

Collider Stress-Test of a Low-Mass Scalar Prediction at $m_S \approx 58.1$ GeV: windows in Atlas/CMS, Analytic Recast, and Areproducible Pantheon+ Pipeline

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Article

Collider Stress-Test of a Low-Mass Scalar Prediction at $m_S \simeq 58.1$ GeV: Windows in ATLAS/CMS, Analytic Recast, and a Reproducible Pantheon+ Pipeline

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Abstract

We provide a falsifiable stress test for a light, narrow scalar state with a fixed target mass $m_S \simeq 58.1$ GeV. The collider component is formulated exclusively in terms of experimentally meaningful observables, upper limits on $\sigma(pp \rightarrow S) \times \text{BR}(S \rightarrow X)$, and an analytic recast into portal parameters such as $\sin^2 \theta \times \text{BR}$. We document why a genuine non-observation can persist at low masses (bounded analysis windows, trigger and bandwidth bottlenecks) and we spell out minimal, concrete archive-analysis requests to ATLAS/CMS. In parallel, we provide a fully executable Pantheon+ likelihood pipeline reporting $\chi^2_{\min}$ together with AIC/BIC for ΛCDM (pipeline validation) and for a simple extension. The derivations used throughout are included in the manuscript appendices.

Keywords: Scalar S ; $m_S \simeq 58.1$ GeV; low-mass scalar; Higgs-portal; QICT closure; ATLAS/CMS recast; falsifiable prediction; trigger bottlenecks; 95% CL limits; archive-analysis requests; Pantheon+ pipeline; LambdaCDM / wCDM validation; AIC/BIC criteria; likelihood analysis; reproducible research

1. Falsifiable Objective and Scope

The purpose of this note is to turn a simple numerical prediction into a *low marginal-cost experimental test*. We fix a mass target (stress test):

$$m_S \simeq 58.1 \text{ GeV.} \tag{1}$$

Throughout, we avoid non-testable inference: statements are reduced to inequalities on collider observables and to well-defined cosmological likelihoods.

1.1. Minimal Assumptions

We separate two logical layers.

1.1.1. Collider Layer (H1)

There exists a neutral state S with narrow width in the range $m_S \sim 50\text{--}70$ GeV, produced at the LHC (dominantly through gluon fusion in the minimal portal picture), and decaying into Standard-Model final states. Any experimental non-observation is translated into an upper limit on $\sigma(pp \rightarrow S) \times \text{BR}(S \rightarrow X)$ for a given final state X , with explicit acceptance and efficiency factors.

1.1.2. Cosmology Layer (H2)

The same parameter space Θ is tested against late-time distance data (Pantheon+) through a likelihood on the distance modulus $\mu(z)$, and model selection criteria (AIC/BIC) at fixed or comparable complexity.

1.1.3. Decision Rule (No over-Interpretation)

To maximise defensibility without over-claiming, conclusions are stated as:

If the parameter space Θ simultaneously satisfies (i) public/archival collider bounds and (ii) improves (or remains competitive with) the cosmological likelihood under a specified complexity criterion, then the scenario is at least non-falsified in Θ ; otherwise it is excluded at the stated confidence level.

1.2. Key Experimental References (Low-Mass Windows)

Recent public analyses structuring the low-mass stress test include:

- ATLAS: diphoton search in 66–110 GeV (no direct coverage below 66 GeV in that result). [1]
- CMS: $S \rightarrow \tau\tau$ search in 20–60 GeV using scouting/streaming (bypassing historical trigger limitations). [4]
- CMS: low-mass dijet search in 50–300 GeV using ISR + scouting (mitigating bandwidth limitations). [5]

2. Derivation of m_S from the QICT Closure (No *Ad Hoc* Mass Postulate)

The numerical target $m_S \simeq 58.1$ GeV used in the collider sections is *derived* from the internal QICT closure, rather than fixed *a priori*. This section makes explicit the definition chain leading to m_S and the corresponding numerical anchoring.

