categories**
- Where quoted, **global significances remain below discovery level.**
- Different **mass resolutions** and different **ranges** probed



Local deviations across masses and final states

- Nearby masses occur in different final states and topologies. They should be treated as a **set of testable hypotheses**, not one excess.

- Consistency of topology, production mode, daugther masses spin, width and relative rates could make excesses cross-interesting

Four physics cases to carry the discussion

- Summary plots set the scale. **Original analysis details carry the physics cases.**

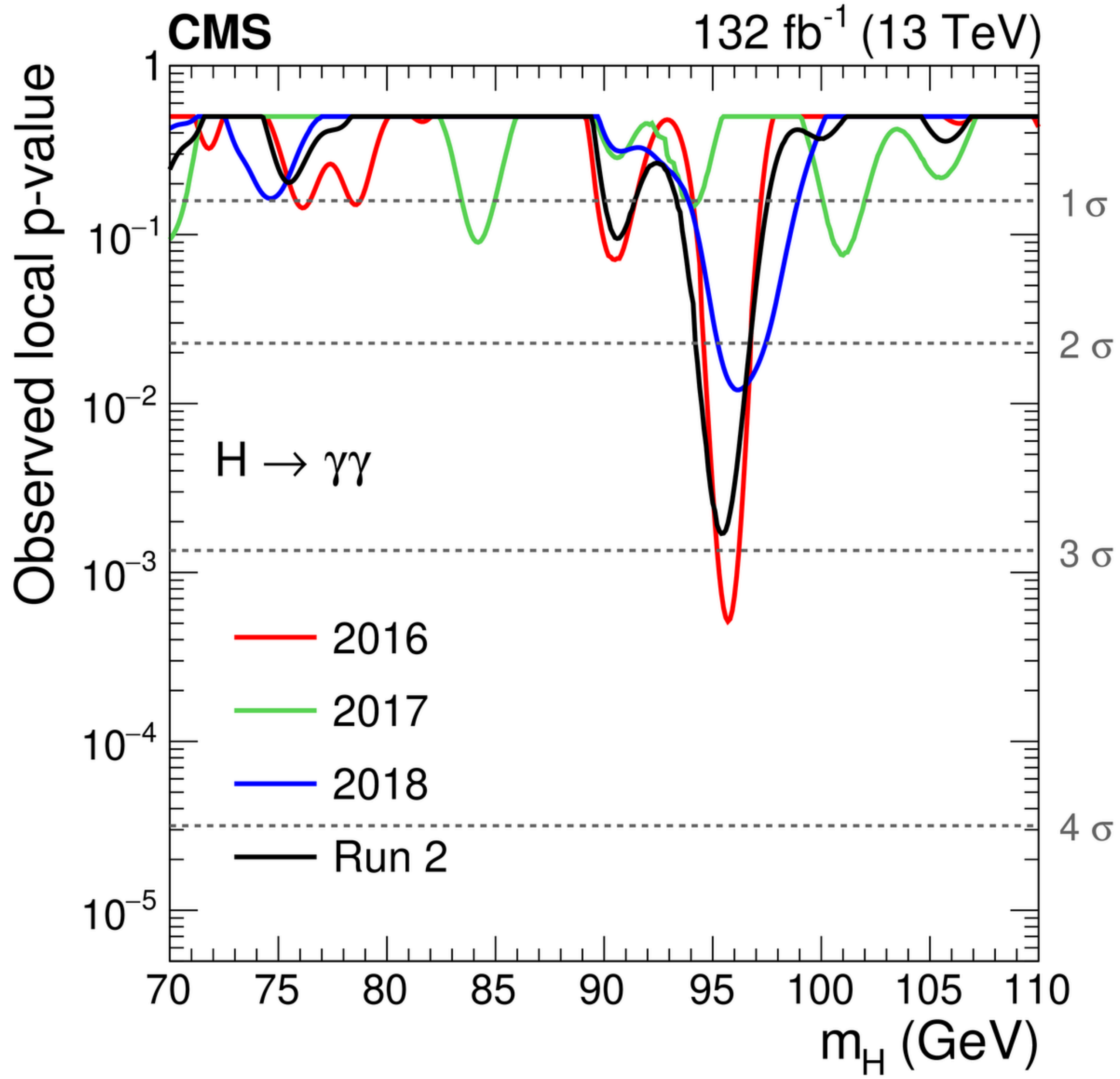
Physics cases	←-------→	**Scientific questions**
95 GeV light scalars	**γγ and ττ**	Multi-channel and cross-experiment consistency
650–700 GeV heavy states	**γγbb, WW, γγ, multiple final states**	Difference between true replication and mass coincidence
H125 exotic decays new decays	**4e and 4b/6b**	Reconstruction frontier and new phase spaces
Displaced H decays LLP frontier	**H→**$\gamma\gamma_d$, γ_d **invisible** **H→**$Z_D Z_D$	Dedicated triggers and physics reach.

The 95 GeV region

- Some relevant questions: CMS **cross-channel consistency**, ATLAS **direct or neighbouring tests**, and whether the LEP mass coincidence adds physics coherence.

The 95 GeV region: photons

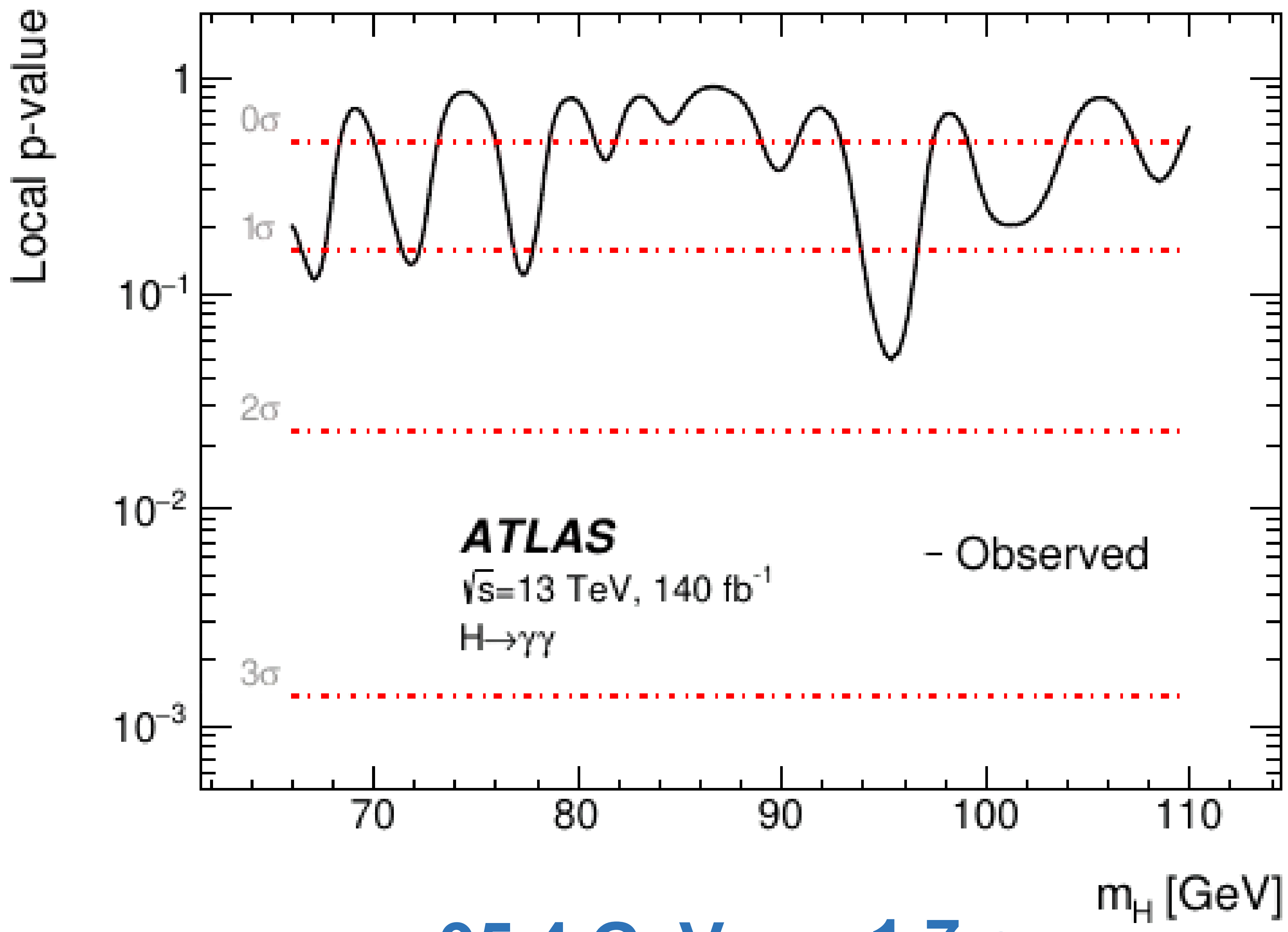
CMS HIG-20-002



95.4 GeV **2.9 (1.3) σ**

The year-by-year minima in the same neighbourhood, but global sign. is modest.

ATLAS arXiv:2407.07546

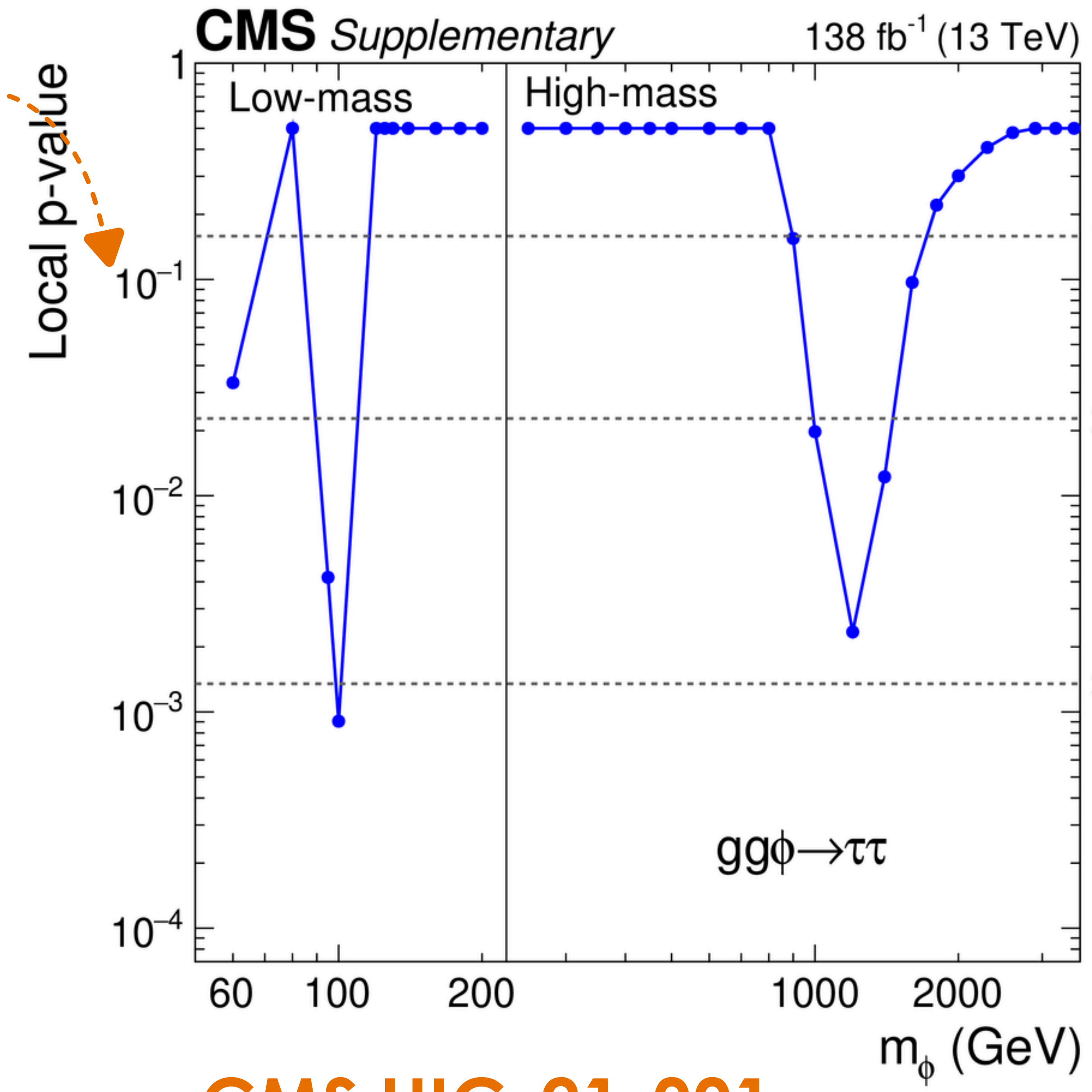


95.4 GeV **1.7 σ**

The mass is covered by both experiments in γγ, the strength of the feature is not replicated.

Assessment of the 95 GeV case including ττ

Global context	**mixed**	1.3σ in γγ, 2.3–2.7σ in ττ
Internal stability	**useful**	year and channel breakdowns exist
Independent test	**incomplete**	ATLAS γγ covers 95 GeV, ττ coverage is asymmetric
Physics coherence	**open**	a common scalar hyp. must fit rates and prod. modes
Run 3 persistence	**missing**	a predefined update remains decisive



CMS HIG-21-001
95 GeV 2.6 (2.3)σ
100 GeV 3.1 (2.7)σ

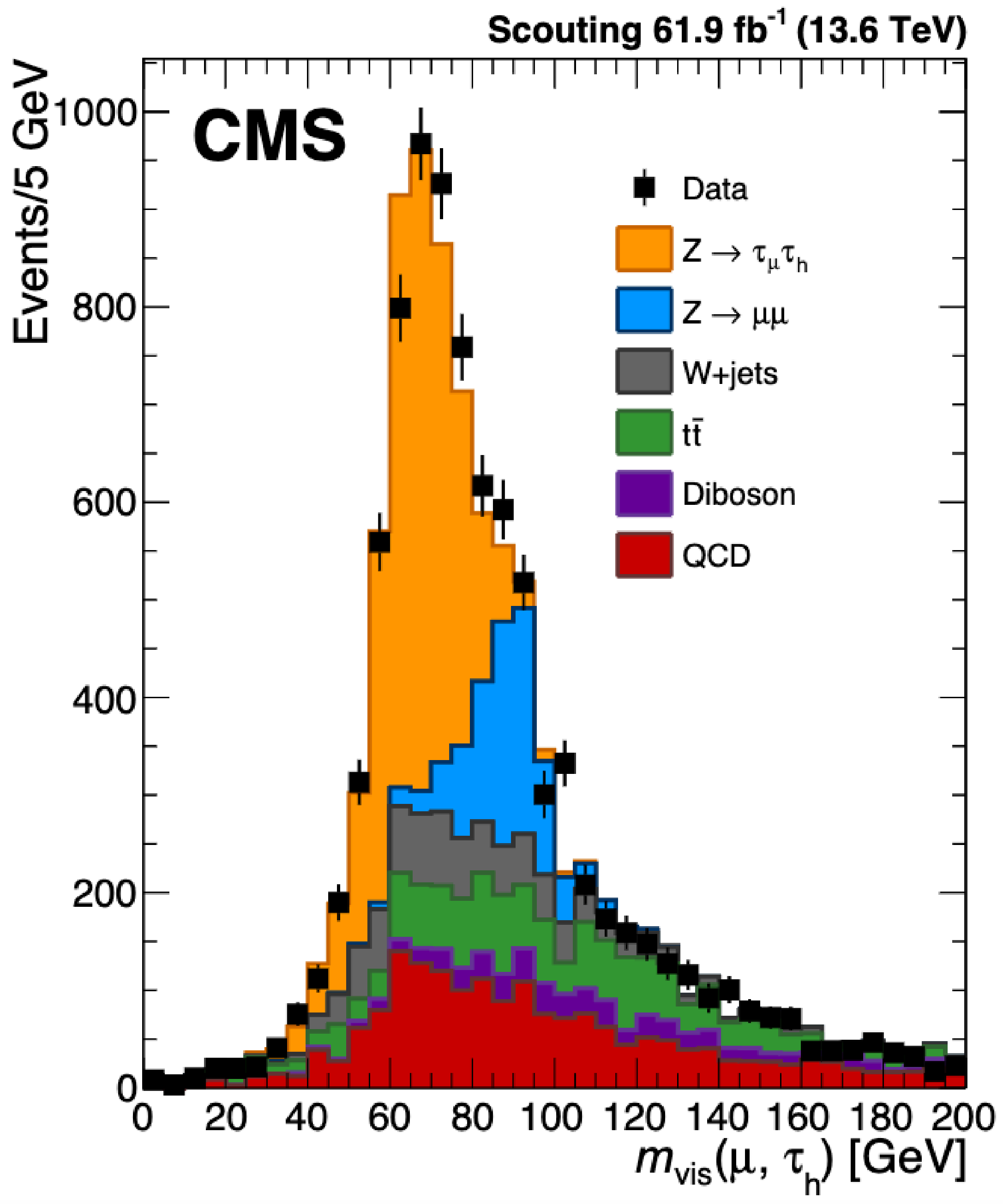
- Worth a targeted Run 3 test (in progress): evaluate compatible signal behaviour, ideally with independent data and a consistent rate interpretation.

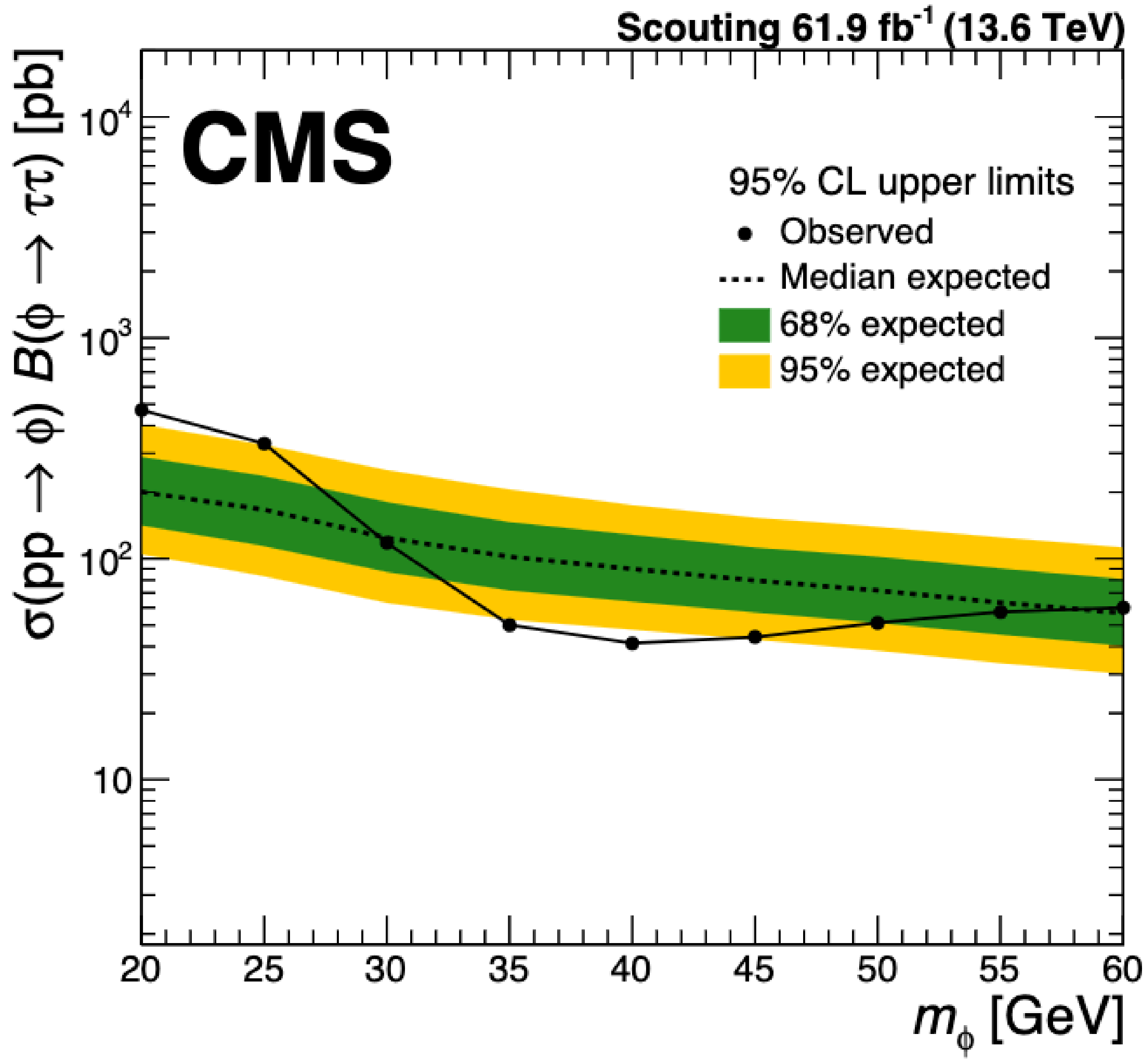
Dedicated data streams:a door to low mass intervals

- The 95 GeV story also exposes a broader **low-mass acceptance challenge**
  - E.g.: **Scouting Run 3**: richer event content enables dedicated **tau leptons** reconstruction from all info stored in scouting dataset

CMS EXO-24-012

  - From standard reconstruction (pT > 20 GeV) down to **5 GeV**, w/ a **dedicated NN**
  - Reduced event content
  - Direct ττ sensitivity in Run 3

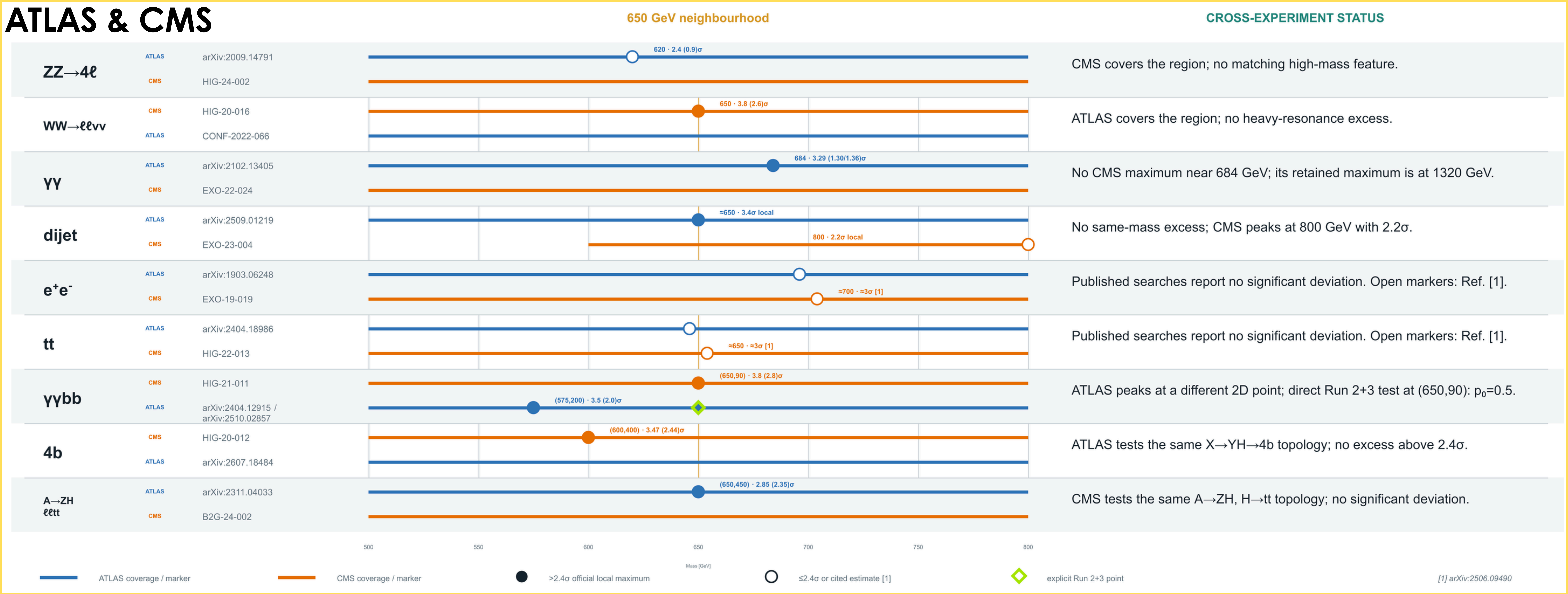




- Methodological relevance: t**he gain comes from changing what is recorded** not just from accumulating more luminority

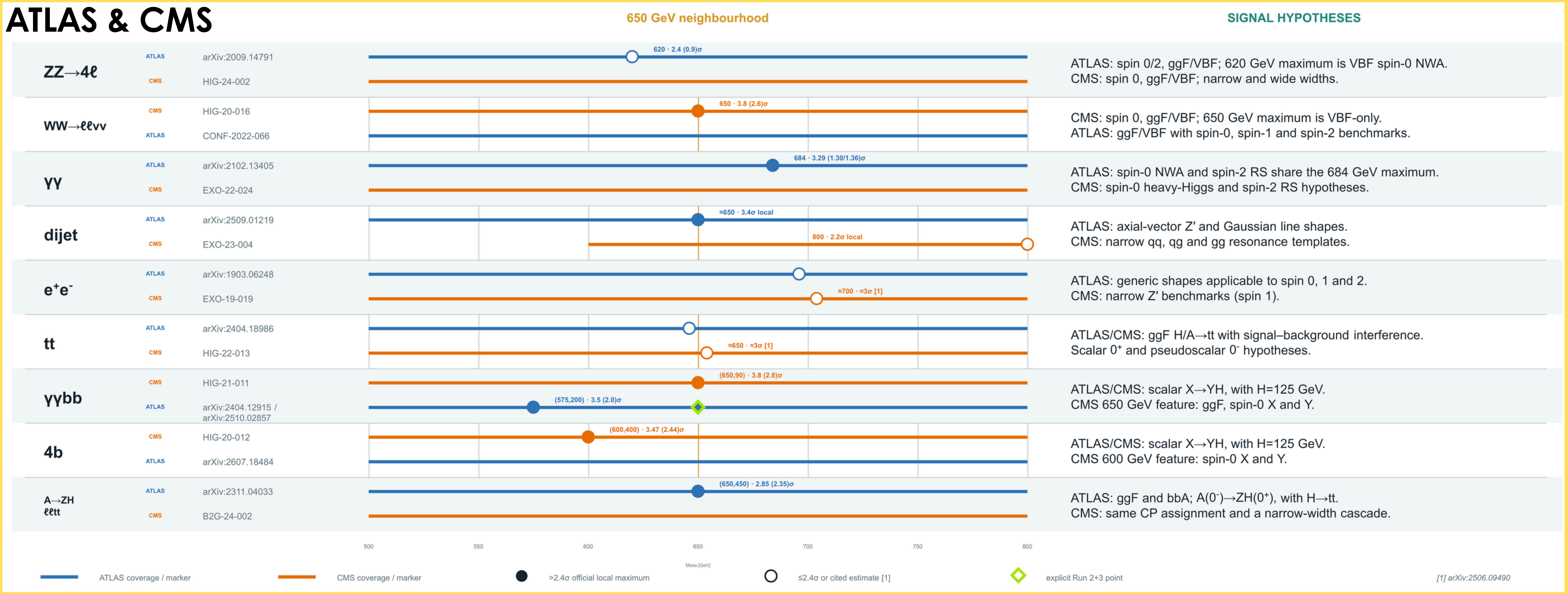
The 650–700 GeV region across final states

- The apparent **mass clustering** emerges from published maxima, direct non-confirmations and phenomenological readings.
- Coverage is broad, but **no final state shows a same-mass excess in both experiments.**



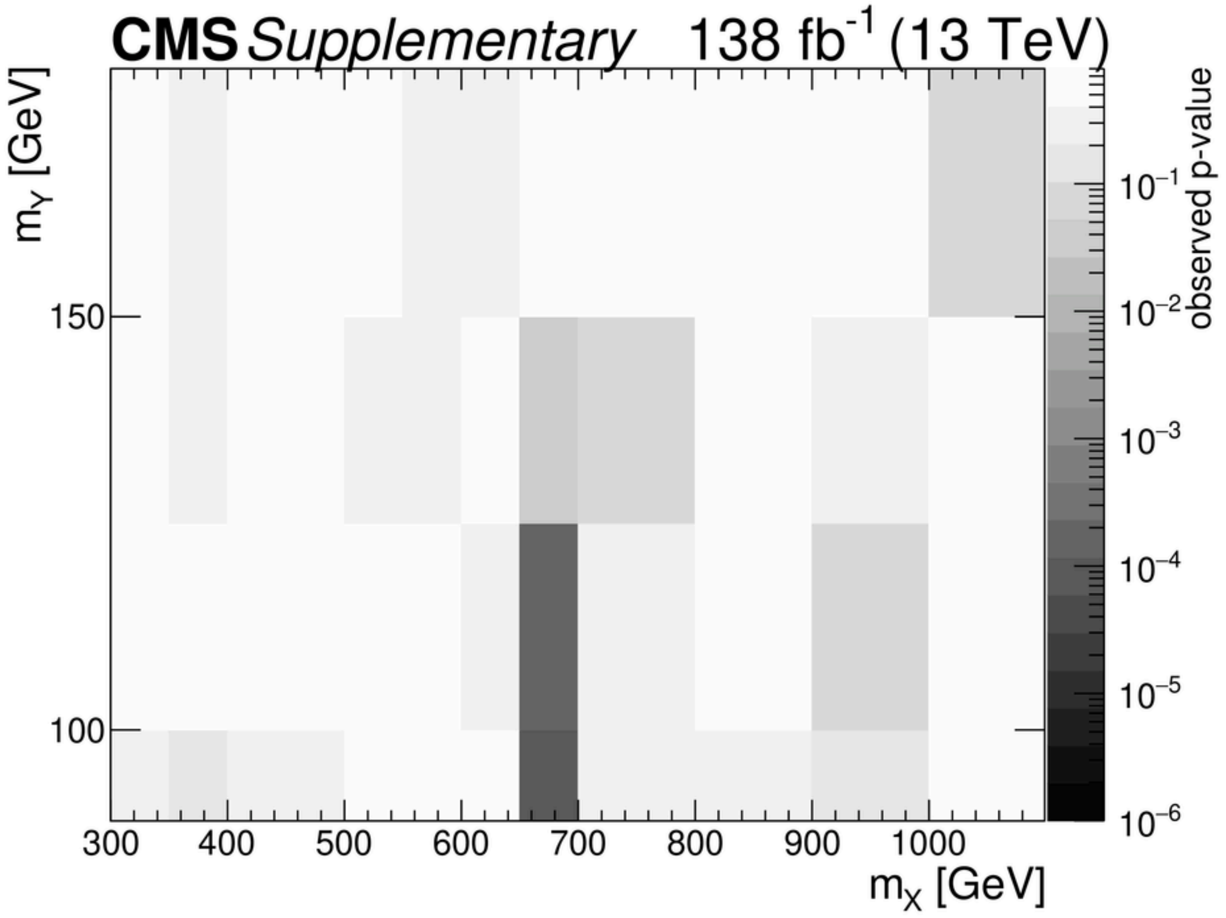
The 650–700 GeV region across signal hypotheses

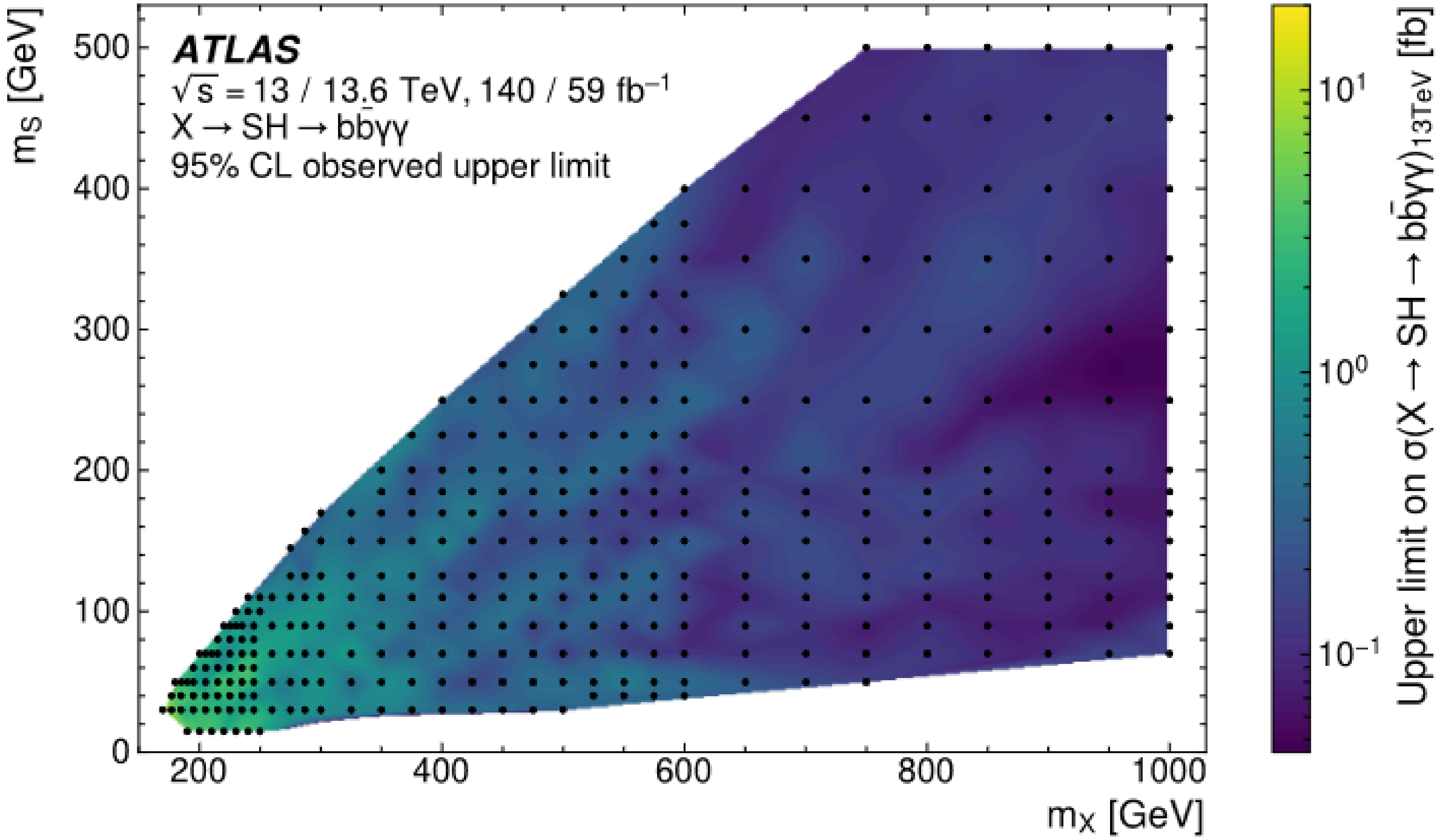
- The **production mechanisms and spin assumptions** differ across channels, so these inputs do not yet define a single experimental hypothesis.



X→YH→bbγγ: a point-by-point replication test

- The parent coordinate becomes comparable only after fixing the daughter mass, final state and signal hypothesis.





CMS HIG-21-011

(650,90) GeV · 3.8 (2.8) σ

ATLAS arXiv:2404.12915

(575,200) GeV · 3.5 (2.0) σ

ATLAS arXiv:2510.02857

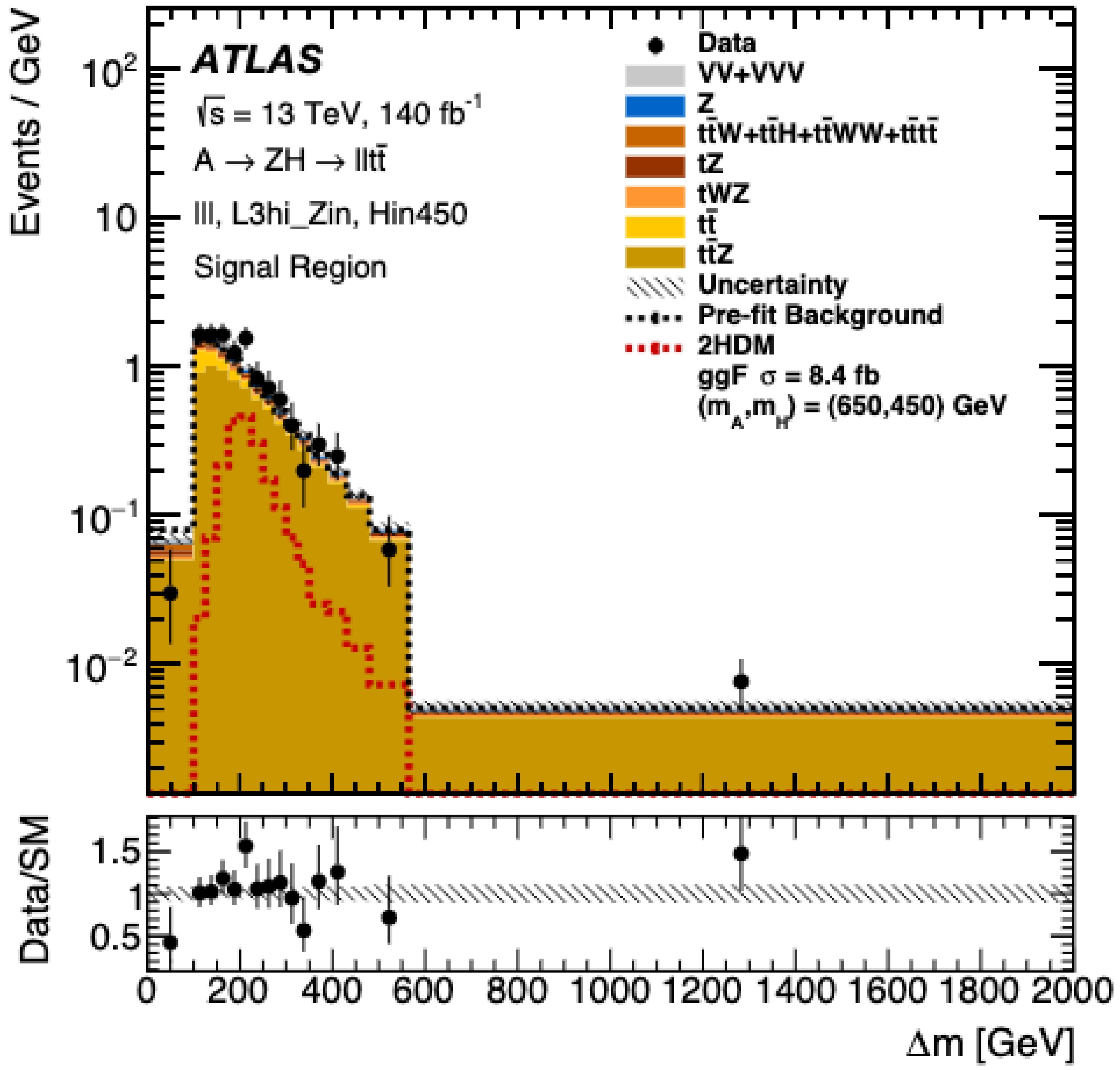
140 fb^{-1} Run 2 + 58.6 fb^{-1} Run 3

@ (650,90): p_0 = 0.5 · CMS maximum absent

- Best example of independent new data performing point-by-point replication test

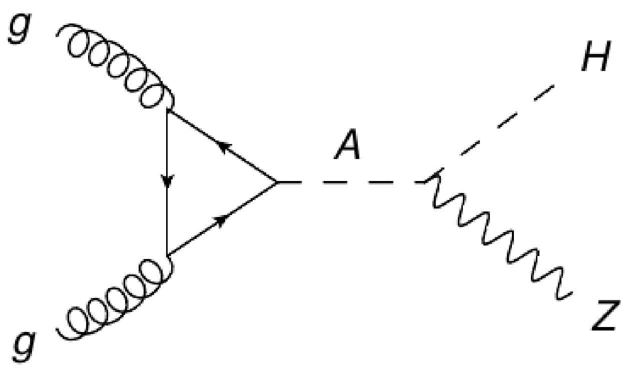
A→ZH→(ee/μμ)(tt) at 650 GeV

- Here the daughter is H(450), with a CP-odd parent and both ggF and bbA production.

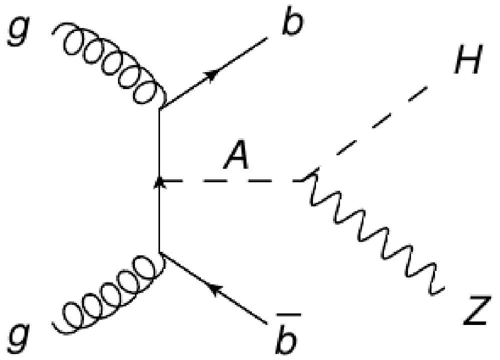


$$\Delta m = m(\ell\ell tt) - m(tt)$$

ATLAS arXiv:2311.04033



ggF



bbA

- Z→ee/μμ; H→tt with one semileptonic t decay
- 3 e/μ, ≥4 jets, ≥2 b tags; simultaneous SR/CR fit

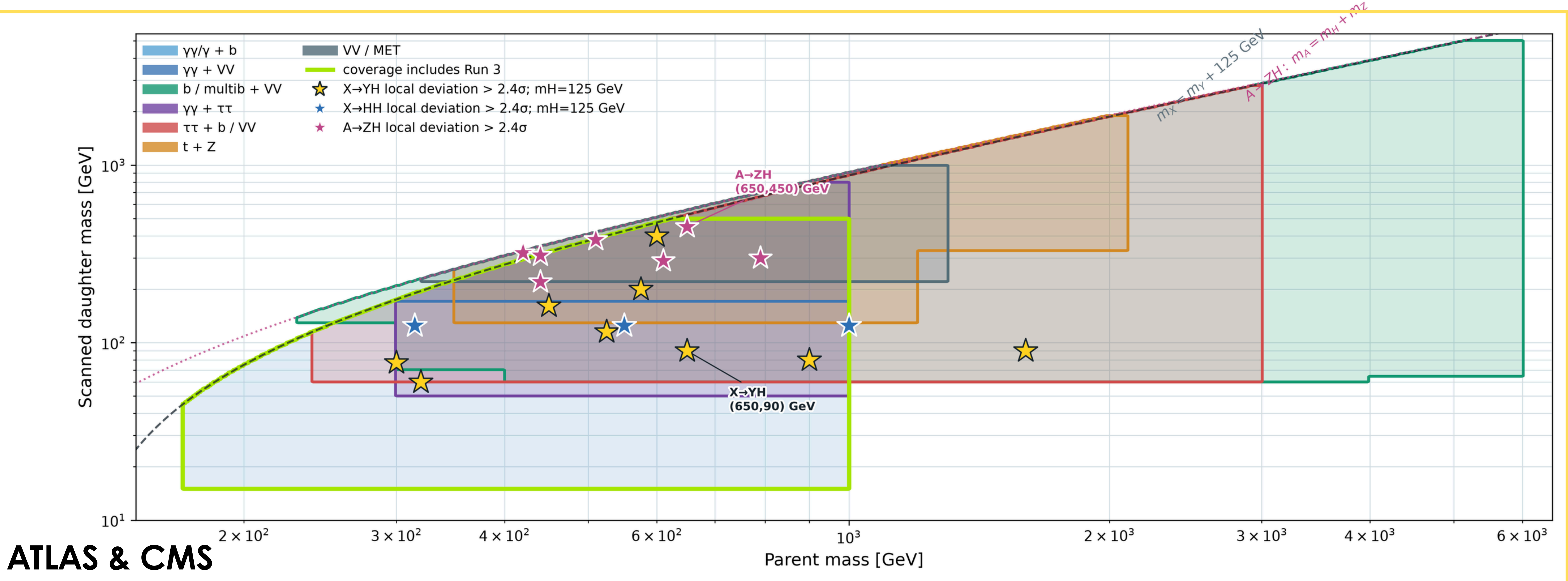
OBSERVED FEATURE: ------→ **(650,450) GeV 2.85 (2.35) σ**