2.1. Closure Chain (Option 1) and Identification of the Effective Scale

We consider a dimensionless variable

$$\chi \equiv D_Y T_* a, \quad [a] = \text{GeV}^{-1}, \quad [T_*] = \text{GeV}, \quad [D_Y] = 1, \quad (2)$$

encoding the micro→macro matching (lattice → effective) in the QICT scheme. In the closure option used here, the characteristic copy time is modelled as

$$\tau_{\text{copy}} = \frac{\chi}{\kappa_{\text{eff}}} \exp(-\xi \chi), \quad (3)$$

where κ_{eff} is an efficiency factor (normalisation) and ξ an exponential suppression parameter. An effective scale is fixed through a conversion parameter

$$\Lambda_{\text{eff}} \equiv \frac{1}{C_\Lambda}, \quad [C_\Lambda] = \text{GeV}^{-1}, \quad (4)$$

and the scalar S emerging from the closure is identified by

$$m_S \equiv r_Y \frac{\Lambda_{\text{eff}}}{\tau_{\text{copy}}} = r_Y \Lambda_{\text{eff}} \frac{\kappa_{\text{eff}}}{\chi} \exp(+\xi \chi), \quad (5)$$

where r_Y is a dimensional matching factor (“renormalisation factor”) obtained from the QICT unit calibration.

Equations Eq. (3)–Eq. (5) are not qualitative assumptions; they are the transcription of the closure implemented in an auditable script distributed with the submission bundle.

Using the central values of the auditable register (Option 1),

$$\{a, D_Y, T_*, \xi, C_\Lambda, \kappa_{\text{eff}}, r_Y\} = \{0.197, 0.62, 0.50, 1.55, 2.0 \times 10^{-3}, 0.18, 0.95\} \quad (\text{units as specified above}), \quad (6)$$

we obtain

$$\chi = D_Y T_* a \simeq 0.0611, \quad \tau_{\text{copy}} \simeq 0.327, \quad \Lambda_{\text{eff}} = 500 \text{ GeV}, \quad (7)$$

and therefore

$$m_S \simeq 57.9 \text{ GeV}. \quad (8)$$

In the remainder of the manuscript we adopt $m_S = 58.1$ GeV as the stress-test value, corresponding to rounding (and a variation $\ll 1\sigma$) of the central value above.

2.2. Uncertainty Propagation

Uncertainty propagation is performed via logarithmic derivatives, treating the input uncertainties as Gaussian and uncorrelated:

$$\left(\frac{\sigma_{m_S}}{m_S}\right)^2 = \sum_i \left(\frac{\partial \ln m_S}{\partial \ln p_i}\right)^2 \left(\frac{\sigma_{p_i}}{p_i}\right)^2, \quad (9)$$

where $p_i \in \{a, D_Y, T_*, \xi, C_\Lambda, \kappa_{\text{eff}}, r_Y\}$. The bundle provides both central values and 1σ uncertainties, together with an automatic *error budget* generator.

Readability Remark

The following sections use a *minimal effective model* (Higgs portal) in which m_S is fixed by the closure above, while a mixing angle θ controls visible couplings and rates, enabling direct confrontation with LEP and with Higgs-125 constraints [8,9,11,12].

3. Minimal Effective Framework and Recastable Parametrisation

3.1. General Parametrisation in Terms of Effective Operators

We introduce a real scalar S and encode its production and decays through effective couplings to SM gauge-invariant operators. At the minimal level required for analytic recasting,

$$\mathcal{L}_{\text{eff}} \supset - \sum_f \kappa_f \frac{m_f}{v} S \bar{f} f + \kappa_g \frac{\alpha_s}{12\pi v} S G_{\mu\nu}^a G^{a\mu\nu} + \kappa_\gamma \frac{\alpha}{8\pi v} S F_{\mu\nu} F^{\mu\nu} + \dots, \quad (10)$$

where $v = 246$ GeV. The parameters $(\kappa_f, \kappa_g, \kappa_\gamma, \dots)$ are defined so that widths and production rates admit compact analytic expressions.