TOPOLOGY-MATCHED TEST

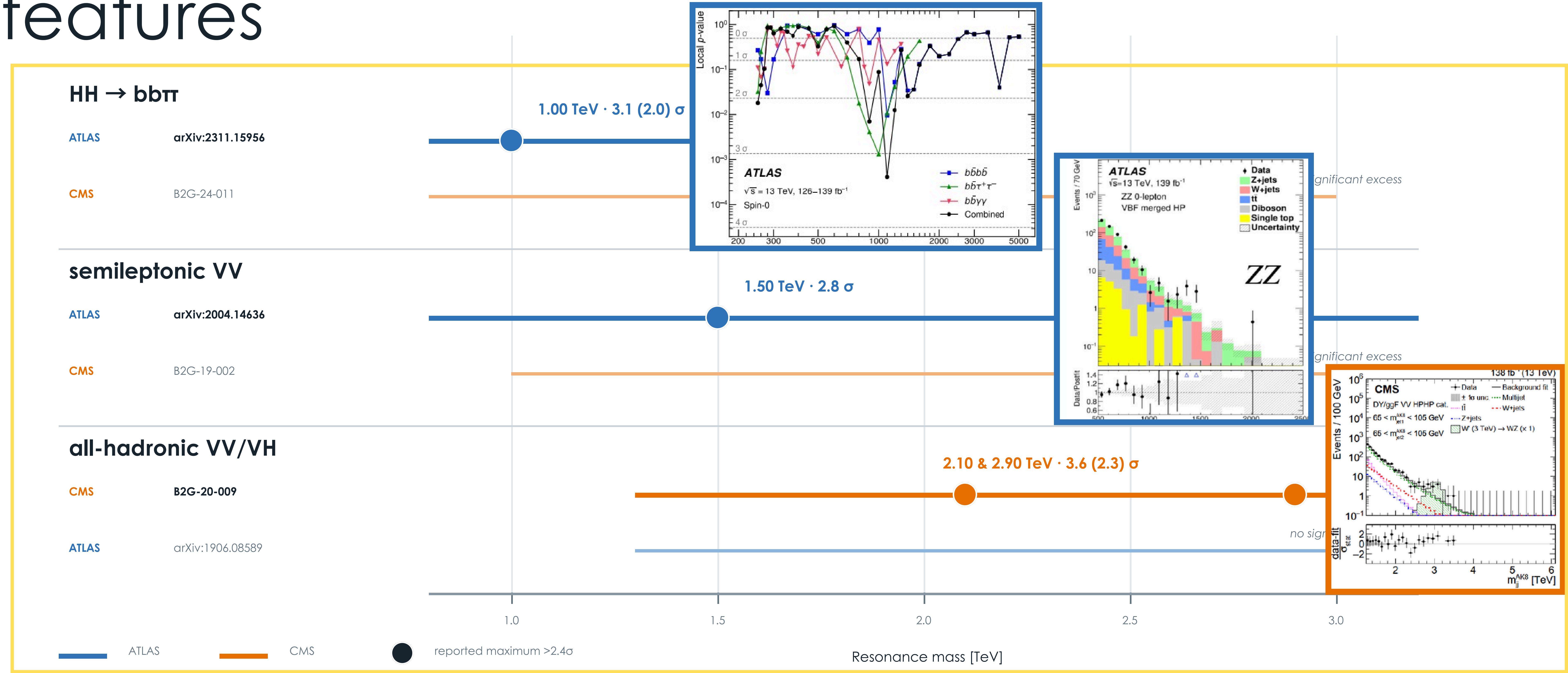
- **CMS B2G-24-002** covers semileptonic and all-hadronic tt.
- Largest fluctuation: **1.5 σ at (850,500) GeV**; data consistent with the SM.

Expanding the search across masses and cascade topologies

- The broader map identifies **overlapping coverage** and **independent tests** across the search programme, providing the experimental basis for evaluating structured interpretations

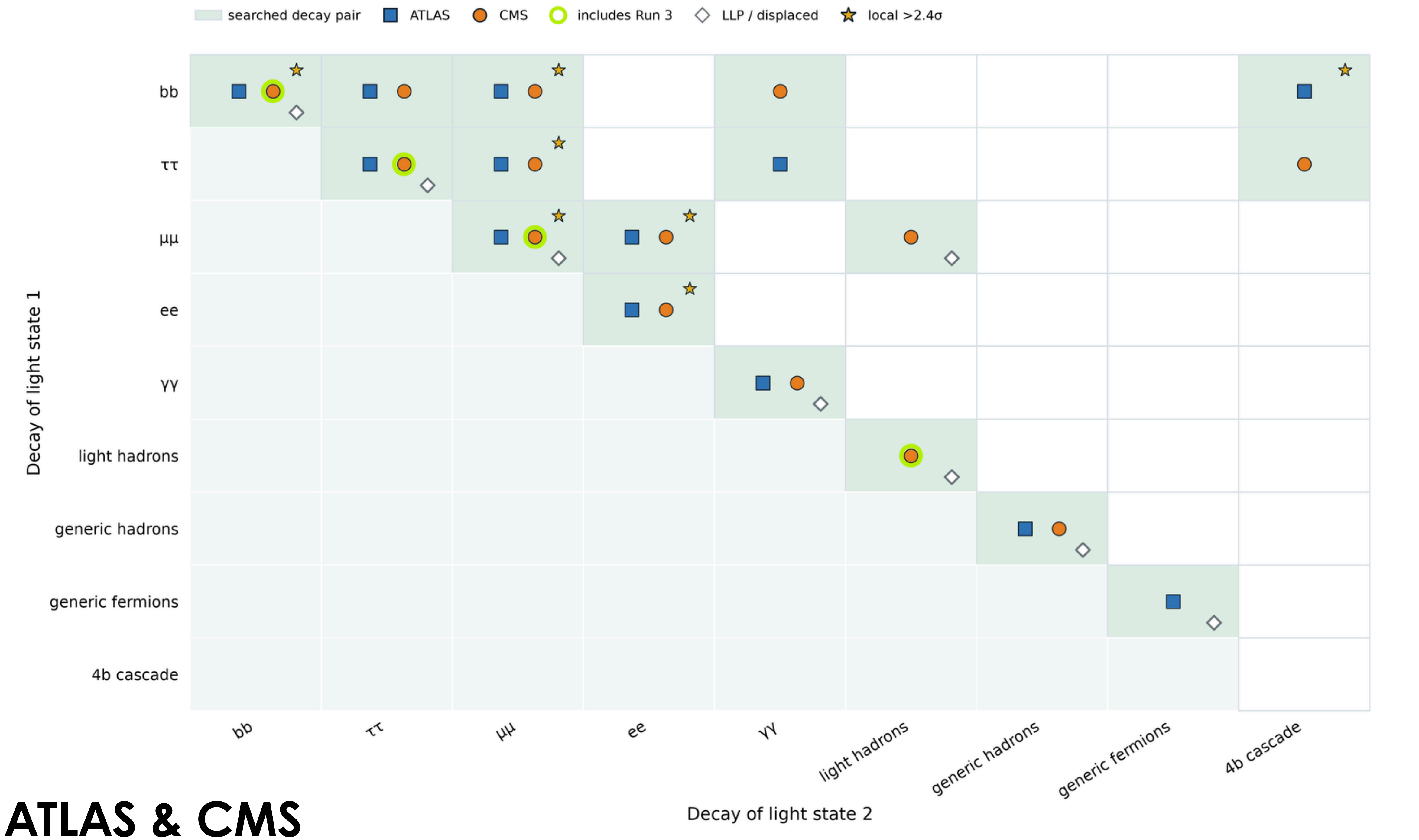


Beyond the cascade map: three high-mass features



- A **recurrence claim** (see e.g. arXiv:2506.09490) requires one predefined test of the masses, quantum numbers, spin/CP, width hypothesis, production mode and relative rates.

Exotic Higgs decays add new experimental axes



ATLAS & CMS

NEW SEARCH STRATEGIES:

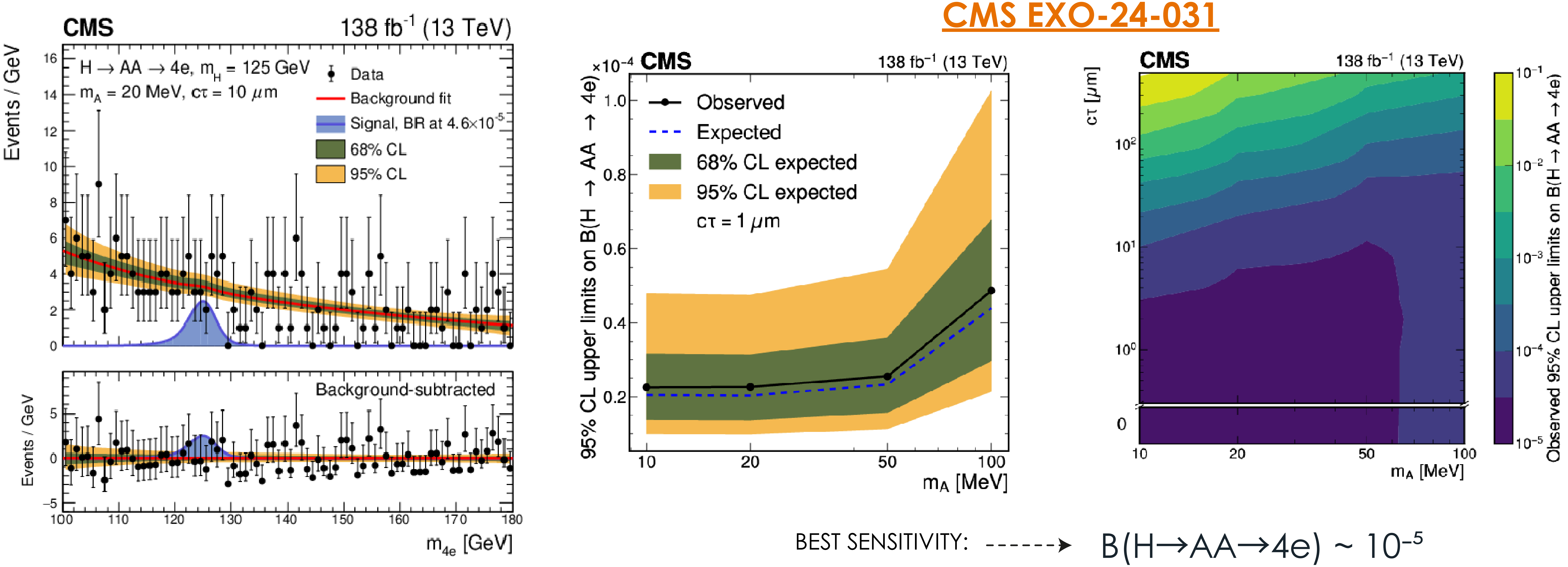
- **COLLIMATION**: Merged objects recover very light daughters
  - CMS H → aa → 4e
  - ATLAS H → aa → 4b/6b
- **VISIBILITY**: Dedicated trigger
  - ATLAS Run 3 H → $\Upsilon\Upsilon_d$ in ggF
- **LIFETIME & EVENT RECORDING**: Scouting retains low-pT, displaced resonances
  - CMS Run 3 H → $Z_D Z_D$ → 4μ

- Mass, collimation and lifetime determine both what can be reconstructed and what can be recorded.

Light daughters into dedicated merged electron-pair object

- **New reconstructed object** opens order of magnitudes of previously inaccesible phase spacess.
- Tracker and calorimeter information are combined in a multivariate merged-pair identifier.

CMS EXO-24-031



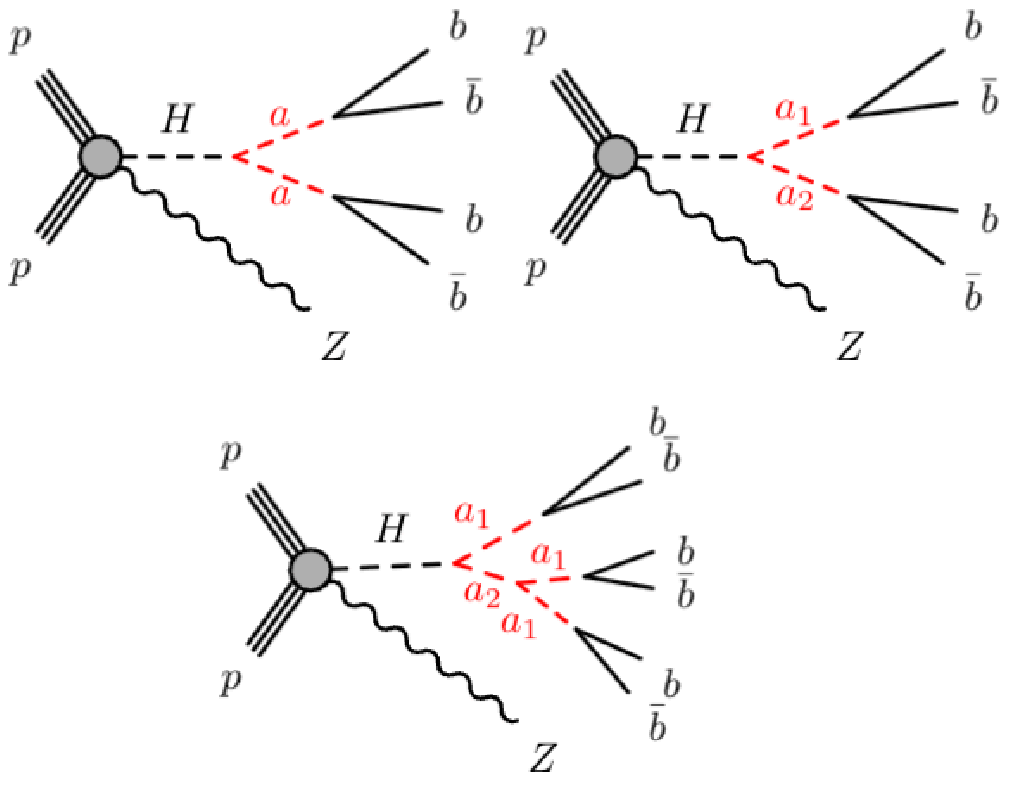
BEST SENSITIVITY: ------→ $B(H\rightarrow AA\rightarrow 4e) \sim 10^{-5}$

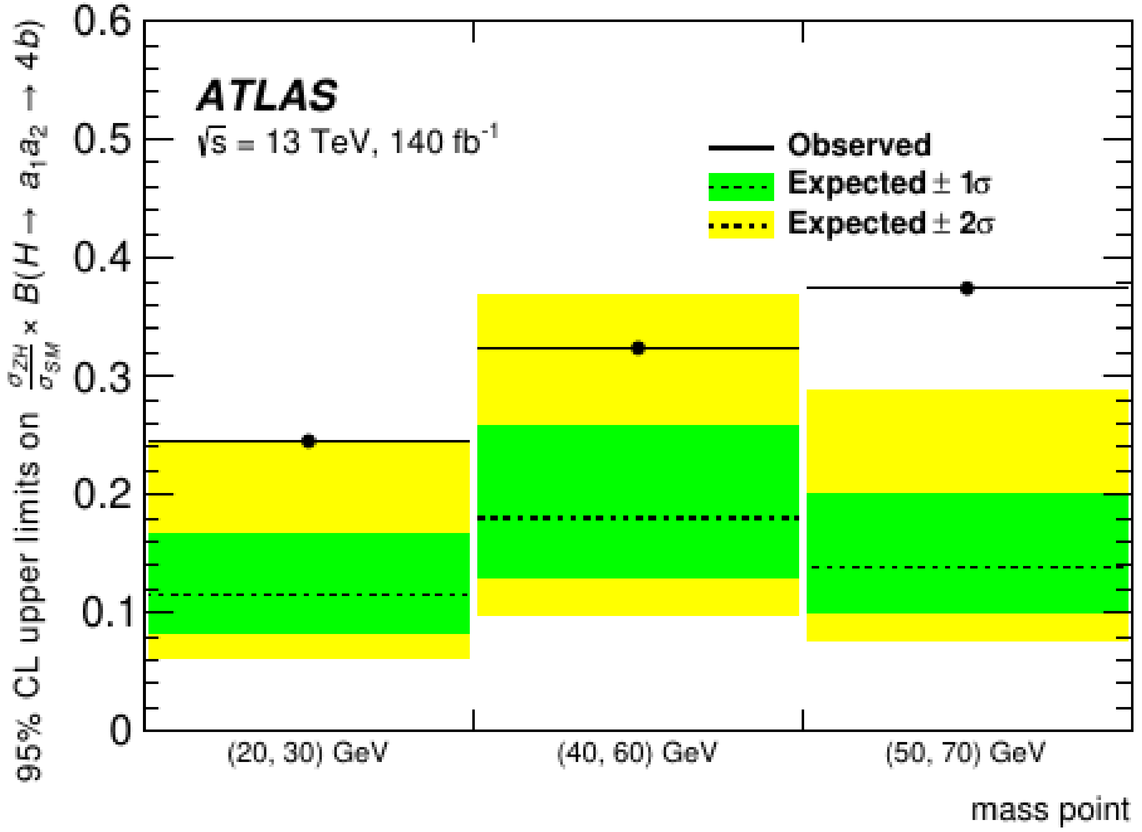
- TOPOLOGY-MATCHED TEST **ATLAS arXiv:2110.13673**

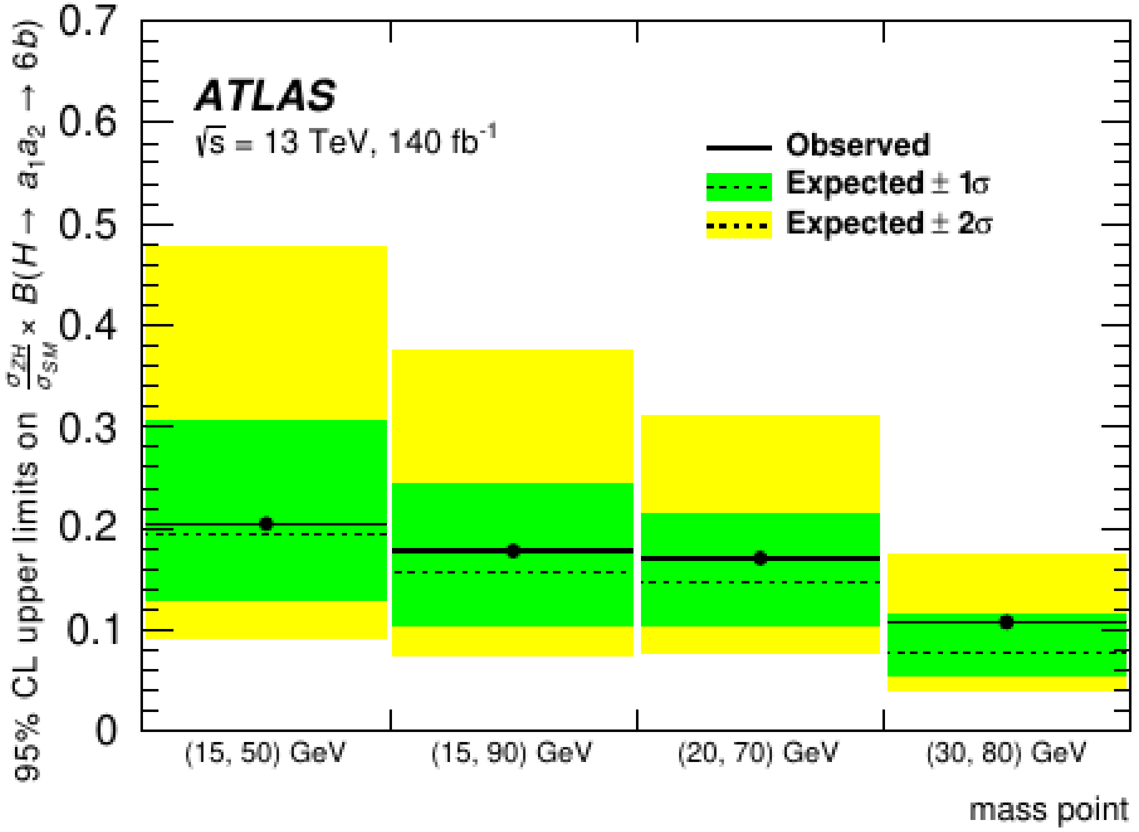
Merged b-jets recover the low-mass Higgs decay

- The transition **from merged b-jets to resolved b-jets** is part of the signal model, not merely a reconstruction detail.

[ATLAS arXiv:2507.01165](#)







ma ≲ 20 GeV
merged double-b b-jets

ma ≳ 25 GeV
resolved standard b-jets

high multiplicity
soft secondary vtx outside jets

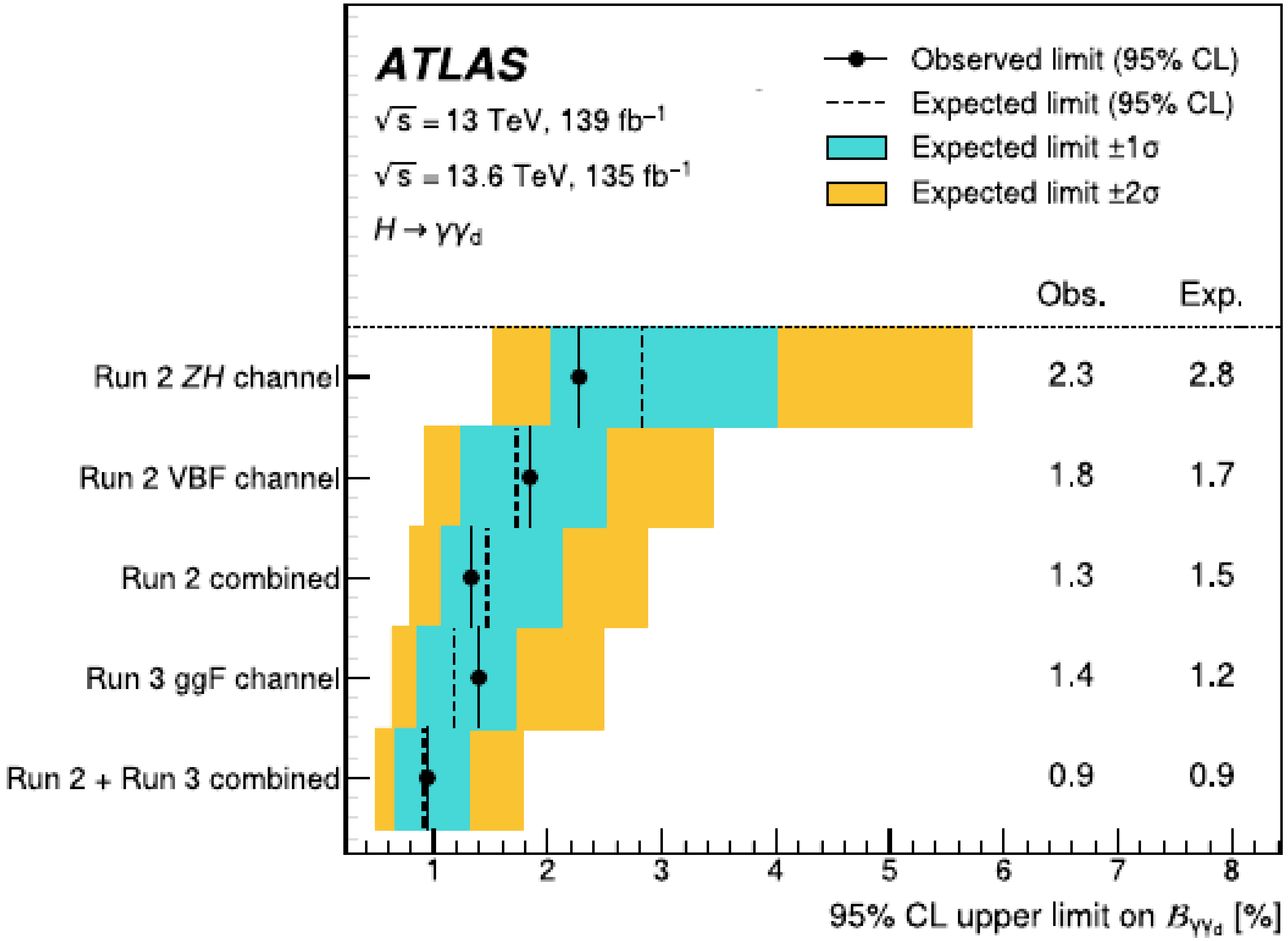
LARGEST DEVIATIONS: ------→ **ma=25 GeV 2.83 (2.04)σ** **(ma_1,ma_2)=(50,70) GeV 3.28 (2.57)σ**

- TOPOLOGY-MATCHED TEST [CMS HIG-18-026](#)

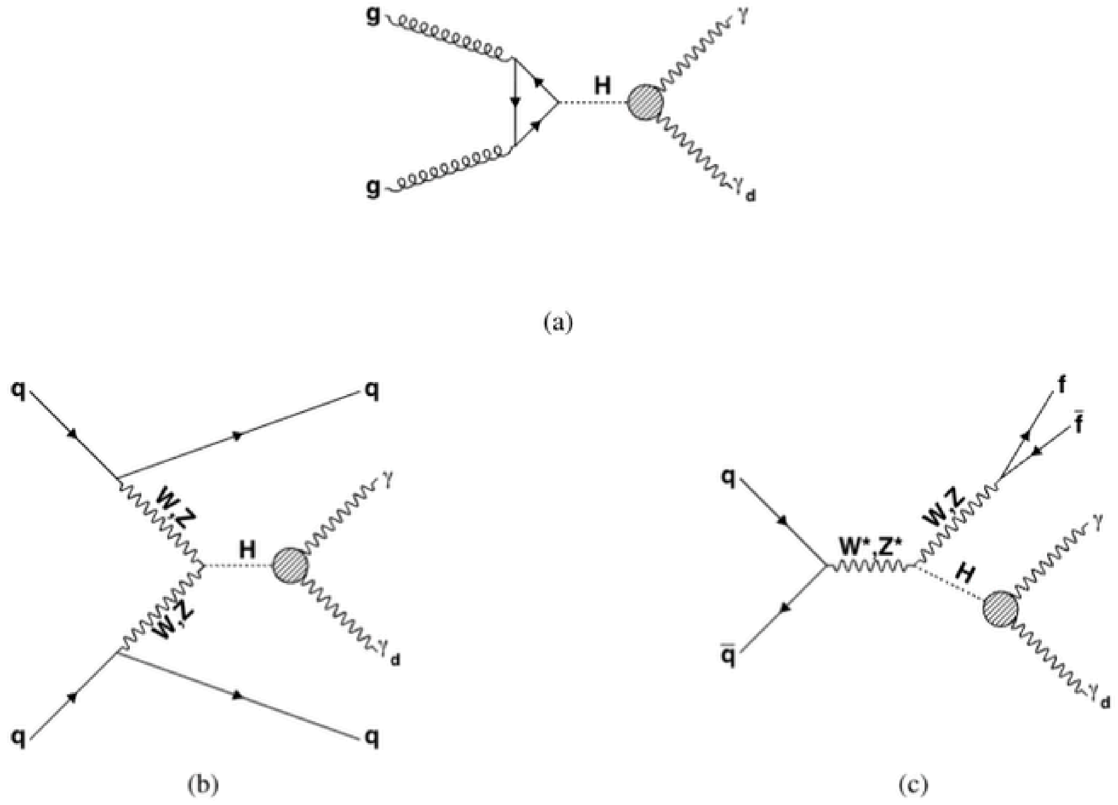
Dedicated Run 3 trigger opens the ggF H→ $\gamma\gamma_d$

- A **dedicated 2023 trigger** makes ggF accessible at ATLAS; the Run 2+3 combination reaches a 0.9% observed limit.

ATLAS arXiv:2606.14362



H→ $\gamma\gamma_d$, γ_d invisible



95% CL limits on B(H→ $\gamma\gamma_d$)

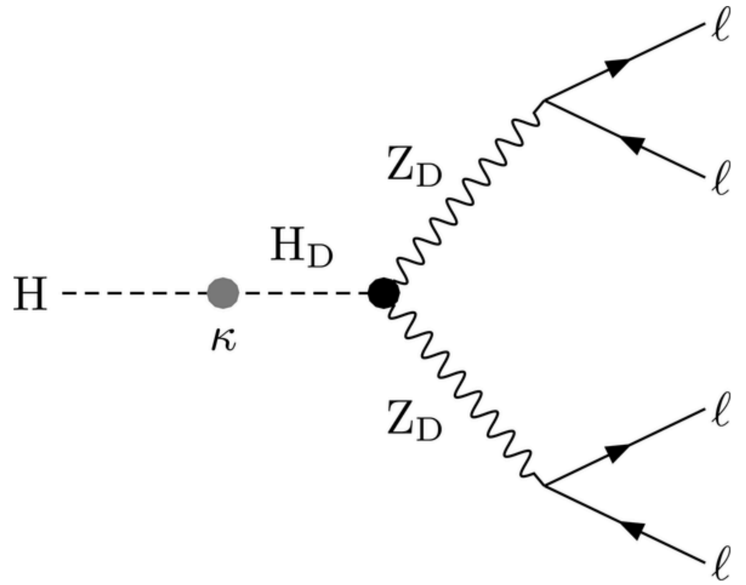
Run 3 1.4% (1.2%)
Run 2+3 0.9% (0.9%)

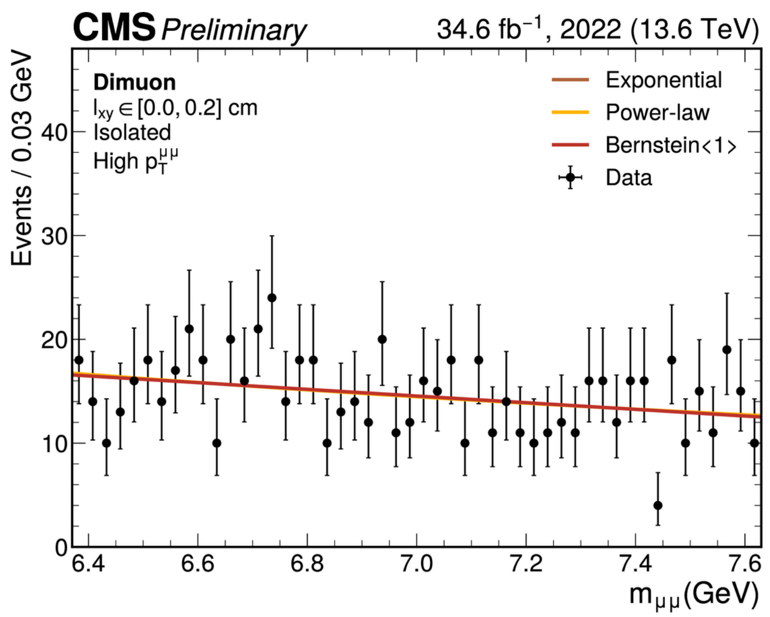
No significant excess

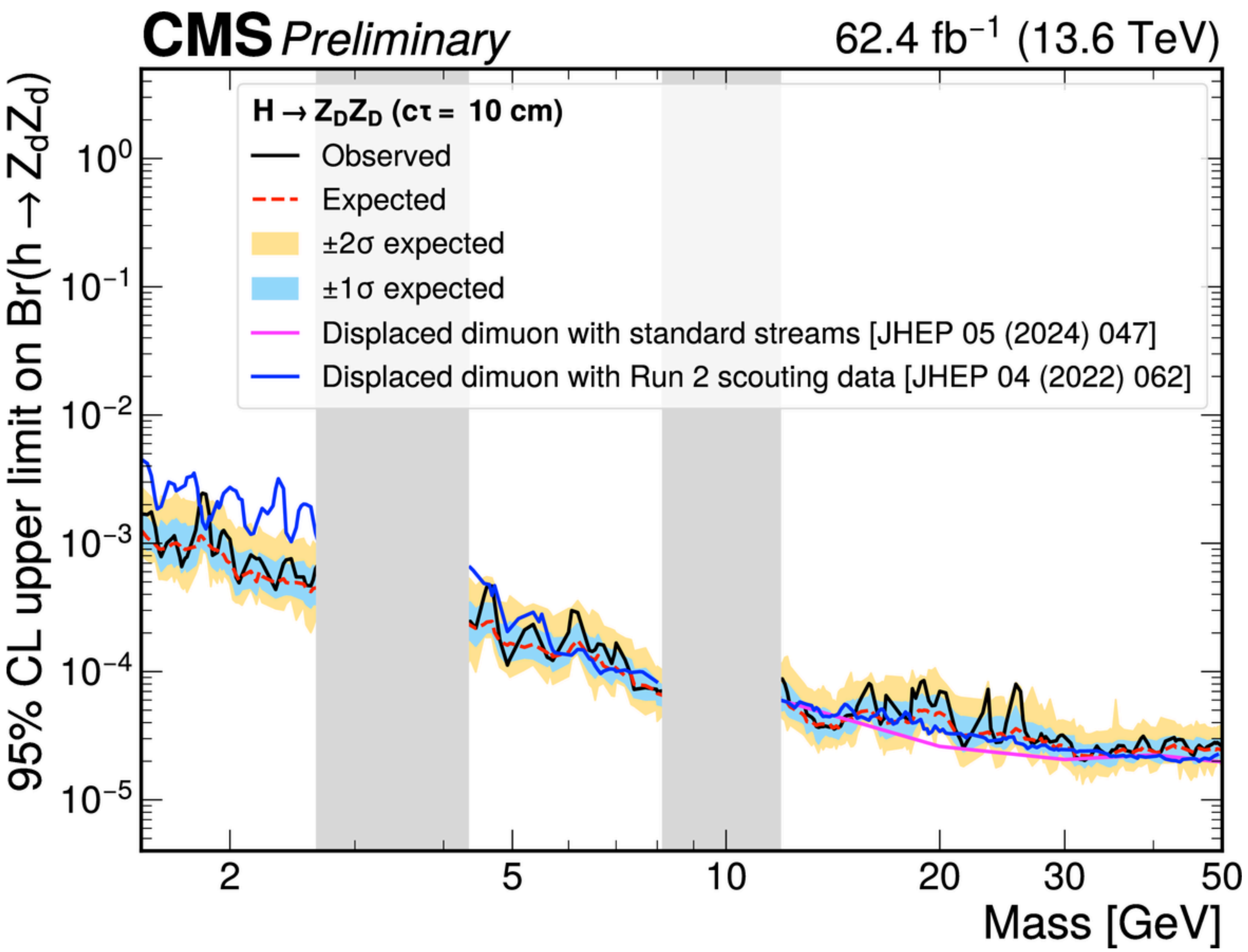
- TOPOLOGY-MATCHED TEST CMS EXO-19-007 and CMS EXO-20-005

Scouting defines a new displaced Higgs reach

- Compact scouting content retains the resonance information while **low thresholds open the long-lived (cτ 0.1–100 cm)** Higgs portal.







CMS EXO-24-016

DIMUON SCOUTING STREAM

L1 ≥2 μ, pT > 8 GeV

HLT OS μμ, pT > 3 GeV, |η| < 2.4

REDUCED EVENT CONTENT	dimuon mass resolution within 1% of offline
BACKGROUND	constrained directly from smooth fits to data

No significant excess

- TOPOLOGY-MATCHED TEST **ATLAS arXiv:2311.18298**

From a search inventory to a roadmap

- The current deviations define a limited set of experimental tests, concrete coverage gaps and requirements for reusable analyses.

1 PREDEFINED RUN 3 TESTS

95 GeV
Fixed $\gamma\gamma$ and $\tau\tau$ hypotheses with Run 3-only fits

650 GeV
Exact (650,90) $\gamma\gamma bb$ test and matched WW production categories

MISSING REPLICATIONS
$X\to e\mu$ at 146 GeV and $A\to ZH$ at (420,320) GeV

2 COVERAGE TO COMPLETE

CASCADE FINAL STATES
$X\to YH\to\gamma\gamma\tau\tau$ on one continuous 2D mass grid

EXOTIC H125 DECAYS
Unequal-mass 4b/6b configurations and γ + MET

EVENT-ACCESS GAPS
Low-mass $\tau\tau$ and displaced four-muon decays

3 ANALYSES READY FOR HL-LHC

INDEPENDENT DATA
Use full Run 3 without retuning the Run 2 hypothesis

CONDITIONAL ML
Continuous mass and lifetime grids across resolved and boosted regimes

PRESERVED ANALYSIS
Dedicated streams, efficiency maps and likelihoods ready for the first HL-LHC data

LHC BSM WG

LINK

Retain benchmark coordinates, distinguish exact from complementary counterparts and keep an explicit register of uncovered phase space.

The same framework can standardise fixed-point p_0 reporting, global trial domains, efficiency maps and likelihood release.

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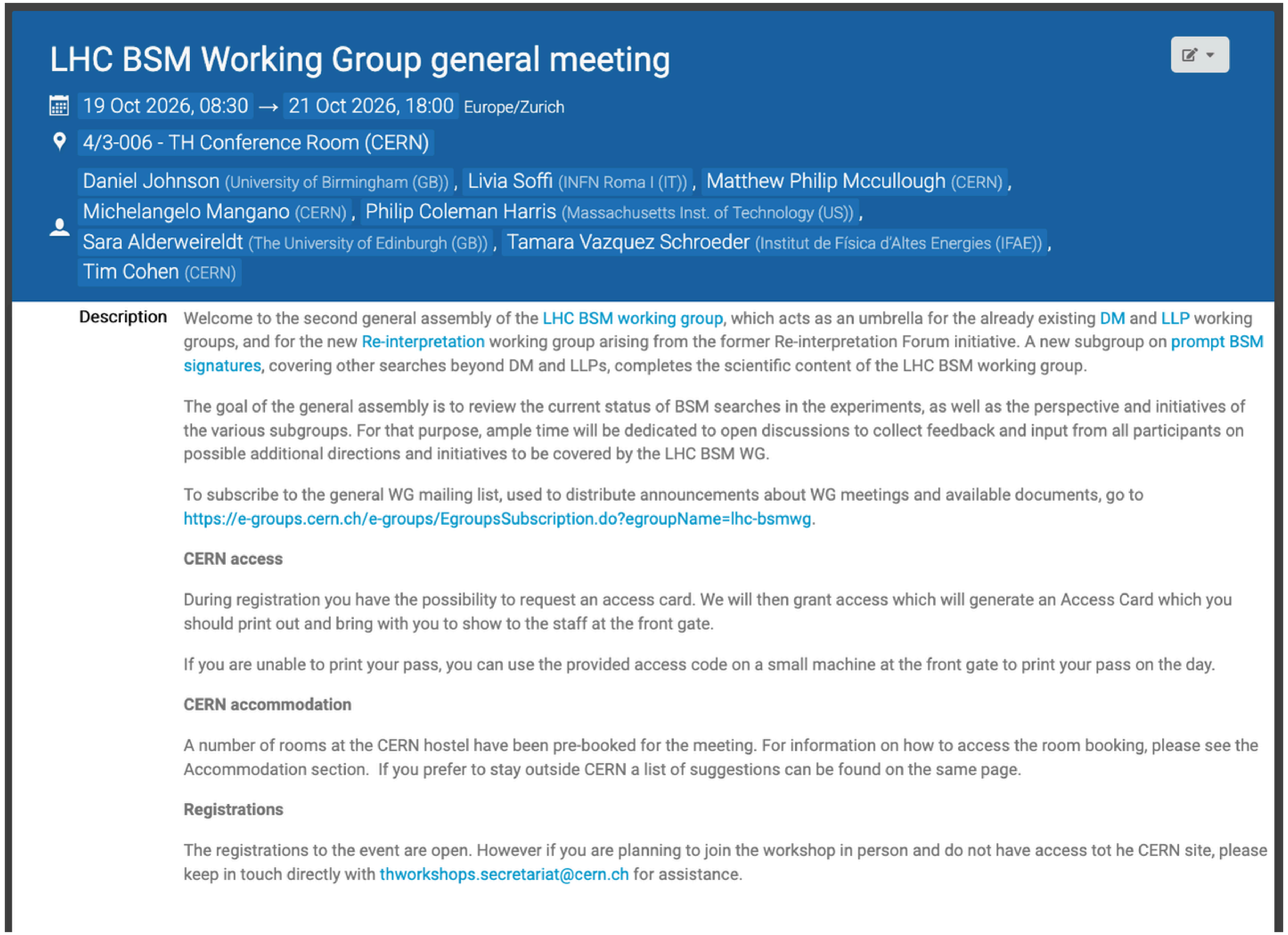
The LHC BSM WG 2026 Workshop

- **19-21 October 2026 @ CERN && ZOOM**
- Review status of **BSM searches across experiments**
- Present **perspectives & initiatives** of all subgroups
- Foster **open discussions** for:
  - Feedback from participants
  - Exploring new directions & initiatives

Register here!!



LHC BSM Working Group general meeting

19 Oct 2026, 08:30 → 21 Oct 2026, 18:00 Europe/Zurich

4/3-006 - TH Conference Room (CERN)

Daniel Johnson (University of Birmingham (GB)), Livia Soffi (INFN Roma I (IT)), Matthew Philip Mccullough (CERN), Michelangelo Mangano (CERN), Philip Coleman Harris (Massachusetts Inst. of Technology (US)), Sara Alderweireldt (The University of Edinburgh (GB)), Tamara Vazquez Schroeder (Institut de Física d'Altes Energies (IFAE)), Tim Cohen (CERN)

Description

Welcome to the second general assembly of the LHC BSM working group, which acts as an umbrella for the already existing DM and LLP working groups, and for the new Re-interpretation working group arising from the former Re-interpretation Forum initiative. A new subgroup on prompt BSM signatures, covering other searches beyond DM and LLPs, completes the scientific content of the LHC BSM working group.

The goal of the general assembly is to review the current status of BSM searches in the experiments, as well as the perspective and initiatives of the various subgroups. For that purpose, ample time will be dedicated to open discussions to collect feedback and input from all participants on possible additional directions and initiatives to be covered by the LHC BSM WG.

To subscribe to the general WG mailing list, used to distribute announcements about WG meetings and available documents, go to https://e-groups.cern.ch/e-groups/EgroupsSubscription.do?egroupName=lhc-bsmwg.

CERN access

During registration you have the possibility to request an access card. We will then grant access which will generate an Access Card which you should print out and bring with you to show to the staff at the front gate.

If you are unable to print your pass, you can use the provided access code on a small machine at the front gate to print your pass on the day.

CERN accommodation

A number of rooms at the CERN hostel have been pre-booked for the meeting. For information on how to access the room booking, please see the Accommodation section. If you prefer to stay outside CERN a list of suggestions can be found on the same page.

Registrations

The registrations to the event are open. However if you are planning to join the workshop in person and do not have access tot he CERN site, please keep in touch directly with thworkshops.secretariat@cern.ch for assistance.

Thank you very much for listening!

BACKUP

Working material — please read this first

These figures are working material for scientific discussion and exploit only public results.

- **Not official or citable**
  They are not approved ATLAS, CMS, CERN or LHC BSM WG material.
- **No universal message is intended**
  The plots are descriptive aids, not a ranking, a confirmation claim or a statistical combination of experiments.
- **The purpose is iteration**
  Feedback should tell us which views are useful, which categories mislead and where the underlying audit needs work.
- **Primary sources always take precedence**
  If a summary conflicts with an original paper or official result page, the primary result wins.

Links [Public repository] [Public workbook data] [Public excess table]

What this work is trying to do

Not another results list. A shared way to look across the programme and decide what is worth improving

01 | **Start from the search programme**
States, cascades, portals, mass roles and final states define the map.

02 | **Use excesses carefully**
They can focus questions, but they do not define the programme or imply coherence.

03 | **Make every summary auditable**
A plotted interval or significance should always lead back to one public source row.

The goal today is to find out which of these views are genuinely useful.

How the workbook was assembled

Discover	Scope	Normalize	Cross-link	Verify
1	2	3	4	5
Official ATLAS, CMS and WG lists	Keep current BSM Higgs searches	Process, final state, dataset and mass role	Counterparts and qualifying deviations	Primary papers and exact plot membership

The plots came last. Unsupported endpoints and significances stayed blank instead of being inferred.

Why one paper can occupy two rows

The unit of the inventory is a scoped analysis entry, not a unique publication.

ONE REFERENCE

stable paper / public result

ENTRY A

one process / final state / mass role

ENTRY B

another topology, interpretation or mass role

Why keep both?