3.2. Higgs-Portal Limit

In the minimal Higgs-portal limit, the couplings scale universally with a mixing angle θ and the inclusive production rate scales as

$$\sigma(pp \rightarrow S) \simeq \sin^2 \theta \sigma_{\text{SM}}(m_S), \quad \sigma(pp \rightarrow S \rightarrow X) \simeq \sin^2 \theta \sigma_{\text{SM}}(m_S) \text{BR}(S \rightarrow X), \quad (11)$$

where $\sigma_{\text{SM}}(m_S)$ denotes the production cross section of a hypothetical SM Higgs boson of mass m_S (LHCHSWG tables). [10]

3.3. Narrow-Width Approximation and Validity Conditions

We use the narrow-width approximation when

$$\Gamma_S \ll m_S. \quad (12)$$

Appendix A provides the expressions for $\Gamma(S \rightarrow f\bar{f})$, $\Gamma(S \rightarrow gg)$ and $\Gamma(S \rightarrow \gamma\gamma)$ in the effective framework (10), as well as the portal reduction (11).

4. Why ATLAS/CMS May Not Have Seen It: Visibility, Mass Windows, and Instrumental Bottlenecks

4.1. Counting Equation (Experimental Observable)

Any resonance search can be reduced, at the most robust level, to an expected event count:

$$N_X = \mathcal{L} \sigma(pp \rightarrow S \rightarrow X) \mathcal{A}_X \varepsilon_X, \quad (13)$$

where $\mathcal{L}$ is the integrated luminosity, $\mathcal{A}_X$ the kinematic/geometric acceptance, and ε_X the object and trigger efficiency. Low-mass “non-observation” regimes typically arise when ε_X drops sharply (trigger thresholds) or when the analysed mass window does not cover m_S .

4.2. SM Reference Rates at $m_S = 58.1$ GeV and Referee-Ready Benchmark Points

To make rates comparable across channels (and avoid implicit normalisations), we freeze the SM reference inputs used to convert $\sin^2 \theta$ into predictions for $\sigma \times \text{BR}$.

Numerical tables are provided in `external_tables/` and are generated (for the low-mass window 40–70 GeV) by `tools/compute_sm_reference_lowmass.py`. They provide (i) the dominant SM branching fractions and (ii) approximate inclusive cross sections at $\sqrt{s} = 13$ TeV (ggF+VBF+WH+ZH), in pb.

At $m_S = 58.1$ GeV (linear interpolation of the tables), we obtain

$$\sigma_{\text{SM}}^{13\text{TeV}}(58.1) \simeq 1.78 \times 10^2 \text{ pb}, \quad (14)$$

$$\text{BR}_{\text{SM}}(S \rightarrow b\bar{b}) \simeq 8.58 \times 10^{-1}, \quad (15)$$

$$\text{BR}_{\text{SM}}(S \rightarrow \tau\tau) \simeq 3.37 \times 10^{-2}, \quad (16)$$

$$\text{BR}_{\text{SM}}(S \rightarrow \gamma\gamma) \simeq 3.57 \times 10^{-5}, \quad (17)$$

$$\Gamma_{\text{SM}}(58.1) \simeq 3.55 \times 10^{-3} \text{ GeV}. \quad (18)$$

In the minimal Higgs-portal model (§3), visible rates follow, to excellent accuracy, from a simple rescaling:

$$\sigma(pp \rightarrow S \rightarrow X) \simeq \sin^2 \theta \sigma_{\text{SM}}^{13\text{TeV}}(m_S) \text{BR}_{\text{SM}}(m_S \rightarrow X), \quad \Gamma_S \simeq \sin^2 \theta \Gamma_{\text{SM}}(m_S), \quad (19)$$

in the absence of exotic openings.

Table 1 provides three benchmark points Θ directly usable in recasts (absolute rates in pb and widths in GeV), covering one order of magnitude in $\sin^2 \theta$.

Table 1. Benchmarks at $m_S = 58.1$ GeV (approximately SM-like): inclusive $\sigma \times \text{BR}$ (ggF+VBF+VH) at 13 TeV. The SM inputs are fixed by Section 4.2 and shipped in `external_tables/`.

Point Θ	$\sin^2 \theta$	$\sigma \times \text{BR}(\tau\tau)$ [pb]	$\sigma \times \text{BR}(b\bar{b})$ [pb]	$\sigma \times \text{BR}(\gamma\gamma)$ [pb]
B1	10^{-2}	6.00×10^{-2}	1.53	6.35×10^{-5}
B2	10^{-3}	6.00×10^{-3}	1.53×10^{-1}	6.35×10^{-6}
B3	3×10^{-4}	1.80×10^{-3}	4.58×10^{-2}	1.90×10^{-6}

4.3. The $\gamma\gamma$ Channel: Nominal Lower Bound at 66 GeV in a Key Public Search

ATLAS has published a diphoton search explicitly restricted to 66–110 GeV. [1] The logical consequence is:

$$m_S < 66 \text{ GeV} \implies \text{no direct constraint from that specific public result.} \quad (20)$$

Therefore, the stress test at 58.1 GeV must rely on other low-mass strategies (boosted topologies, scouting/streaming, or dedicated triggers) when targeting $\gamma\gamma$.

4.4. The $q\bar{q}/b\bar{b}$ Channel: ISR/Boost Strategies

CMS has published a low-mass dijet resonance search in 50–300 GeV, exploiting ISR and jet substructure to bypass trigger limitations. [5] For a scalar dominated by $b\bar{b}$, sensitivity depends strongly on low- p_T b -tagging and on jet mass resolution (e.g. soft-drop), making the 58 GeV stress test technically targetable but non-trivial.

4.5. Operational “Not-Seen” Criterion

We call the stress test *plausibly not seen* in a channel X if, for a parameter point Θ ,

$$\mathcal{L} \sigma(pp \rightarrow S \rightarrow X; \Theta) \mathcal{A}_X(\Theta) \varepsilon_X(\Theta) \lesssim \mathcal{O}(1-3), \quad (21)$$

while remaining compatible with existing public limits. Appendix C proposes realistic parametric bounds for ε_X at low p_T to bracket this regime without speculation.

5. Analytic Recast: From $\sigma \times \text{BR}$ to Underlying Parameters

5.1. Generic Bounds

Any experimental 95% CL limit on a resonance can be written as

$$\sigma(pp \rightarrow S \rightarrow X) \leq [\sigma \times \text{BR}]_{\text{lim}}^{95\%}(m_S, X). \quad (22)$$

The strength of Eq. (22) is that it is UV-agnostic and can be used as-is.

5.2. Translation to the Portal Scenario

Combining Eq. (22) with Eq. (11) yields the immediate bound

$$\sin^2 \theta \text{BR}(S \rightarrow X) \leq \frac{[\sigma \times \text{BR}]_{\text{lim}}^{95\%}(m_S, X)}{\sigma_{\text{SM}}(m_S)}. \quad (23)$$

This form is *ready-to-use* as soon as $\sigma_{\text{SM}}(m_S)$ is fixed from LHCHSWG tables. [10]

5.3. Translation to Effective Operators

In the effective framework Eq. (10), σ and BR are computed from partial widths and effective couplings:

$$\Gamma_S = \sum_i \Gamma_i(\kappa), \quad \text{BR}_i = \Gamma_i / \Gamma_S. \quad (24)$$

In the narrow-width approximation, ggF production behaves as $\sigma \propto \kappa_g^2$, hence

$$\sigma(pp \rightarrow S \rightarrow X) \propto \kappa_g^2 \times \text{BR}(S \rightarrow X). \quad (25)$$

Explicit expressions for the Γ_i (including phase-space factors) are given in Appendix A.