No lost coverage

No double-counted claim

Exact plot membership

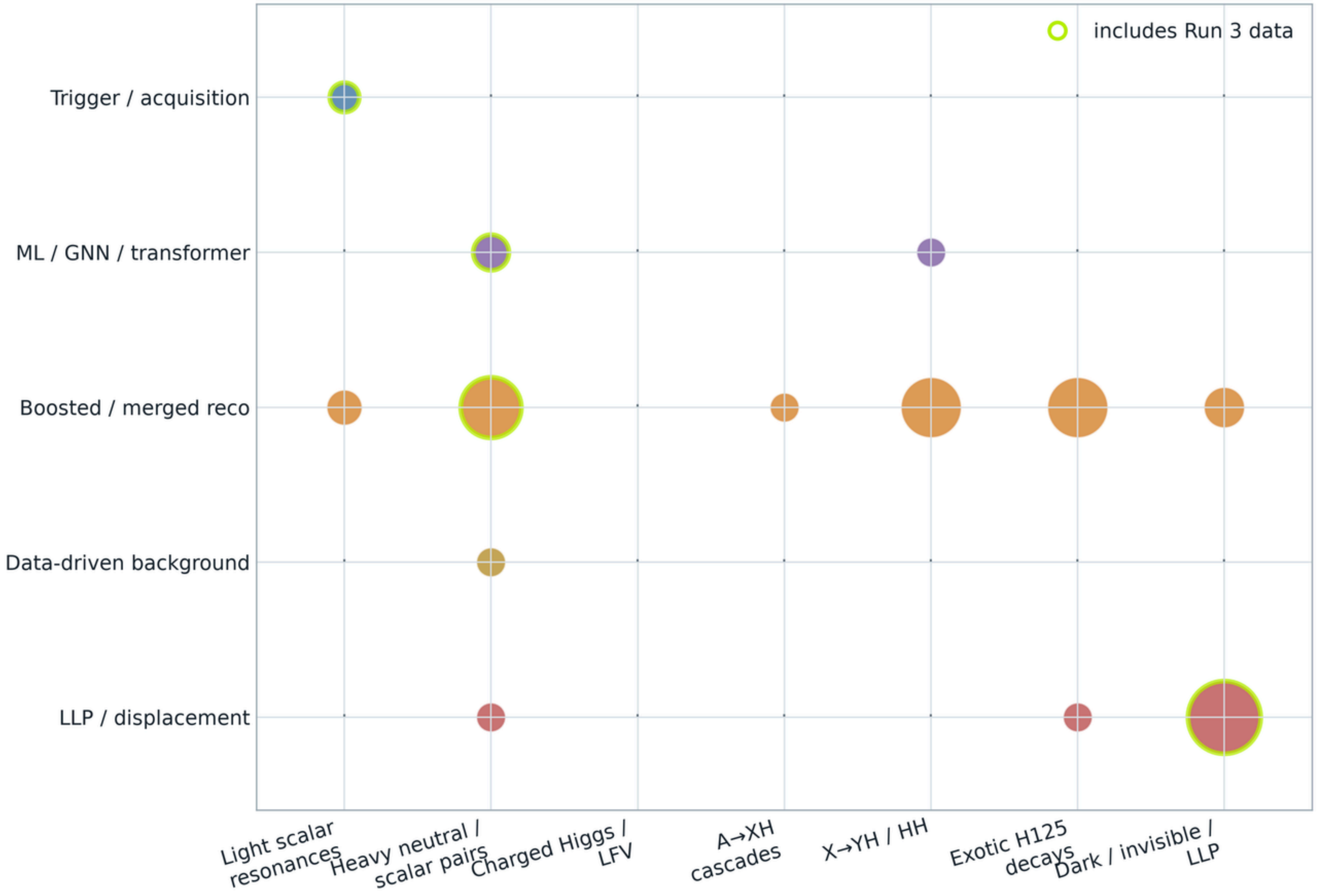
Repeated references are intentional; inventory_entry_id ties every excess and counterpart to the correct scoped process.

What made these searches exp. possible?

Where future sensitivity is being won

The frontier is not only more luminosity: it is access to softer, more merged, rarer and displaced signatures.

Explicit technology anchors



What these capabilities unlock

Trigger / acquisition

lower thresholds and difficult production modes

anchors: τ

ML / GNN / transformer

high-dimensional tagging and background discrimination

anchors: γγ/γ + b, photons, MET / invisible

Boosted / merged reco

acceptance when decay products overlap

anchors: ττ + b, VV, b / multib, photons

Data-driven background

control of multijet, fake-object and smooth-spectrum backgrounds

anchors: hadronic / merged

LLP / displacement

lifetimes from sub-mm displacement to detector-scale decays

anchors: displaced / LLP

Scouting is not explicitly identified in the public summaries — verify externally before claiming it.

Bubble area reflects conservative keyword frequency. The map identifies programme-enabling capabilities, not collaboration-wide adoption rates.

Source: public analysis, excess and capability tables · experiments combined

Triggers, ML, merged-object reconstruction and displaced signatures are part of the physics map, not technical footnotes.

Why 2.4σ local?

A pragmatic screening threshold for the catalogue

2.4σ

DEFAULT LOCAL THRESHOLD

2σ 3σ

broader coverage less noise

Operational meaning

It selects entries for review. It does not define evidence for new physics.

Why this compromise

Sensitivity below 3σ	Several comments considered deviations above 2σ interesting. Conservative systematics and background estimates can reduce their apparent significance, so a 3σ cut may hide useful candidates.
Control of catalogue noise	A threshold near 2σ can admit many statistical fluctuations, especially in searches with many bins or dimensions. Moving to 2.4σ reduces the volume while retaining more coverage than 3σ.
Required safeguards	Rank entries by local significance, show the global significance when available, and always report the corresponding result from the other experiment, including values below threshold or missing coverage.
Counterpoint from the discussion	For very broad scans, some contributors preferred a tighter global-significance threshold because the look-elsewhere effect can make 2.4σ local fluctuations common.

How excess values were transcribed

Observed local significance strictly above 2.4σ

1	**Primary source**	Use the paper or official public result, not a secondary summary.
2	**Mass coordinate**	Take the explicitly reported mass point or local maximum; keep the full tuple for multi-mass hypotheses.
3	**Observed local σ**	Copy the quoted observed value and remove fit uncertainties from the compact label.
4	**Quoted global only**	Leave it blank when the source does not quantify it; retain upper bounds as upper bounds.
5	**No reconstruction**	Do not recalculate, interpolate or infer a significance or mass point.

A blank global field means not quoted — never zero.

Example

(mX, mY) = (650, 90) GeV

3.8 (2.8) σ

local (global)

In 1D plots the first quoted coordinate is used; the complete tuple remains in the data and in 2D views.

AI-assisted research setup

Environment

OpenAI Codex desktop
Local, version-controlled workspace
Tool access for web, files, spreadsheets, plots, and slides

Model

GPT-5.6-sol
High reasoning setting in this task
Agentic, multi-step work with tool use

What the model label does not prove

The model is not a physics source. Scientific provenance comes from the cited papers, public analysis pages, the workbook, and reproducible scripts.

Exact context-window and output limits depend on the serving configuration and should not be used as scientific metadata.

Division of work b/t the agent and the physicist

Agent

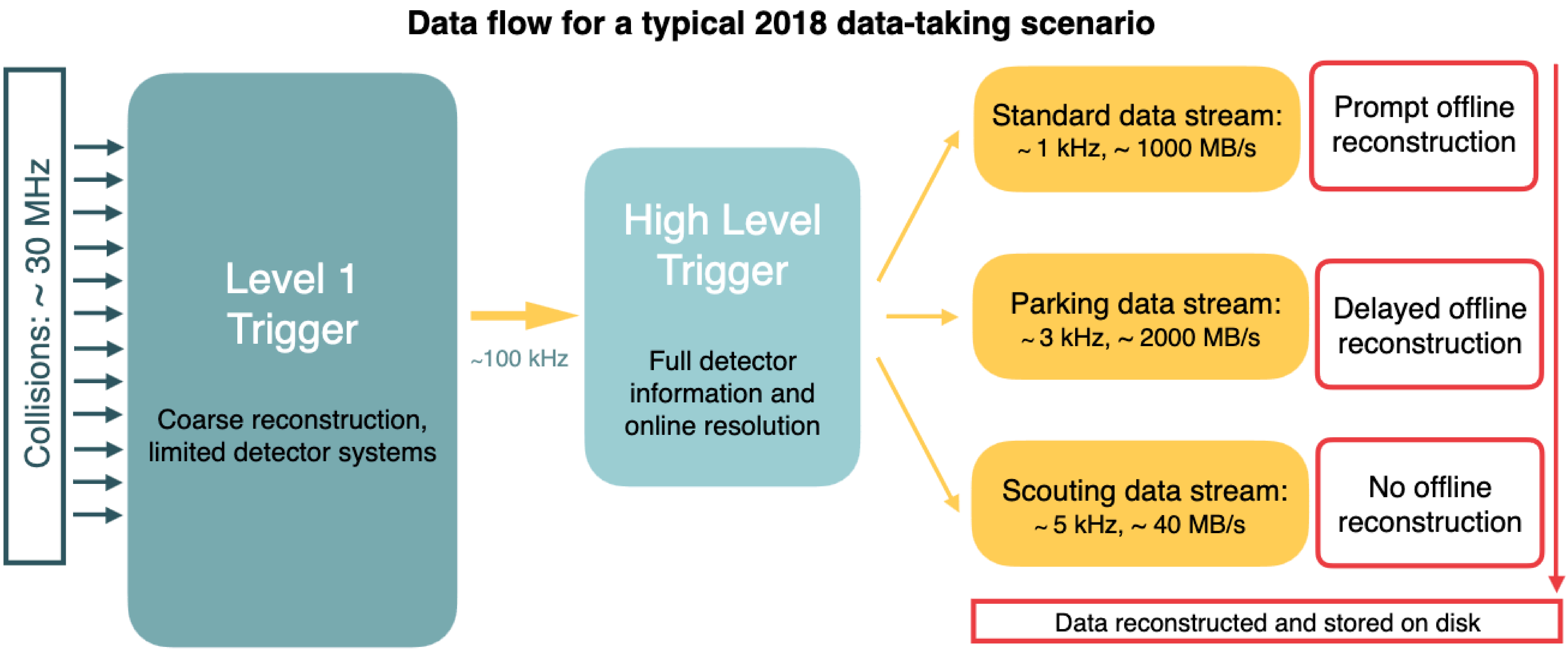
Cross-linked references and official result pages
Normalised categories, masses, final states, and significance fields
Generated reproducible plots and workbook views
Repeated consistency checks after each correction

Physicist

Defined the scientific scope and the category boundaries
Resolved ambiguous counterparts and excess interpretations
Corrected source information and controlled the narrative
Accepted or rejected every material change

The main gain was scale: many repetitive checks became tractable while scientific judgement remained explicit.

CMS Scouting



Scouting opportunities at Run 2 & 3

- L1: hardware processors, information from the calorimeters and muon detectors, rate around 100kHz within a fixed latency of about 4 μs

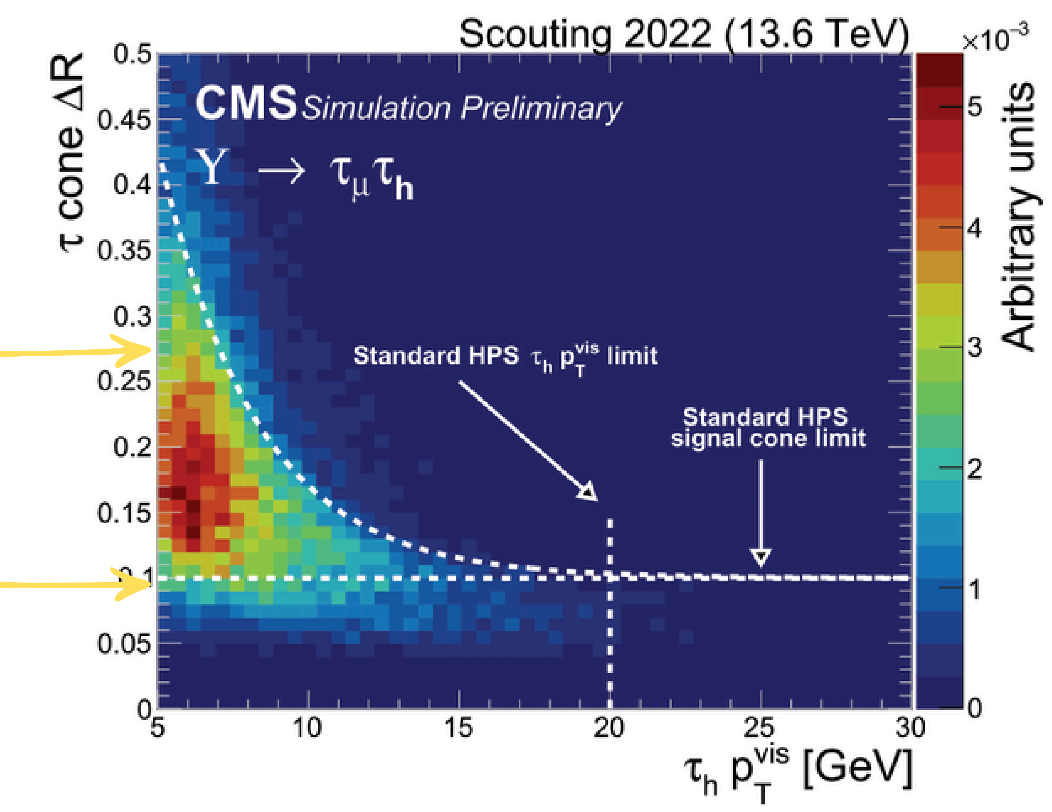
- High-Level Trigger (HLT): processors running a version of the Particle Flow (PF) algorithm optimized and reduces the event rate to around 1kHz before data storage

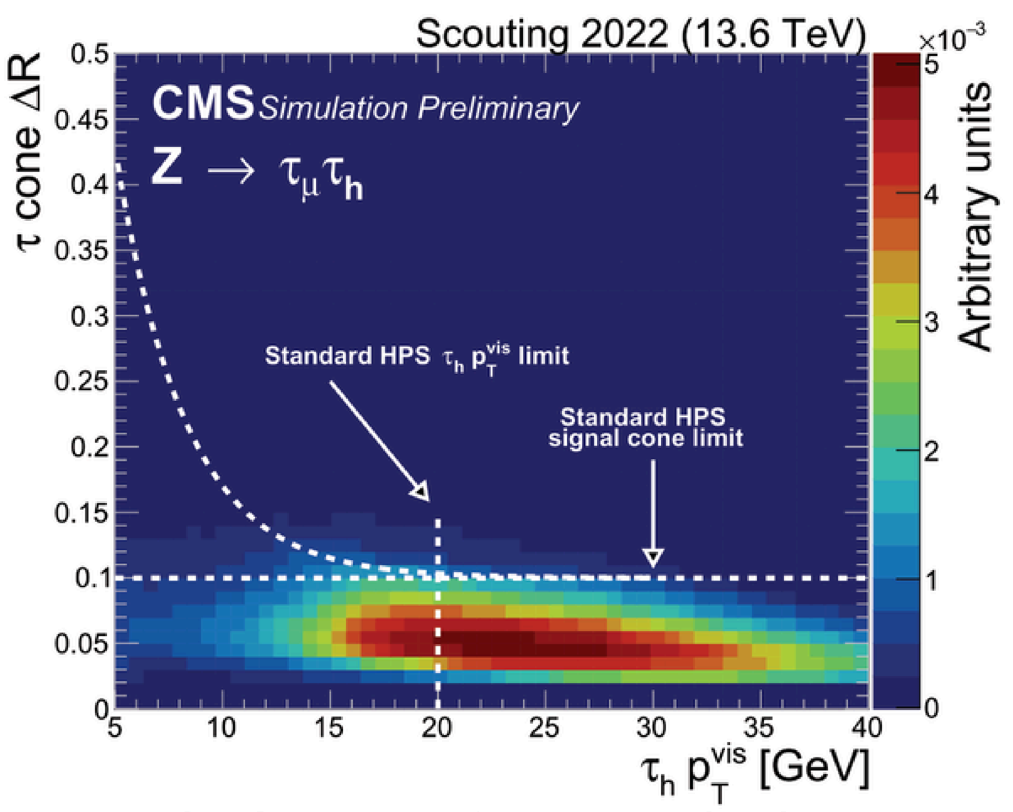
Decay mode	Branching Ratio [%]	Tag name
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$	(17.82 ± 0.04)	
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$	(17.39 ± 0.04)	
$\tau^- \to h^- \nu_\tau$	(11.51 ± 0.05)	1-prong
$\tau^- \to h^- h^+ h^- \nu_\tau$	(9.80 ± 0.05)	3-prong
$\tau^- \to h^- \pi^0 \nu_\tau$	(25.93 ± 0.09)	1-prong, 1-strip
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	(9.31 ± 0.05)	1-prong, 2-strip
Other	8.24	

- Scouting dataset includes Particle Flow (candidates of the following types: e/γ, K0, π± and μ±)
- **Calorimeter strips to associate to neutral hadrons build from scratch from e/γ candidates(no available hits in the scouting collection)**
- **Dedicated Neural Network to discard fakes (cannot use calo hits)**

$\text{signal cone} < 2.8^{-0.3\times(p_T(\tau_h)[\text{GeV}]-1.4)+0.1}$

$R_{\text{signal cone}} = \frac{3.0}{E_T^{vis}[\text{GeV}]}$





Signal cone:region of the jet where decay products can be found

Tau cone: maximum ΔR between any of the τh constituents and the τh axis

Tau cone<=signal cone

CMS NOTE-2024/006

Scouting opportunities at Run 2 & 3

- Events processed in real time with reduced content, permitting recording of larger data samples.

Table 3: Comparisons of the event rate, event size, and total bandwidth between the standard and scouting trigger strategies, for an LHC fill corresponding to data collected in 2018 with $\mathcal{L}_{\text{inst}} \approx 1.8 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ at the start of the fill, one of the highest at the LHC in Run 2, and pileup around 50.

Data stream	Event rate [Hz]	Event size	Total bandwidth [MB/s]
Standard muons	600	0.86 MB	485
Standard jets/H_T	400	0.87 MB	385
Scouting Calo muons and Calo H_T	5970	8.9 KB	45
Scouting PF jets and PF H_T	1766	14.8 KB	25

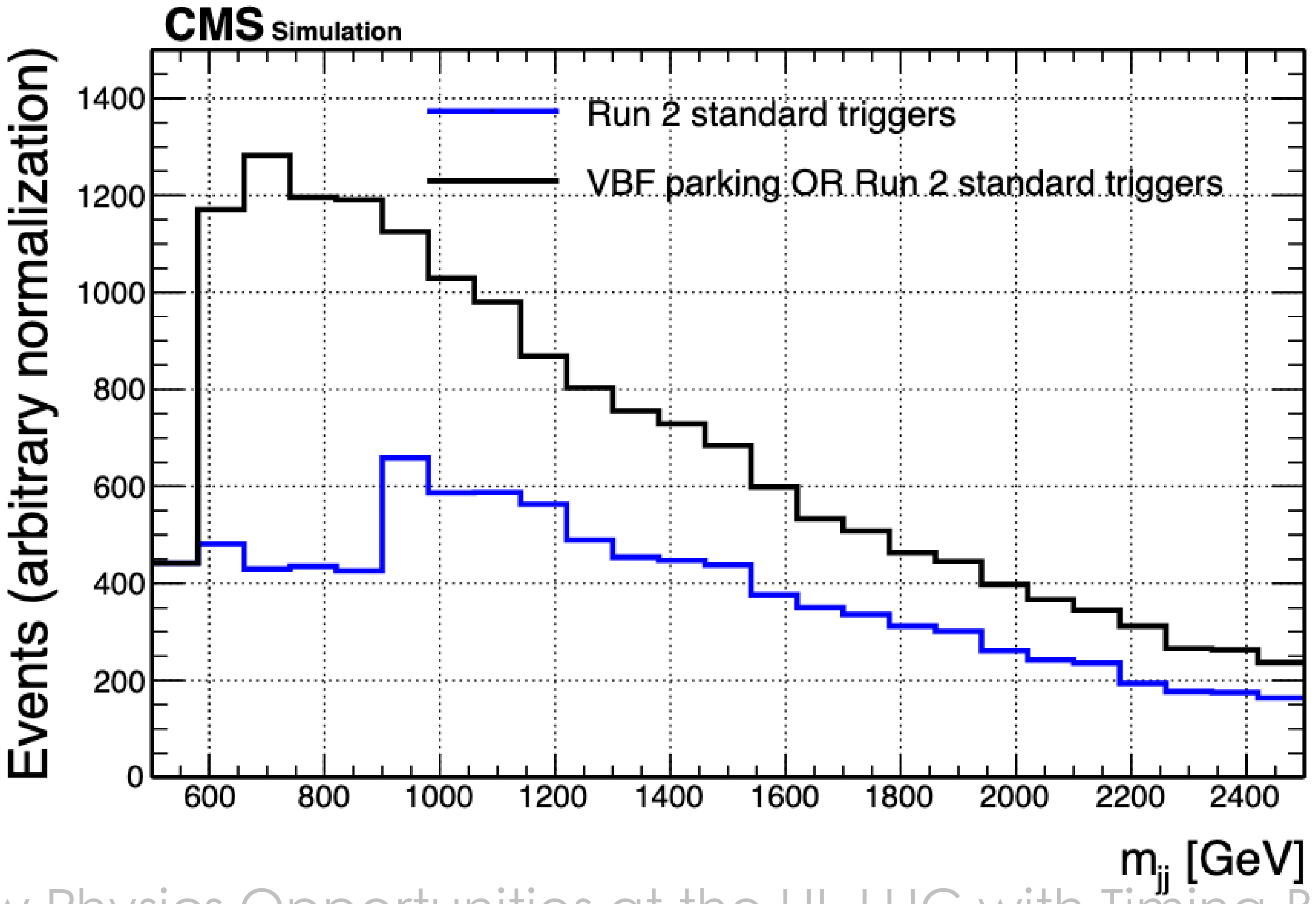
Year	$\mathcal{L}_{\text{inst}}$ [cm^{-2}s^{-1}]	PU	Standard rate [Hz]	Parking rate [Hz]	Scouting rate [Hz]
2018	1.2×10^{34}	38	1000	3000	5000
2022	1.5×10^{34}	46	1800	2440	22000
2023	1.7×10^{34}	48	1700	2660	17000