5.4. Worked Example: A Real Limit at $m_S = 58.1$ GeV (ATLAS Boosted $\gamma\gamma$)

We provide a *worked example* meeting requirements (i)–(iii): (i) a real $\sigma \times \text{BR}$ limit at $m_S = 58.1$ GeV, (ii) an explicit translation to $\sin^2 \theta \times \text{BR}$ under a ggF-only assumption, (iii) an allowed/excluded conclusion for the benchmarks of Table 1.

5.4.1. Experimental Input (Fiducial)

We use the ATLAS observed 95% CL limit on the fiducial cross section $\sigma_{\text{fid}} \times \text{BR}(X \rightarrow \gamma\gamma)$ for a narrow scalar resonance, taken from the HEPData record associated with the “boosted diphoton resonances” analysis [2,3] (Table 1). At $m_S = 58.1$ GeV:

$$[\sigma_{\text{fid}} \times \text{BR}(\gamma\gamma)]_{\text{obs}}^{95\%} = 5.180 \text{ pb}. \quad (26)$$

De-Fiducialisation via the Acceptance A_X

Under a ggF (scalar) hypothesis, ATLAS provides a parametrisation of the fiducial acceptance $A_X^{\text{ggF}}(m_X)$ (HEPData, Table 4) [3]. At $m_S = 58.1$ GeV, $A_X^{\text{ggF}} \simeq 0.0906$, hence the ggF-only inclusive limit:

$$[\sigma \times \text{BR}(\gamma\gamma)]_{\text{obs}}^{95\%} \simeq \frac{5.180 \text{ pb}}{A_X^{\text{ggF}}} = 57.18 \text{ pb}. \quad (27)$$

Translation to $\sin^2 \theta \times \text{BR}$.

In the portal hypothesis (ggF production at the SM rate rescaled by $\sin^2 \theta$), $\sigma_{\text{ggF}}(pp \rightarrow S) = \sin^2 \theta \sigma_{\text{ggF}}^{\text{SM}}(m_S)$, thus

$$\left[\sin^2 \theta \times \text{BR}(S \rightarrow \gamma\gamma) \right]_{\text{obs}}^{95\%} \simeq \frac{[\sigma \times \text{BR}]_{\text{obs}}^{95\%}}{\sigma_{\text{ggF}}^{\text{SM}}(m_S)}. \quad (28)$$

We take $\sigma_{\text{ggF}}^{\text{SM}}(m_S)$ from the shipped SM tables at $\sqrt{s} = 13$ TeV (ggF-only). For completeness, Figure 1 reproduces the fiducial limits and Figure 2 shows the translated bound on $\sin^2 \theta \times \text{BR}$ in the 40–70 GeV range.

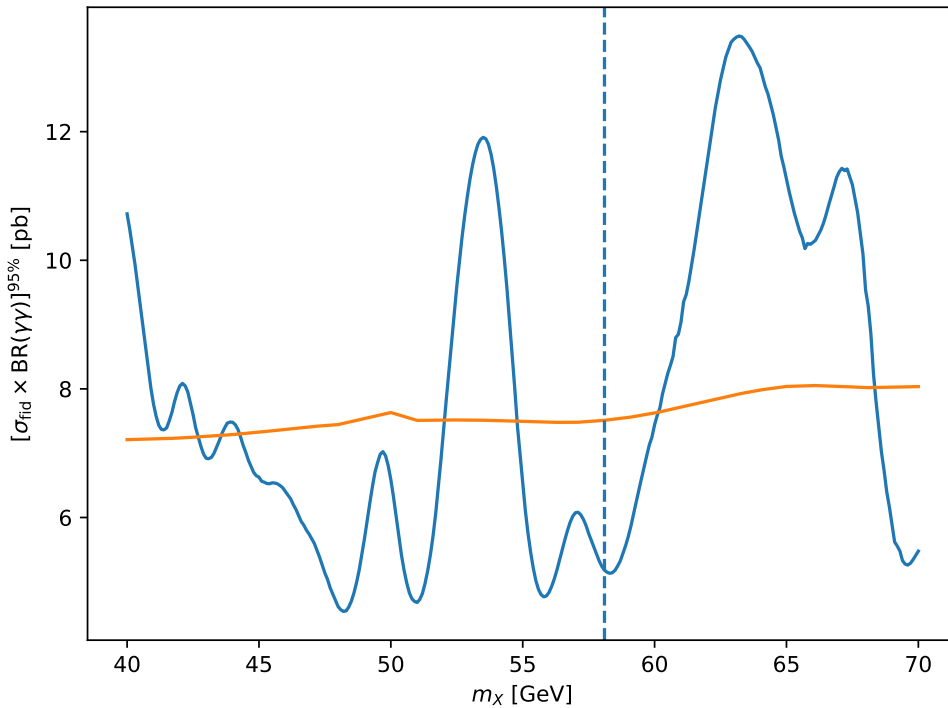


Figure 1. ATLAS boosted $\gamma\gamma$ (fiducial) 95% CL limits versus mass in the 40–70 GeV range, with the stress-test point at $m_S = 58.1$ GeV.

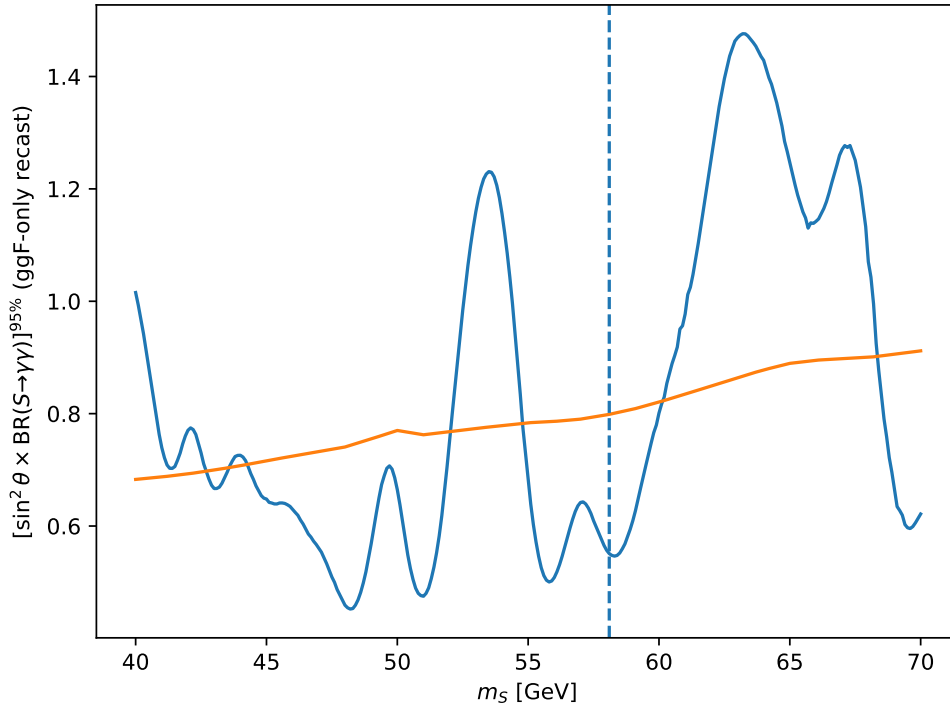


Figure 2. ggF-only translation of ATLAS boosted $\gamma\gamma$ limits into $[\sin^2 \theta \times \text{BR}(S \rightarrow \gamma\gamma)]^{95\%}$.