arXiv:2403.16134

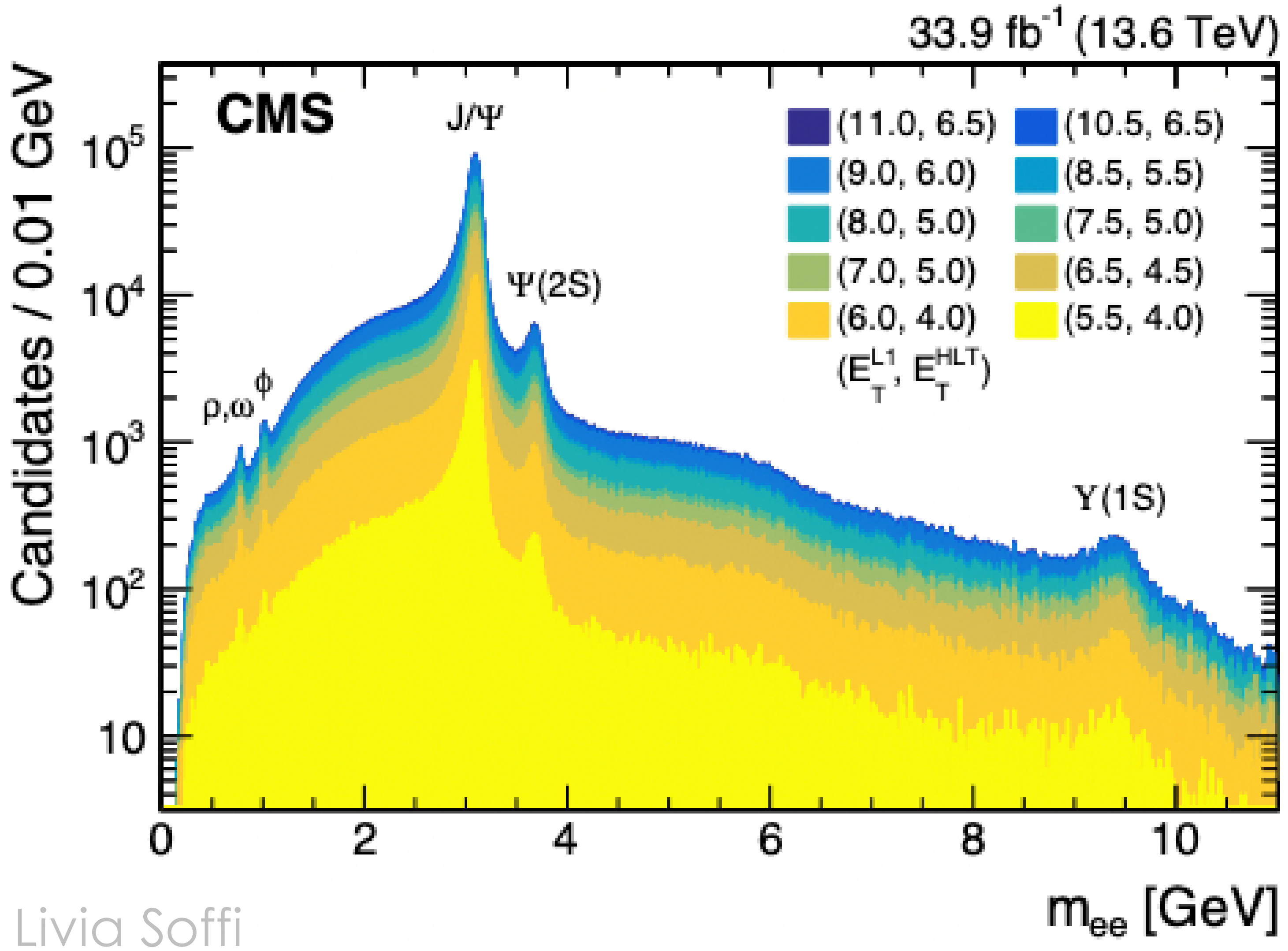
Novel Parking opportunities for Run 3

- Successful execution of the **B parking program during Run 2** garnered significant interest, propelling the **evolution of the parking technique** into a comprehensive and diverse program.
- Since 2022, the definition of data parking has shifted somewhat to include prompt reconstruction (i.e., **processing typically starting within 48 hours**), upon the availability of computing resources.
- **New parking strategies** enable efficient probing currently unexplored experimental signatures that may become of interest in the future.

VBF parking



Dielectrons parking



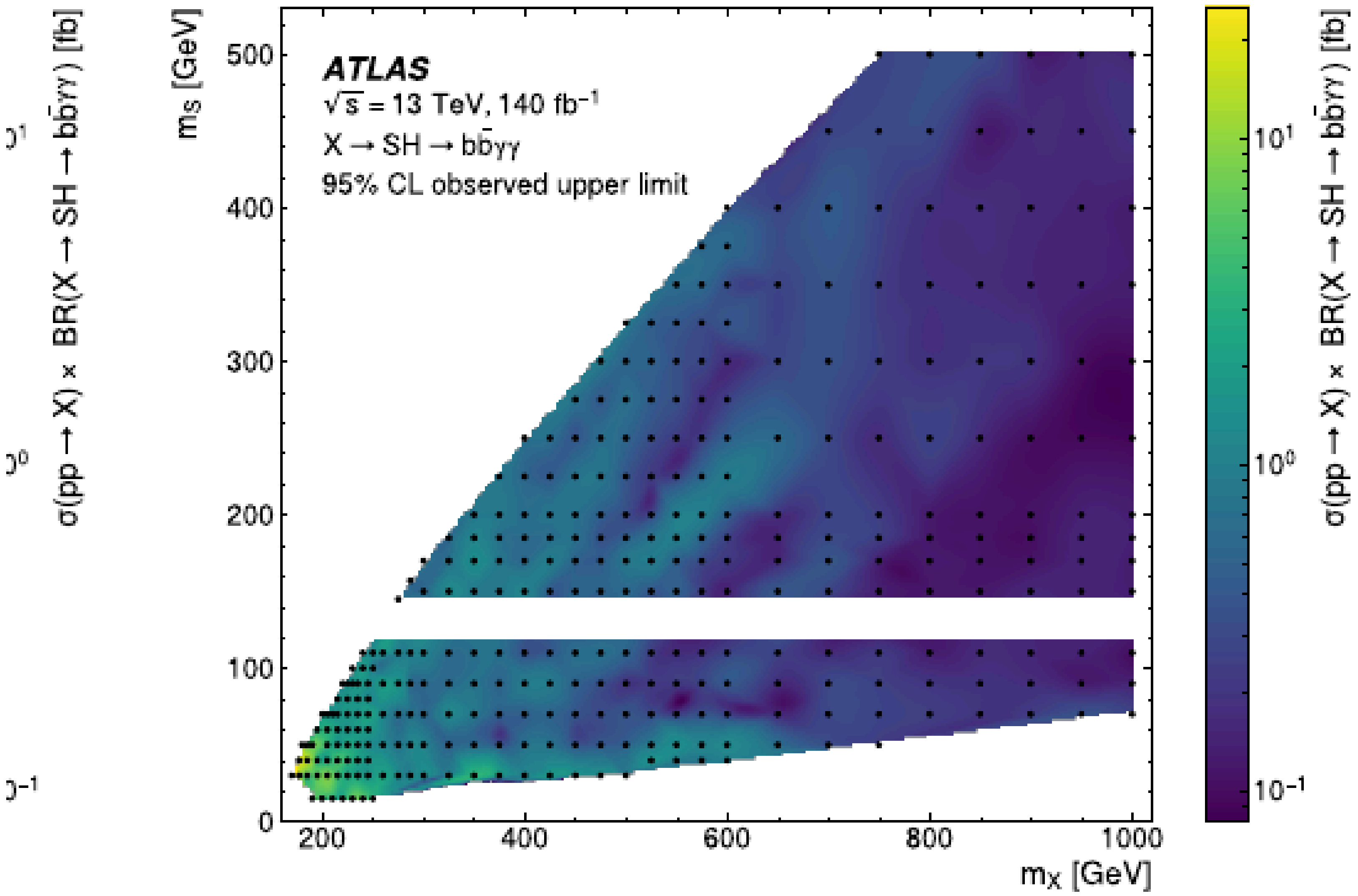
arXiv:2403.16134

ATLAS X → SH → bbγγ: a new maximum and a direct benchmark tes

Run 2, 140 fb^{-1} at 13 TeV · JHEP 11 (2024) 047 · arXiv:2404.12915

ATLAS

X,S: spin-0 · narrow width



Observed 95% CL upper-limit map (not a significance map)

ggF X → S H

S → bb · H → γγ

Both X and S are scalar (spin-0) bosons; narrow-width signal hypothesis.

Largest ATLAS deviation

(mX, mS) = (575, 200) GeV
3.5σ local → 2.0σ global

CMS benchmark tested point-by-point

(650, 90) GeV: ATLAS data are compatible with background, $p_0 > 0.5$.
95% CL upper limit: 0.20 fb.

Why this comparison is sharp

Injecting the CMS best-fit rate (0.35 fb) would produce ≈2.7σ locally in ATLAS; the analysis had sensitivity to a signal of that size.

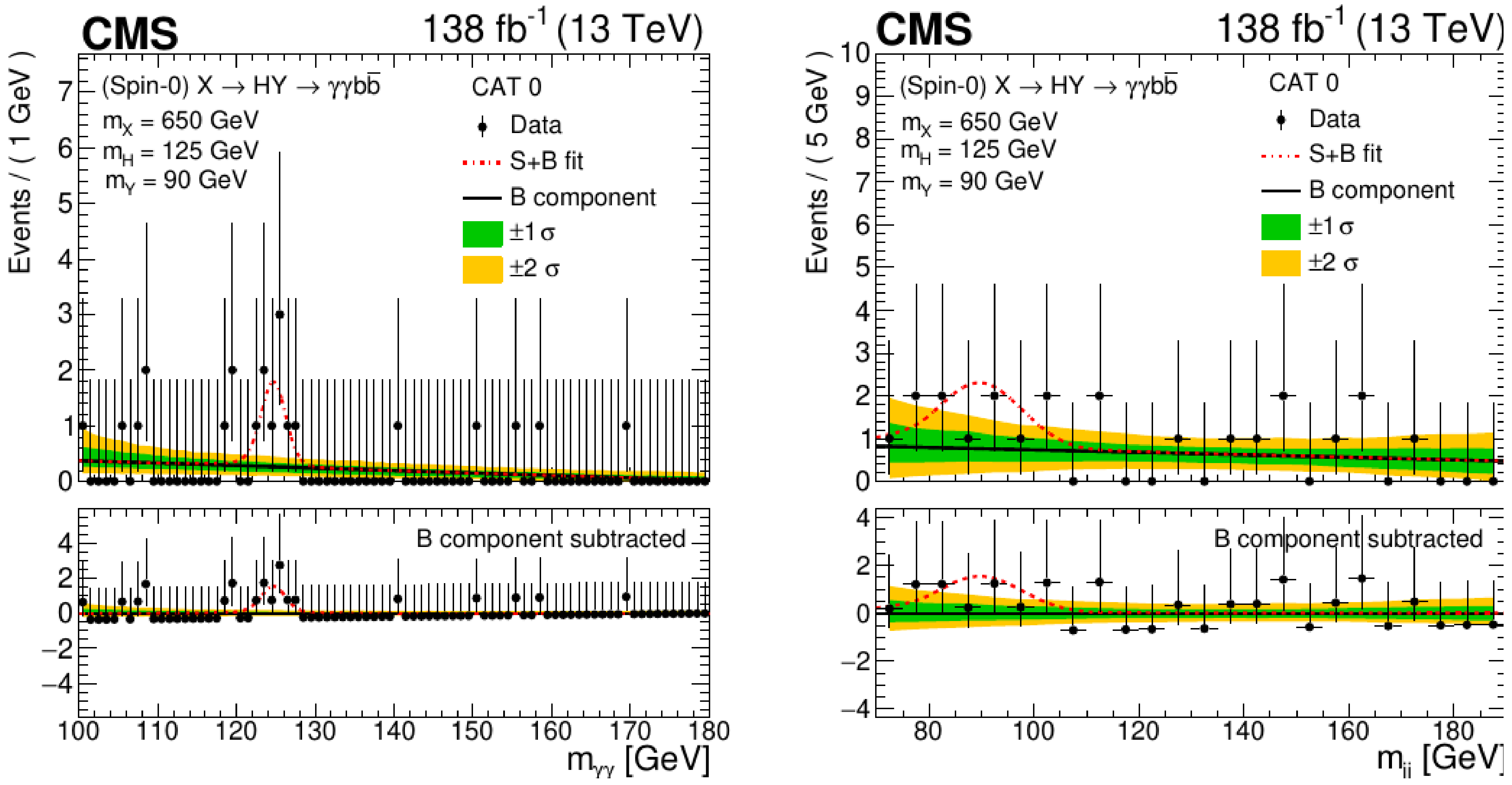
Take-away: the same γγbb topology can host different maxima in the 2D mass plane; the scientifically clean comparison is at the same (mX,mS) coordinate.

Source: ATLAS Collaboration, arXiv:2404.12915 (Fig. 4 and Sec. 8.3).

CMS X → HY → γγbb: the (650, 90) GeV feature

Run 2, 138 fb⁻¹ at 13 TeV · JHEP 05 (2024) 316 · CMS-HIG-21-011 · arXiv:2310.01643

CMS | **HY excess: X spin-0 · Y spin-0**



CMS Fig. 5, lower row: highest-purity category for the (650,90) GeV HY hypothesis

Spin hypotheses

HY search / 650–90 feature: X = spin-0, Y = spin-0; H is the SM spin-0 Higgs. X is generated as a narrow resonance via ggF. Separate HH interpretation: X is also tested as spin-0 radion or spin-2 bulk KK graviton — not the HY excess.

How the signal is extracted

BDT-based categories + an X-mass window using M̃X. Then an unbinned 2D maximum-likelihood fit in (mγγ, mjj), so the excess requires the H→γγ peak and a Y→bb structure simultaneously.

M̃X = mγγjj − (mγγ − mH) − (mjj − mH/Y)

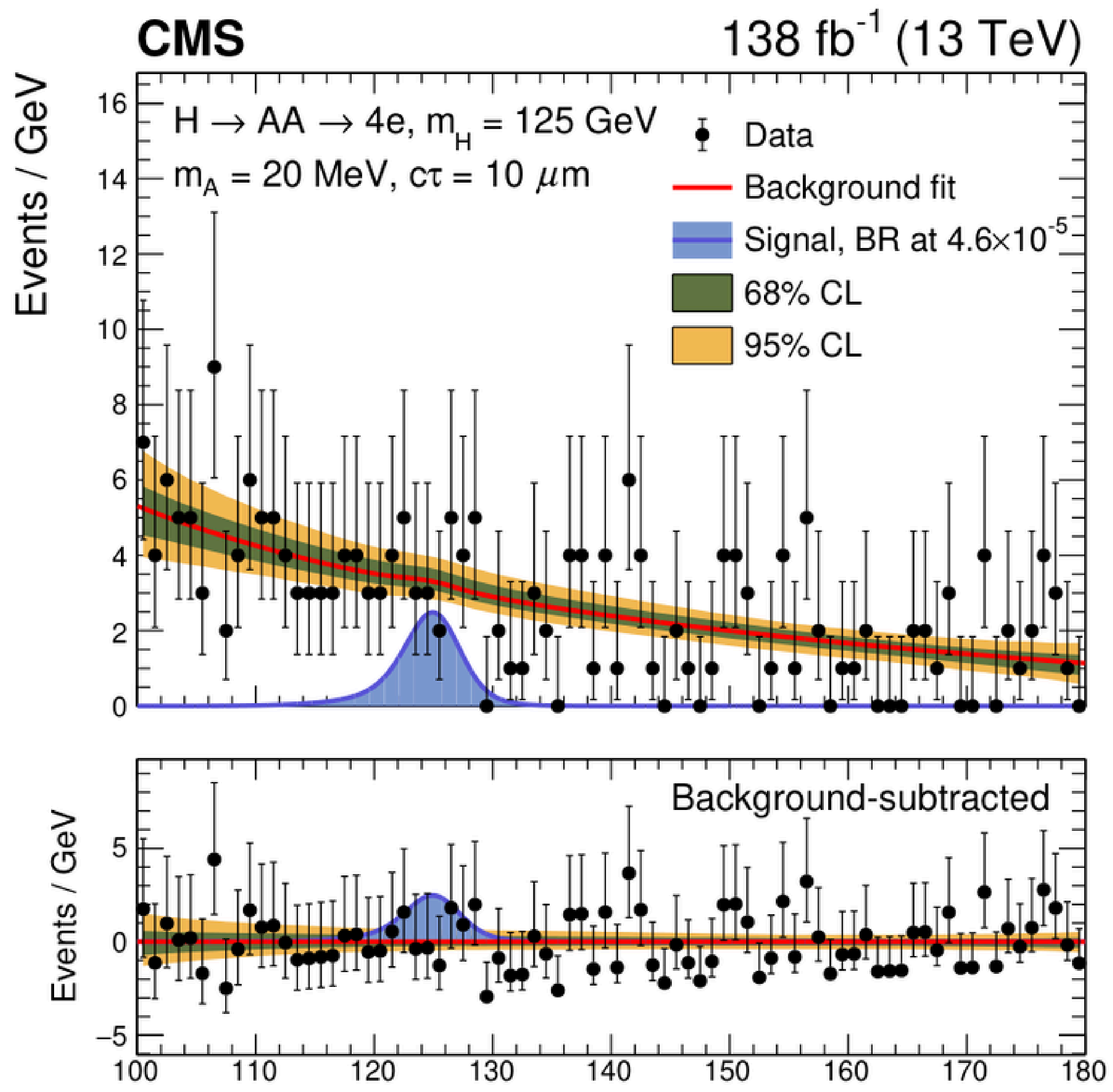
Largest deviation

(mX, mY) = (650, 90) GeV
3.8σ local · 2.8σ global upper bound from a restricted trial region
Best-fit σ×BR(γγbb) = 0.35 +0.17/−0.13 fb

What the plot shows: the fitted excess appears in the lower-row mγγ and mjj projections after selecting the same (650,90) X→HY hypothesis.

Backup: CMS H→AA→4e — resolving merged e^+e^- pairs

CMS-EXO-24-031, 138 fb^{-1} at 13 TeV: first LHC H→AA→4e search for mA = 10–100 MeV and cτ < 100 μm.



Final observable: unbinned fit to m_{4e} around 125 GeV

Benchmark overlay: mA=20 MeV, cτ=10 μm, BR=4.6×10^{-5}; no significant excess is observed.

What is a “merged electron pair” (MEP)?

A very light A produces two charged particles so close that ECAL sees one electromagnetic cluster. The tracker can still separate two GSF tracks: the analysis deliberately combines tracker angular resolution with ECAL energy.

1 Reconstruct the MEP seed

Match two GSF tracks to the same ECAL cluster: ΔR(track,cluster)<0.015, pT(track)>5 GeV, <2 missing inner hits, ECAL energy >25 GeV.

2 Require a physically consistent pair

Track-vector-sum pT must agree with the ECAL-cluster pT within 70%; adaptive two-track vertex χ^2<5; isolation uses tracker+ECAL+HCAL activity in 0.015<ΔR<0.3.

3 Identify signal-like MEPs with a GBDT

XGBoost uses ECAL shower shapes, track separation and vertex displacement; pT and energy are excluded to avoid biasing the classifier to one ALP kinematic region.

Performance / statistical use

- 70% signal-efficiency working point; rejects about 75% of Z→ee, 55% of γ+jets and 60% of diphoton MEP candidates after isolation.
- Two MEPs form the Higgs candidate; the m_{4e} spectrum is fit with data-driven nonresonant background + resonant H→γγ conversion background.

Take-away: tracker+ECAL MEP ID opens H→AA→4e for O(10 MeV) ALPs, reaching branching-fraction sensitivity O(10^{-5}).

Excess references 1/4

Unique references ordered by their first retained mass point. Multiple features from one reference remain together.

Exp.	Reference	Category	Final state	Mass point · local (global) σ
CMS	HIG-22-003	Exotic H125	γ	3 · 2.6 (1.3) σ
ATLAS	HMBS-2024-58	Exotic H125	τ	5.4 · 3.4 σ
CMS	HIG-24-014	Light scalar	γ	13.6 · 3.5 (1.9) σ
ATLAS	arXiv:2507.01165	Exotic H125	b / multib	25 · 2.83 (2.04) σ; (50,70) · 3.28 (2.57) σ
ATLAS	arXiv:2110.13673	Exotic H125	e/μ	28 · 2.5 σ
CMS	NPS-25-005	Exotic H125	b / multib	45 · 3 (1.7) σ
ATLAS	arXiv:2110.00313	Exotic H125	b / multib	52 · 3.3 (1.7) σ
CMS	HIG-21-001	Light scalar / Heavy neutral / pairs	τ	95 · 2.6 (2.3) σ; 100 · 3.1 (2.7) σ; 1200 · 2.8 (2.2) σ
CMS	HIG-20-002	Light scalar	γ	95.4 · 2.9 (1.3) σ
ATLAS	arXiv:2410.16781	X→YH / HH	e/μ	(110,30) · 2.7 (1.6) σ; (350,75) · 2.8 (0.5) σ
ATLAS	arXiv:2302.05225	Charged Higgs / LFV	τ	125 · 2.5 σ

Excess references 2/4

Unique references ordered by their first retained mass point. Multiple features from one reference remain together.

Exp.	Reference	Category	Final state	Mass point · local (global) σ
ATLAS	arXiv:2302.11739	Charged Higgs / LFV	b / multib	130 · 3 (2.46) σ
CMS	HIG-24-002	Heavy neutral / pairs	VV	137.8 · 3 (1.8) σ
CMS	HIG-22-002	Charged Higgs / LFV	e/μ	146 · 3.8 (2.8) σ
CMS	EXO-21-018	Light scalar	τ	156 · 2.9 (1.4) σ
CMS	SUS-24-001	Heavy neutral / pairs	b / multib	250 · 3.2 (2.4) σ; 300 · 2.7 (1.9) σ
CMS	B2G-24-001	X→YH / HH	γγ/γ + b	(300,77) · 3.33 (0.65) σ
ATLAS	arXiv:2210.05415	X→YH / HH / A→XH	b / multib	315 · 2.5 (1.3) σ; (420,320) · 3.8 (2.8) σ; 550 · 2.7 (1.3) σ; (790,300) · 3.9 (2.1) σ
CMS	HIG-22-012	X→YH / HH	γγ + τ	(320,60) · 2.6 (2.2) σ; (450,161) · 3.2 (0.3) σ; (525,115) · 3.2 (0.1) σ
ATLAS	arXiv:2407.10798	Charged Higgs / LFV	VV	375 · 3.3 (2.5) σ
ATLAS	arXiv:2002.12223	Heavy neutral / pairs	τ	400 · 2.7 (1.9) σ
ATLAS	arXiv:2011.05639	A→XH	VV	(440,220) · 3.1 (1.3) σ; (440,310) · 2.9 (0.82) σ; (610,290) · 3.1 (1.3) σ

Excess references 3/4

Unique references ordered by their first retained mass point. Multiple features from one reference remain together.

Exp.	Reference	Category	Final state	Mass point · local (global) σ
ATLAS	arXiv:2401.04742	X→YH / HH	VV	(510,380) · 2.5 σ
ATLAS	arXiv:2404.12915	X→YH / HH	γγ/γ + b	(575,200) · 3.5 (2) σ
CMS	HIG-20-012	X→YH / HH	b / multib	(600,400) · 3.47 (2.44) σ
ATLAS	arXiv:2311.04033	A→XH	b / multib	(650,450) · 2.85 (2.35) σ
CMS	HIG-20-016	Heavy neutral / pairs	VV	650 GeV [VBF only] · 3.8 (2.6) σ, [floating VBF fraction] · 3.8 (2.4) σ 800 GeV [SM production mixture] · 3.2 (1.7) σ. 950 GeV [ggF only] · 2.6 (0.4) σ
CMS	HIG-21-011	X→YH / HH	γγ/γ + b	(650,90) · 3.8 (2.8) σ
ATLAS	arXiv:2102.13405	Heavy neutral / pairs	γ	684 GeV [spin-0, narrow width] · 3.29 (1.30) σ, [spin-2, k/MPl = 0.01] · 3.29 (1.36) σ
CMS	EXO-22-022	Heavy neutral / pairs	γ	(720,5.04) · 3.57 (1.07) σ
ATLAS	arXiv:2307.14759	Heavy neutral / pairs	t / tb	900 · 2.8 σ
CMS	B2G-23-007	X→YH / HH	VV	(900,80) · 3.3 (<1) σ

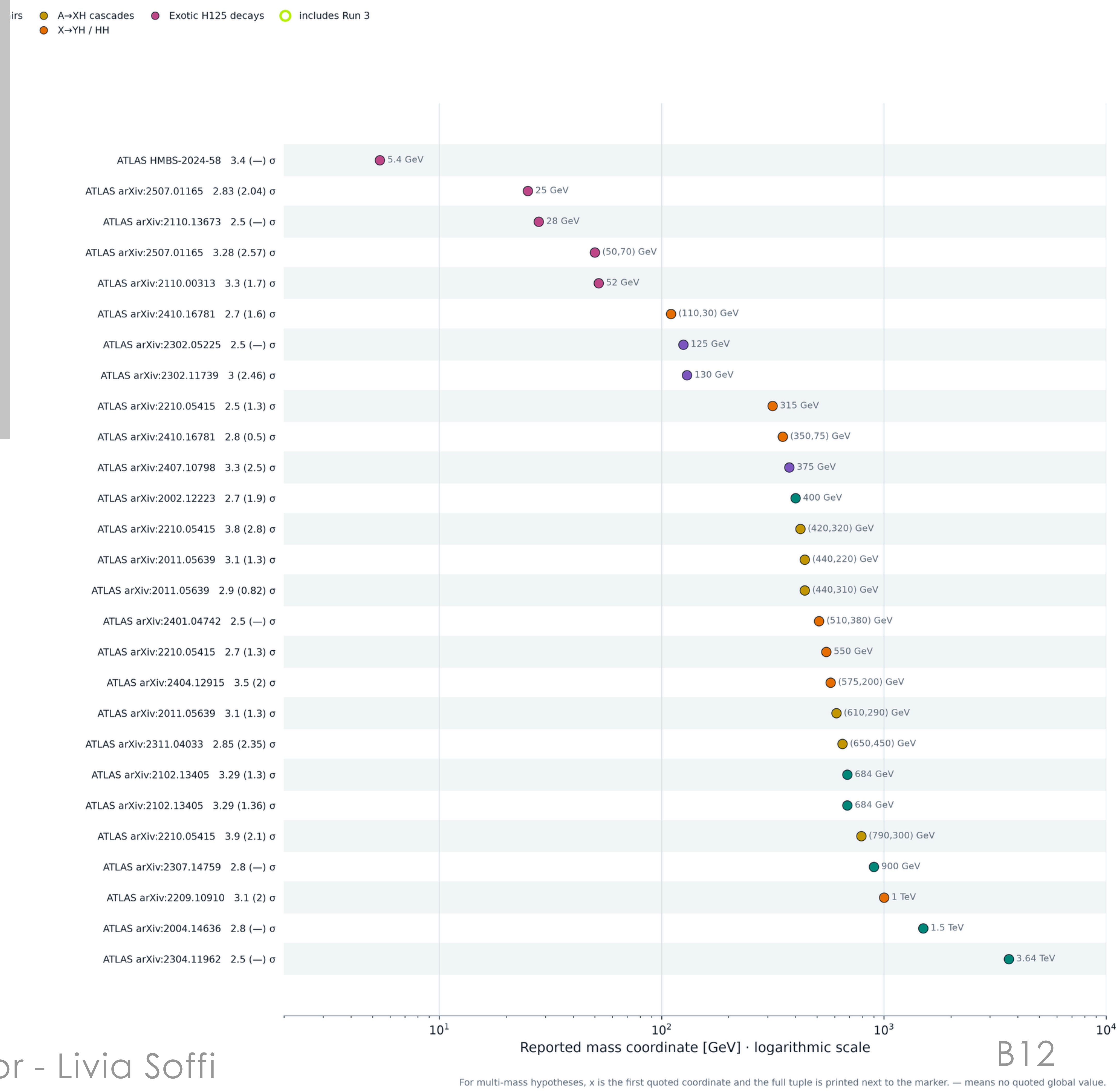
Excess references 4/4

Unique references ordered by their first retained mass point. Multiple features from one reference remain together.

Exp.	Reference	Category	Final state	Mass point · local (global) σ
ATLAS	arXiv:2209.10910	X→YH / HH	ττ + b	1000 · 3.1 (2) σ
CMS	B2G-19-006	Heavy neutral / pairs	e/μ	1000 · 3 σ
CMS	EXO-22-024	Heavy neutral / pairs	γ	1320 · 2.6 (0.8) σ
ATLAS	arXiv:2004.14636	Heavy neutral / pairs	VV	1500 · 2.8 σ
CMS	B2G-21-003	X→YH / HH	b / multib	(1600,90) · 3.1 (0.7) σ
CMS	B2G-20-009	Heavy neutral / pairs	VV	2100, 2900 [two local maxima] · 3.6 (2.3) σ
CMS	EXO-20-007	Heavy neutral / pairs	hadronic / merged	(2900,400) · 3.2 (1.8) σ
ATLAS	arXiv:2304.11962	Heavy neutral / pairs	γ	3640 · 2.5 σ
CMS	EXO-25-021	Heavy neutral / pairs	e/μ	5200 · 2.6 σ
CMS	HIG-22-006	Outside main taxonomy	b / multib	SM-like VHH hypothesis (no mass scan) · 2.6 σ

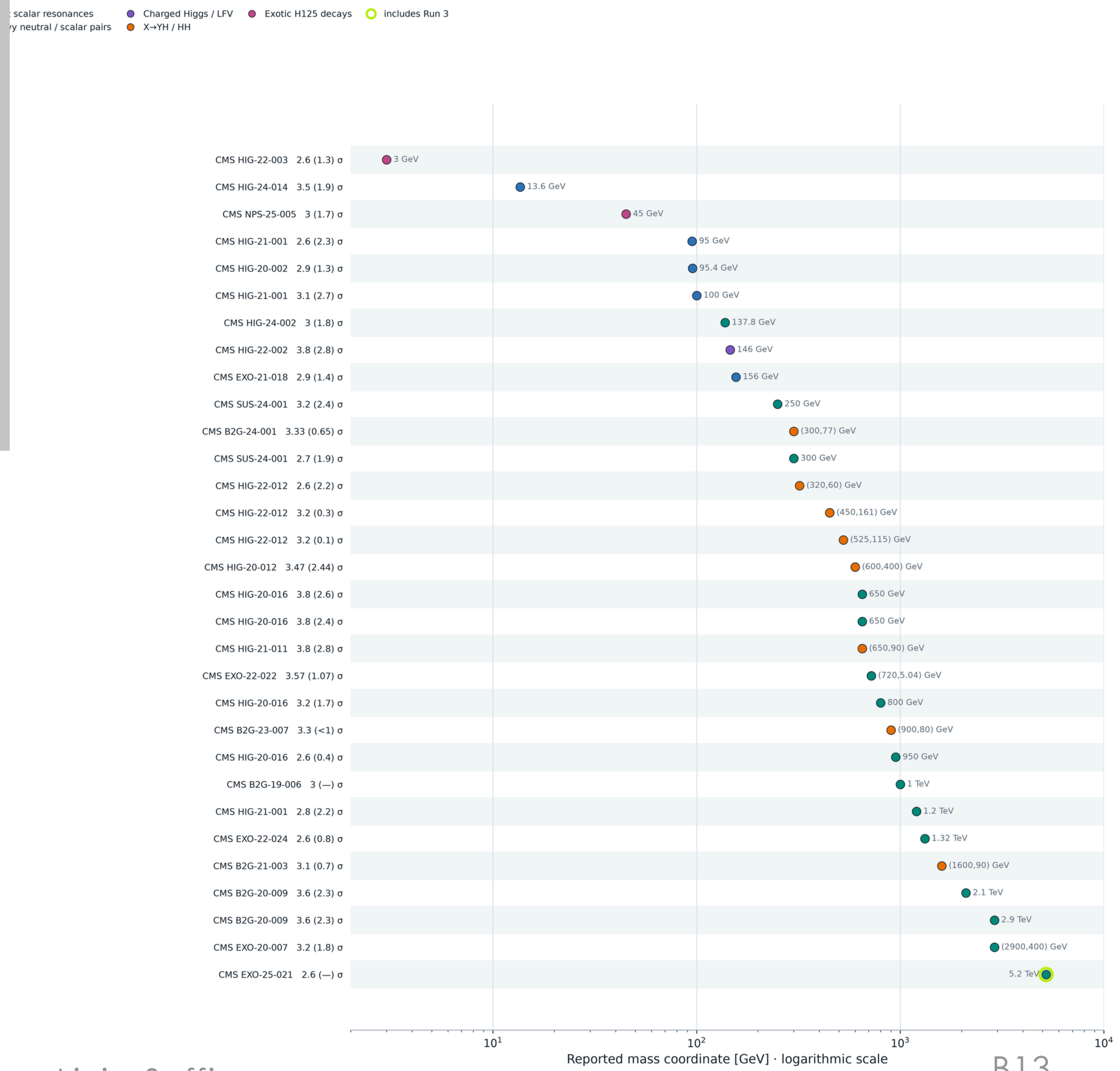
ATLAS entries with retained deviations

Each row shows the quoted mass coordinate and local or global significance for one ATLAS inventory feature.



CMS entries with retained deviations

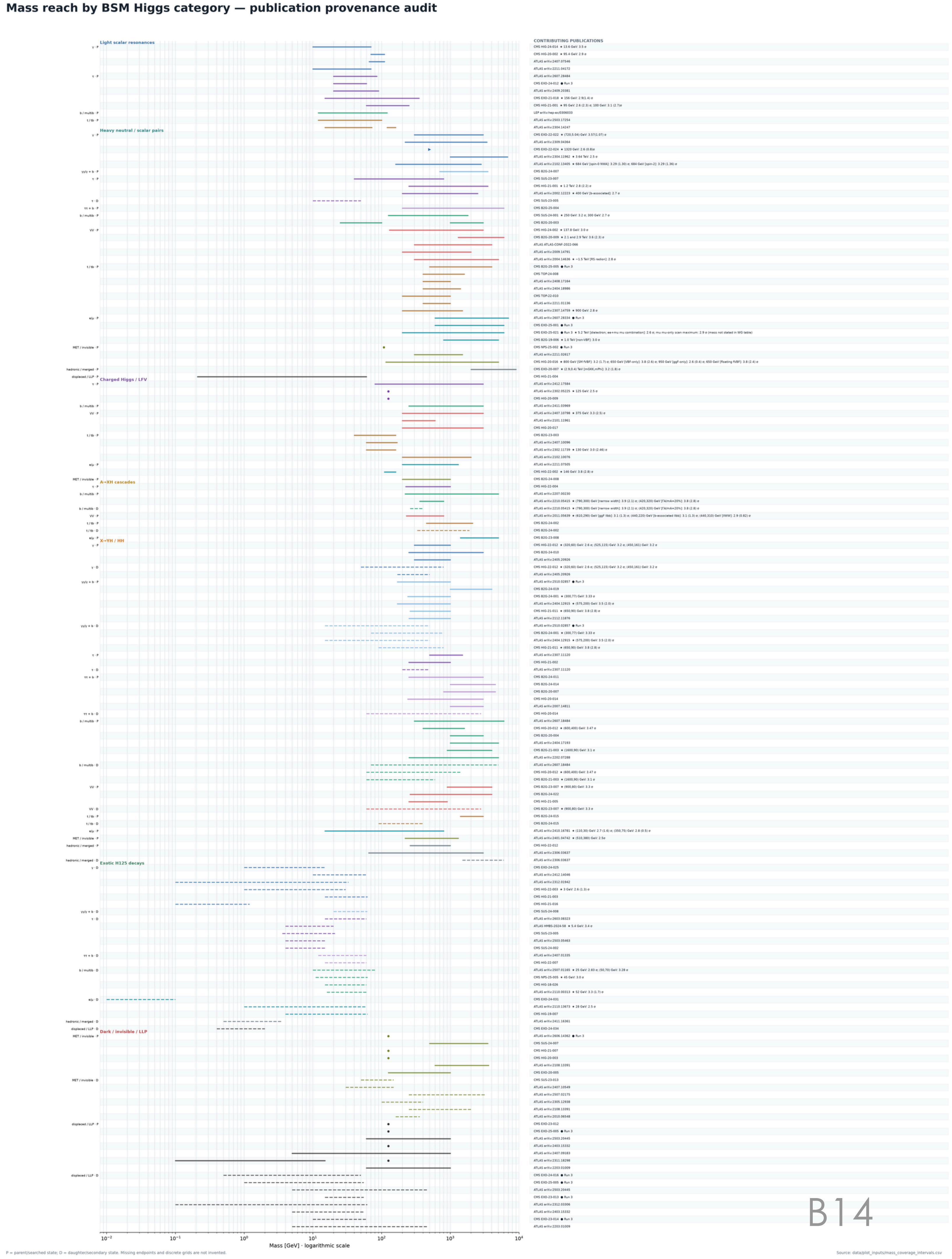
Each row shows the quoted mass coordinate and local or global significance for one CMS inventory feature.



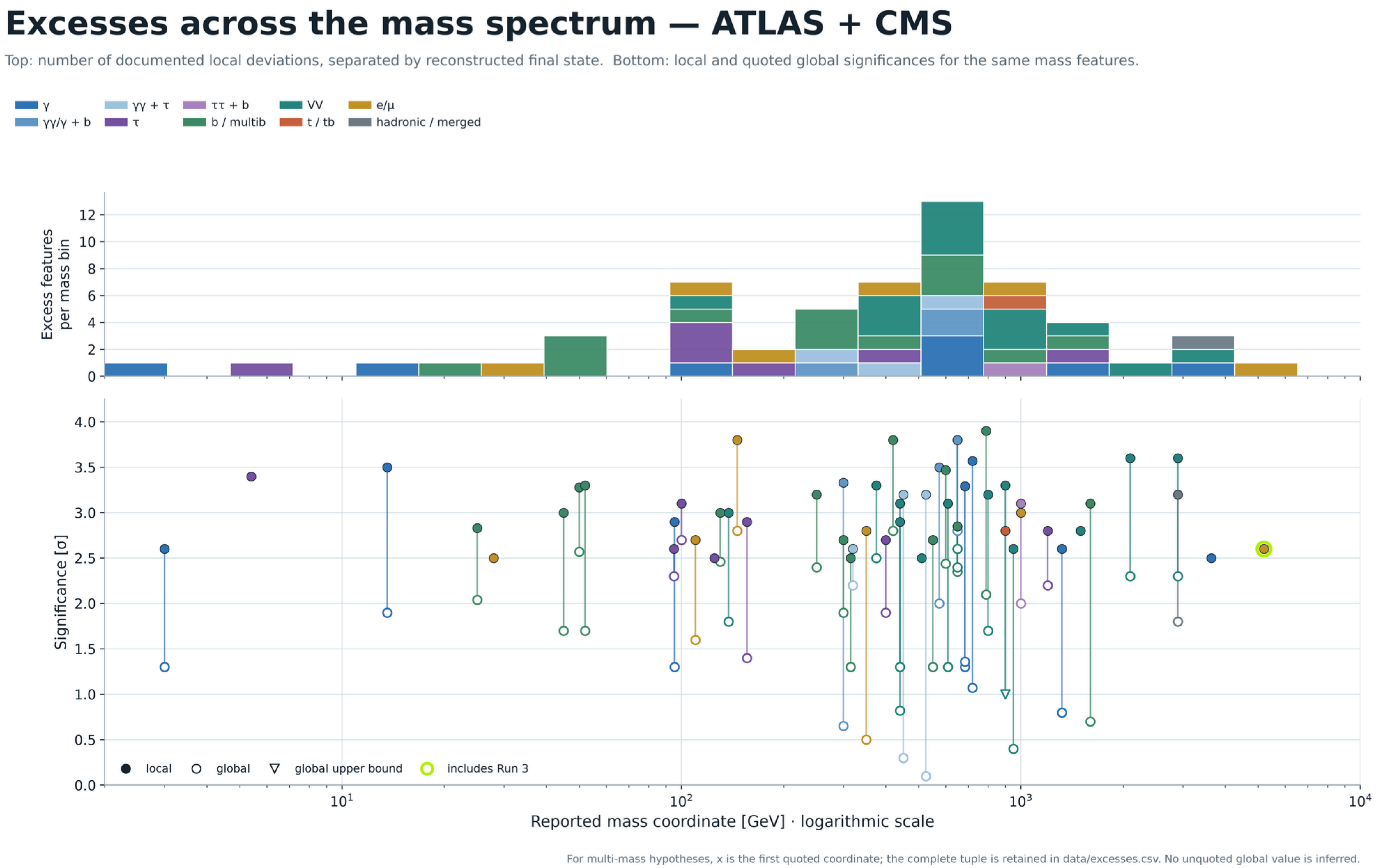
For multi-mass hypotheses, x is the first quoted coordinate and the full tuple is printed next to the marker. — means no quoted global value.

Mass-coverage provenance

- The publication-level view lists every interval behind the inclusive mass envelopes.

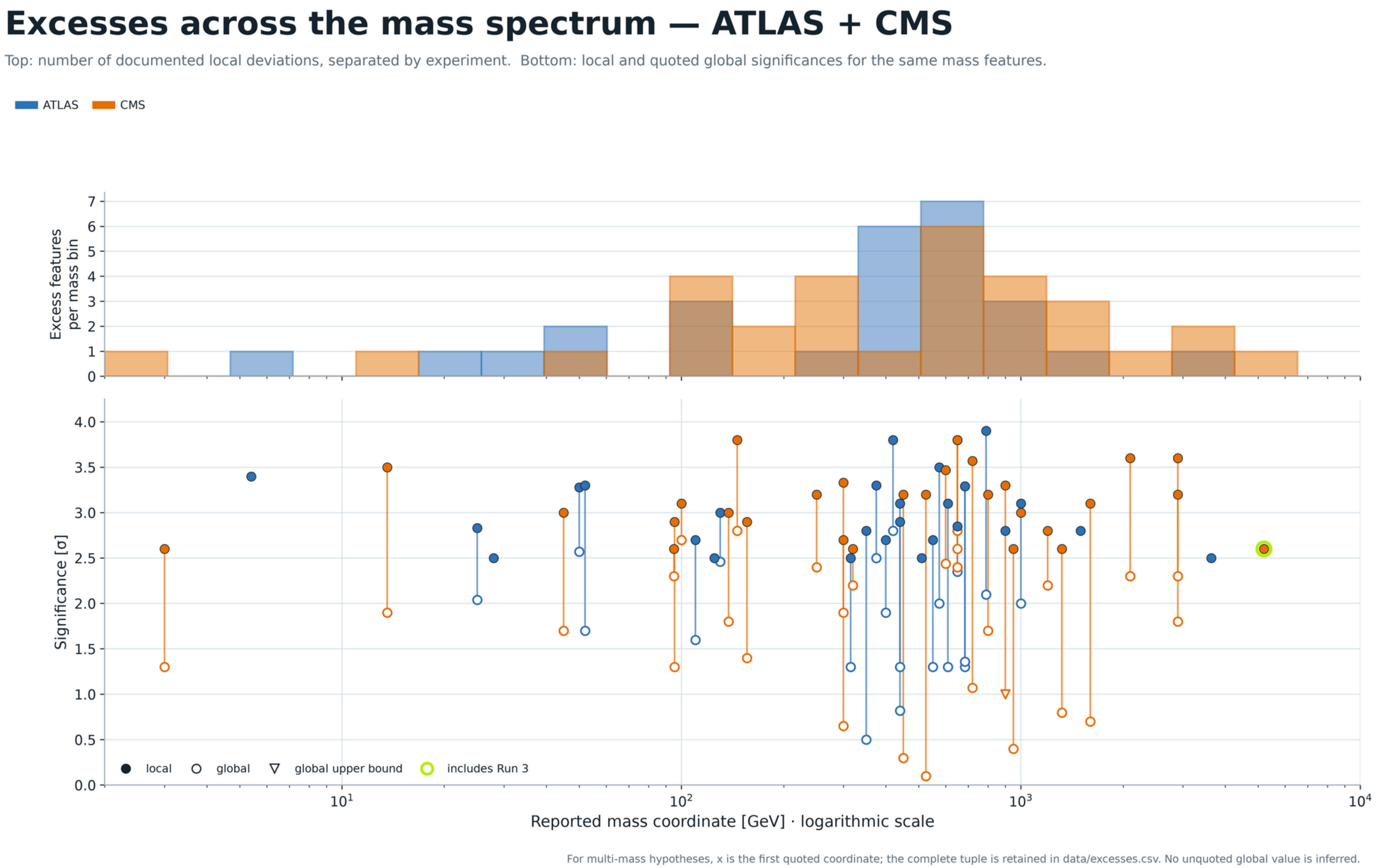


The same deviations, organised by final state



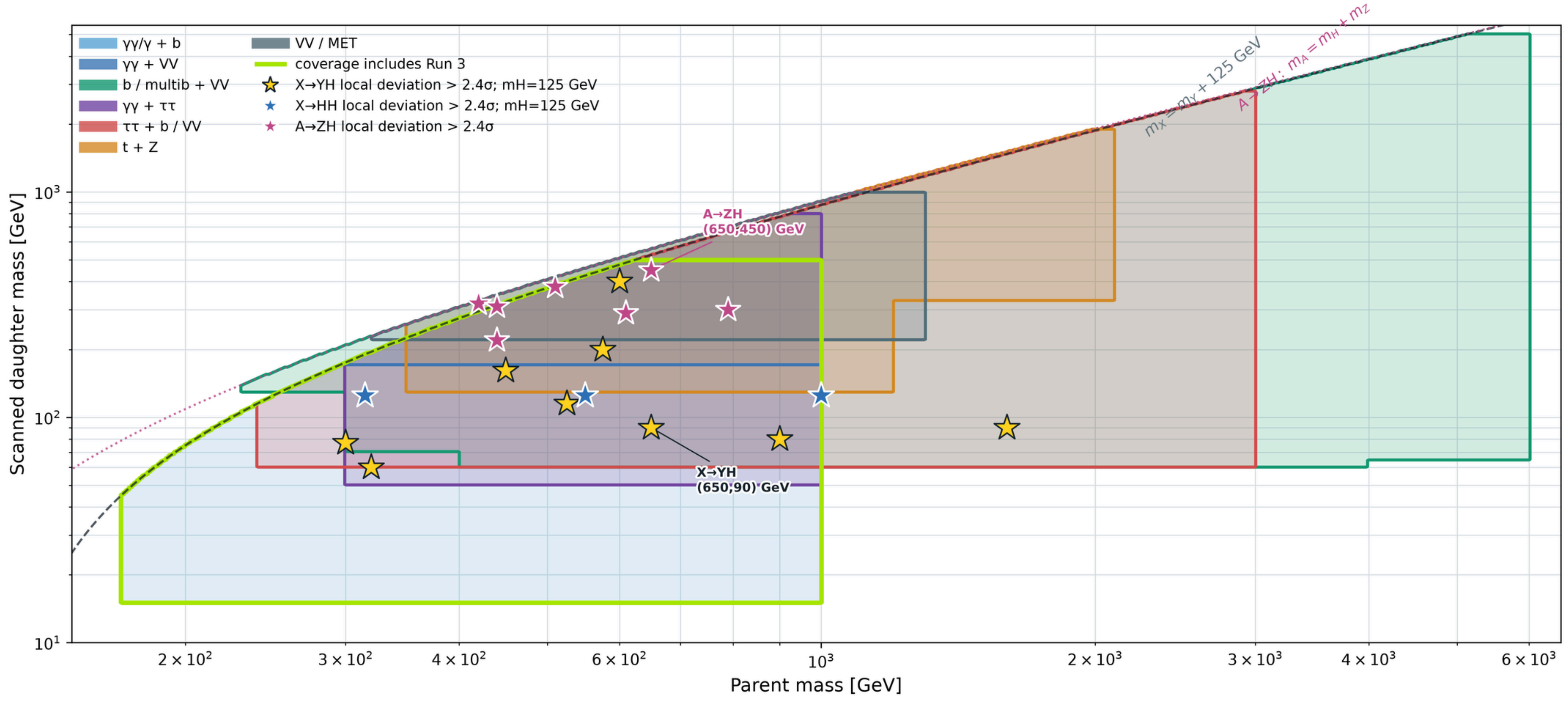
The final-state view shows whether a mass neighbourhood is supported by one signature or recurs across experimentally different channels.

The same excess spectrum, separated by exp.



Both experiments populate several of the same broad mass regions. A common mass neighbourhood still requires a topology-matched cross-check.

X→YH/X→HH/A→ZH coverage in the 2D plane

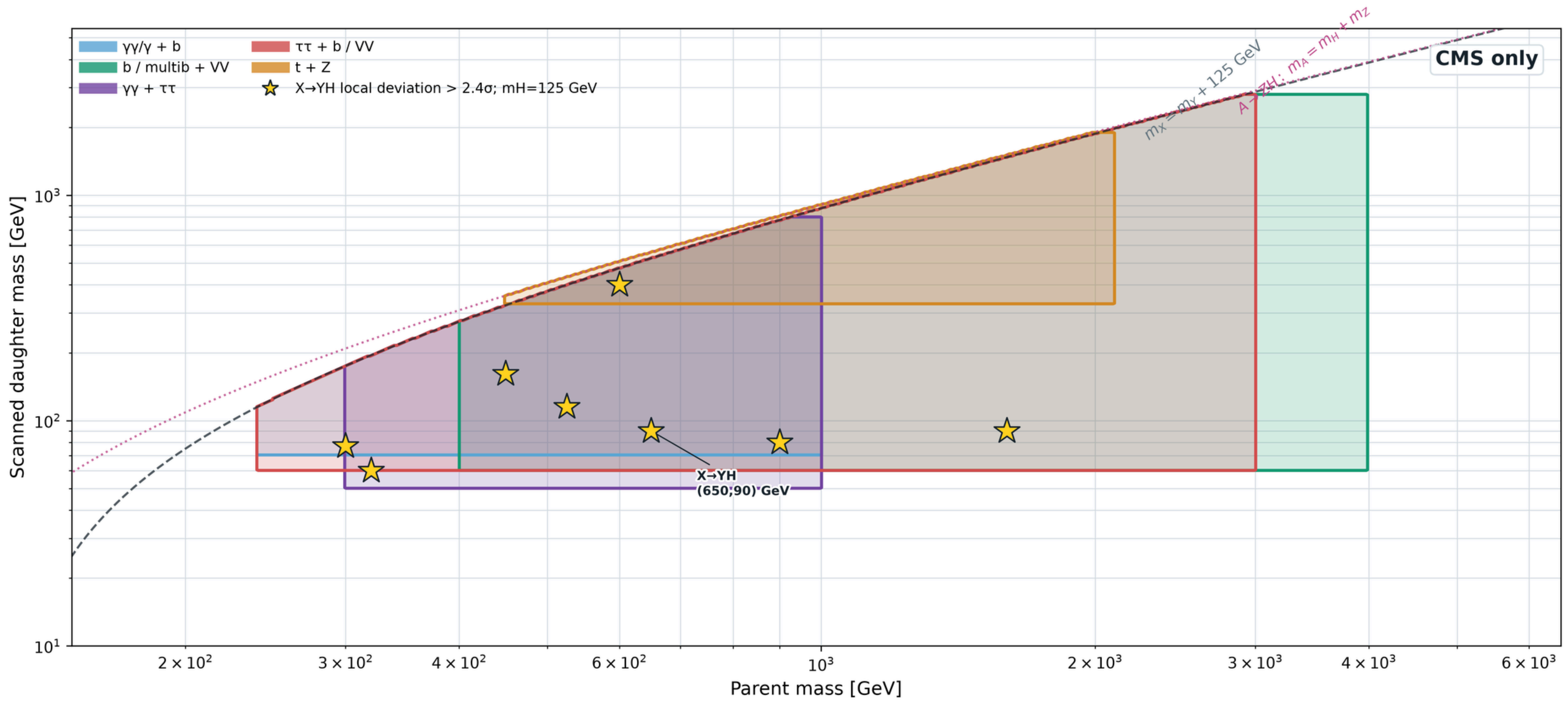


Excess-point references

Reference	mass point · local (global)
$X \to YH_{125}$	
☆ CMS B2G-24-001	(300,77) · 3.33 (0.65) σ
☆ CMS HIG-22-012	(320,60) · 2.6 (2.2) σ
☆ CMS HIG-22-012	(450,161) · 3.2 (0.3) σ
☆ CMS HIG-22-012	(525,115) · 3.2 (0.1) σ
☆ ATLAS arXiv:2404.12915	(575,200) · 3.5 (2.0) σ
☆ CMS HIG-20-012	(600,400) · 3.47 (2.44) σ
☆ CMS HIG-21-011	(650,90) · 3.8 (2.8) σ
☆ CMS B2G-23-007	(900,80) · 3.3 (<1) σ
☆ CMS B2G-21-003	(1600,90) · 3.1 (0.7) σ
$A \to ZH$	
★ ATLAS arXiv:2210.05415	(420,320) · 3.8 (2.8) σ
★ ATLAS arXiv:2011.05639	(440,220) · 3.1 (1.3) σ
★ ATLAS arXiv:2011.05639	(440,310) · 2.9 (0.82) σ
★ ATLAS arXiv:2401.04742	(510,380) · 2.5 σ
★ ATLAS arXiv:2011.05639	(610,290) · 3.1 (1.3) σ
★ ATLAS arXiv:2311.04033	(650,450) · 2.85 (2.35) σ
★ ATLAS arXiv:2210.05415	(790,300) · 3.9 (2.1) σ
$X \to H_{125}H_{125}$	
★ ATLAS arXiv:2210.05415	315 · 2.5 (1.3) σ
★ ATLAS arXiv:2210.05415	550 · 2.7 (1.3) σ
★ ATLAS arXiv:2209.10910	1000 · 3.1 (2.0) σ

XX (YY) = local (global) significance; only local > 2.4σ.

X→YH/X→HH/A→ZH coverage in the 2D plane - CMS Only

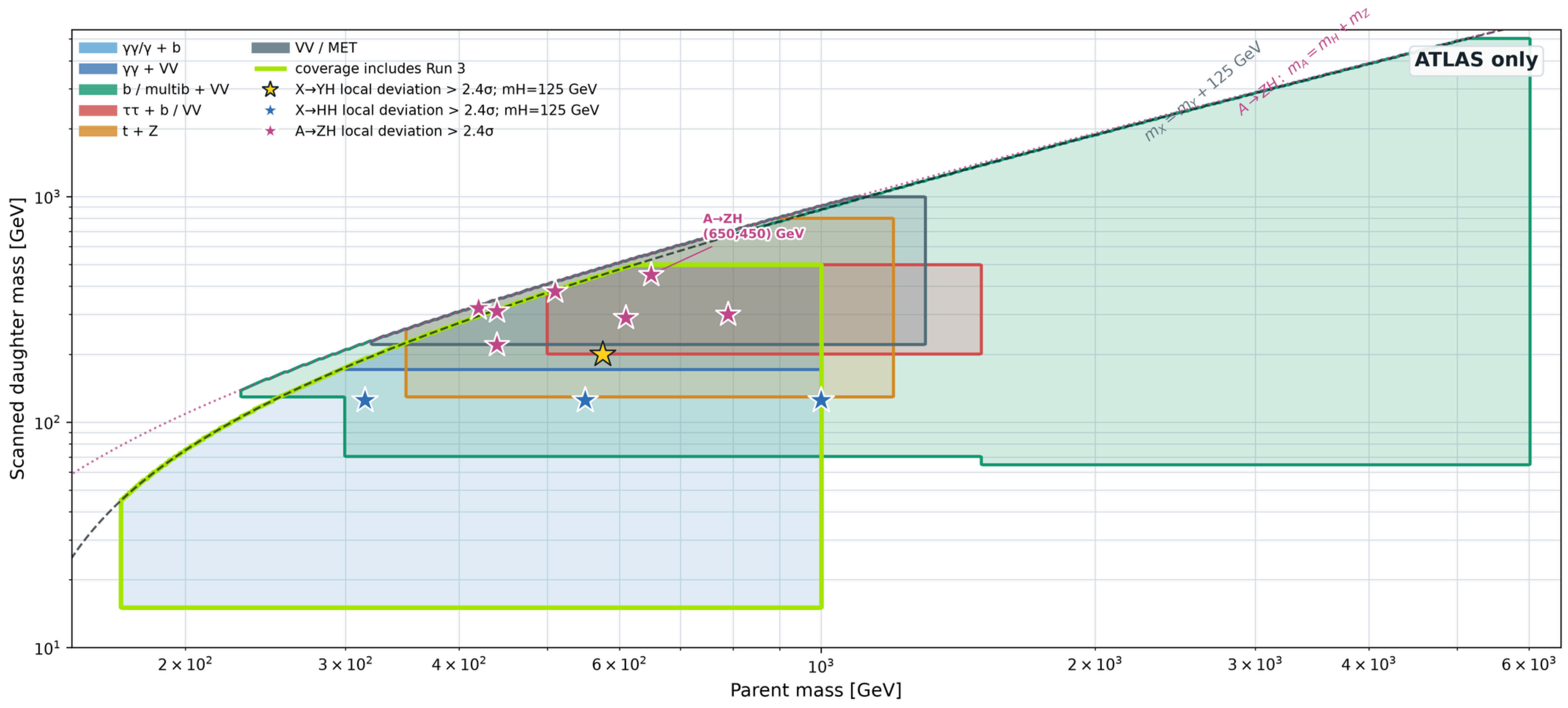


Excess-point references

Reference	mass point · local (global)
$X \to YH_{125}$	
☆ **CMS B2G-24-001**	(300,77) · 3.33 (0.65) σ
☆ **CMS HIG-22-012**	(320,60) · 2.6 (2.2) σ
☆ **CMS HIG-22-012**	(450,161) · 3.2 (0.3) σ
☆ **CMS HIG-22-012**	(525,115) · 3.2 (0.1) σ
☆ **CMS HIG-20-012**	(600,400) · 3.47 (2.44) σ
☆ **CMS HIG-21-011**	(650,90) · 3.8 (2.8) σ
☆ **CMS B2G-23-007**	(900,80) · 3.3 (<1) σ
☆ **CMS B2G-21-003**	(1600,90) · 3.1 (0.7) σ

XX (YY) = local (global) significance; only local > 2.4σ.

X→YH/X→HH/A→ZH coverage in the 2D plane - ATLAS only



Excess-point references

Reference	mass point · local (global)
$X \to YH_{125}$	
☆ ATLAS arXiv:2404.12915	(575,200) · 3.5 (2.0) σ
$A \to ZH$	
★ ATLAS arXiv:2210.05415	(420,320) · 3.8 (2.8) σ
★ ATLAS arXiv:2011.05639	(440,220) · 3.1 (1.3) σ
★ ATLAS arXiv:2011.05639	(440,310) · 2.9 (0.82) σ
★ ATLAS arXiv:2401.04742	(510,380) · 2.5 σ
★ ATLAS arXiv:2011.05639	(610,290) · 3.1 (1.3) σ
★ ATLAS arXiv:2311.04033	(650,450) · 2.85 (2.35) σ
★ ATLAS arXiv:2210.05415	(790,300) · 3.9 (2.1) σ
$X \to H_{125}H_{125}$	
★ ATLAS arXiv:2210.05415	315 · 2.5 (1.3) σ
★ ATLAS arXiv:2210.05415	550 · 2.7 (1.3) σ
★ ATLAS arXiv:2209.10910	1000 · 3.1 (2.0) σ

XX (YY) = local (global) significance; only local > 2.4σ.

Run 3 confirmation priorities

A decisive update uses a fixed signal hypothesis and an independent dataset. Nearby structures remain supporting information.

FEATURE	RUN 2 EVIDENCE	INDEPENDENT INFORMATION	DECISIVE RUN 3 TEST
95 GeV light scalar	CMS HIG-20-002: γγ 95.4 GeV, 2.9 (1.3)σ CMS HIG-21-001: ττ 95 GeV, 2.6 (2.3)σ; 100 GeV, 3.1 (2.7)σ	ATLAS arXiv:2407.07546: γγ at 95.4 GeV, 1.7σ ATLAS ττ searches cover the region without a comparable maximum	Run 3-only fits at fixed 95.4 and 100 GeV. Keep γγ and ττ separate. Combine only under one specified signal model.
X→YH (650,90) GeV	CMS HIG-21-011: γγbb, 3.8 (2.8)σ	ATLAS arXiv:2510.02857 tests the same point with Run 2+3. The fixed-point result gives p_0 = 0.5.	CMS full Run 3 update. ATLAS full Run 3-only result at the fixed point with the same narrow-width hypothesis.
X→WW 650 GeV	CMS HIG-20-016: 3.8σ local Global: 2.6σ for VBF-only; 2.4σ with floating fVBF	ATLAS CONF-2022-066 covers 300–4000 GeV with no feature near 650 GeV. Production categories are not identical.	Match ggF/VBF categories, spin-0 width, event selection and trial range before comparing the Run 3 results.
X→eμ 146 GeV	CMS HIG-22-002: 3.8 (2.8)σ	No exact ATLAS eμ scan in the inventory. ATLAS H125→eτ/μτ is complementary, not a replication.	ATLAS eμ scan over 110–160 GeV and CMS full Run 3 update. Retain 146 GeV as a predefined test.
A→ZH→Zhh (420,320) GeV	ATLAS arXiv:2210.05415: Z4b with ΓA/mA = 20%, 3.8 (2.8)σ	No CMS A→ZH→Zhh→Z4b counterpart is recorded in the inventory.	CMS 2D scan with narrow and 20% width hypotheses. ATLAS full Run 3 update at the same coordinate.

Numbers are local (global) significance. Different production, spin, width or daughter-mass hypotheses are not treated as confirmations.

Specific coverage gaps for full Run 3

The gap definition requires the same topology, final state, mass coordinates and lifetime or width hypothesis.

TOPOLOGY / FINAL STATE	CURRENT RUN 3 OR RUN 2 ANCHOR	WHAT IS STILL MISSING	CONCRETE RUN 3 DELIVERABLE
X→YH→γγττ	CMS HIG-22-012 mX = 300–1000 GeV; mY = 50–800 GeV Several local features; largest quoted global 2.2σ	ATLAS γγ+VV and ττ+VV searches are complementary. The same γγττ topology is absent.	Search both Y(ττ)H(γγ) and Y(γγ)H(ττ) over one continuous 2D grid.
H125→a1a2→4b/6b	ATLAS arXiv:2507.01165 Daughter masses 10–80 GeV; features at 25 and (50,70) GeV	CMS NPS-25-005 covers boosted 4b. It does not reproduce the complete asymmetric 6b phase space.	Full Run 3 resolved-to-merged reconstruction with unequal daughter masses and a common branching-ratio interpretation.
Low-mass φ→ττ	CMS EXO-24-012 Run 3 high-rate stream, 20–60 GeV	No ATLAS counterpart with equivalent Run 3 event recording is listed in the inventory.	A low-threshold ATLAS Run 3 analysis. Extend the CMS mass interval where the stream acceptance remains controlled.
H125→ZDZD→4μ displaced	CMS EXO-24-016 Run 3 dimuon scouting mZD = 0.5–50 GeV; $c\tau_0$ = 0.1–100 cm	ATLAS results cover related displaced signatures, but not the same Run 3 stream and lifetime grid.	Common mass-lifetime coordinates and efficiency maps versus displacement for both experiments.
H125→γ + MET	ATLAS arXiv:2606.14362 135 fb^{-1} of Run 3 plus the Run 2 combination	No CMS counterpart is recorded in the inventory.	CMS full Run 3 search with the same ggF topology and a documented dedicated-trigger acceptance.
HA→ℓℓ + MET	CMS NPS-25-002 Run 2+3 parameterised neural network in a 2D mass grid	No ATLAS counterpart is recorded in the inventory.	ATLAS 2D scan in mH and Δm with interpolation validation and the same visible final state.

These are inventory gaps, not claims that an experiment has no unpublished or ongoing analysis.

Run 3 analyses prepared for the first HL-LHC data

The useful legacy of Run 3 is a test that can be repeated without redefining the signal after the next dataset arrives.

HYPOTHESIS CONTRACT	Freeze the mass point or 2D coordinate, width, spin or CP assignment, production fractions and category composition before unblinding. Define the trial domain. Report the fixed-point p_0 even when another maximum appears. **Applies directly to 95 GeV, (650,90) GeV, 650 GeV WW, 146 GeV eμ and (420,320) GeV A→ZH.**
CONDITIONAL INFERENCE	Train models conditional on the parent and daughter masses instead of one classifier per benchmark. Validate interpolation and background sculpting across the resolved, mixed and boosted regimes. **Current anchors: ATLAS arXiv:2510.02857, CMS NPS-25-002 and CMS B2G-25-005.**
EVENT RECORDING	Retain low-pT and displaced events through high-rate streams, scouting or parking. Keep the trigger-level variables needed for data-driven background estimates and connect prompt and displaced selections through overlapping efficiency maps. **Current anchors: CMS EXO-24-012, CMS EXO-24-016 and ATLAS arXiv:2606.14362.**
EARLY HL-LHC REPEAT	Version the selections, input features, ML calibration, efficiency maps and statistical model. Run the unchanged Run 3 test on the first HL-LHC sample before optimising it for the larger dataset. **WG deliverable: common benchmark coordinates, counterpart status, p_0 and likelihood output conventions, plus an open coverage log.**

Full Run 3 should deliver predefined tests, continuous efficiency maps and preserved likelihoods that remain usable on day one of the HL-LHC.