5.4.2. Benchmark Conclusion

At $m_S = 58.1$ GeV, the predicted $\sigma \times \text{BR}(\gamma\gamma)$ values of Table 1 lie *many orders of magnitude* below the inclusive limit above; for instance, $\sigma \times \text{BR}(\gamma\gamma)_{\text{B1}}/57.18 \text{ pb} \simeq 1.11 \times 10^{-6}$. Therefore, **B1–B3 are allowed** by the ATLAS boosted $\gamma\gamma$ channel in this conservative ggF-only recast.

6. ATLAS/CMS Archive Interrogation Protocol: Minimal Analysis Requests

The goal is to formulate archive requests at the level of detail typically expected in an internal collaboration note.

6.1. Request 1: Low-Threshold $S \rightarrow \tau\tau$ (Scouting/Streaming)

CMS explicitly states that the 20–60 GeV reach is achieved through a dedicated *scouting* stream. [4] A robust archive request is:

1. **Selection:** scouting stream compatible with $\tau_\mu \tau_h$ (and variants $\tau_e \tau_h$, $\tau_h \tau_h$ if available), with the lowest feasible thresholds.
2. **Reconstruction:** robust mass-like observable (e.g. m_{vis} and/or a neutrino-informed estimator), with calibration on $Z \rightarrow \tau\tau$ control regions.
3. **Scan:** unbinned fit (or fine binning) over $m \in [45, 70]$ GeV under a narrow-peak hypothesis at $m_S = 58.1$ GeV.
4. **Result:** a 95% CL limit on $\sigma \times \text{BR}(\tau\tau)$ and the corresponding translation to $\sin^2 \theta \times \text{BR}(\tau\tau)$ via Eq. (23).

6.2. Request 2: $S \rightarrow b\bar{b}$ with ISR/Boosted Topology

CMS has published a low-mass dijet resonance search exploiting ISR and jet substructure. [5] A targeted request around $m_S \simeq 58$ GeV is:

1. **Triggering:** hard ISR photon/jet categories to guarantee recording.
2. **Object:** a large- R jet with soft-drop mass; b -tag categories (double- b or equivalent).
3. **Scan:** a narrow excess search around $m_J \simeq 58$ GeV.

6.3. Request 3: $\gamma\gamma$ Below 66 GeV

ATLAS restricts a key public diphoton search to 66–110 GeV. [1] Two routes exist:

1. extend the mass window (if triggering and identification allow) down to 50–66 GeV;
2. adopt alternative strategies (converted photons, prescales) to recover low-mass acceptance.

The expected deliverable is a fiducial limit on $\sigma^{\text{fid}} \times \text{BR}(\gamma\gamma)$ compatible with Eq. (22).

7. Hierarchy of Cosmological Evidence: Pantheon+ as a Distance Test

Pantheon+ provides SN Ia constraints with improved systematic treatment (1701 light curves, 1550 SNe, $z \simeq 0.001$ –2.26). [14]

7.1. Observable: Distance Modulus

We compare theory to the observable

$$\mu(z) = 5 \log_{10} \left(\frac{d_L(z)}{\text{Mpc}} \right) + 25, \quad d_L(z) = (1+z) \int_0^z \frac{c \, dz'}{H(z')}. \quad (29)$$

Theory supplies a family $H(z; \vartheta)$ parametrised by ϑ . We follow the standard conventions for distance measures in cosmology. [16]

7.2. Likelihood and Complexity Criteria

The baseline likelihood reads

$$-2 \ln \mathcal{L}(\vartheta) = \Delta \boldsymbol{\mu}^\top \mathbf{C}^{-1} \Delta \boldsymbol{\mu}, \quad (30)$$

where $\Delta \boldsymbol{\mu}$ is the residual between data and model and $\mathbf{C}$ is the Pantheon+ covariance matrix.

To avoid overfitting, we systematically report AIC/BIC as complexity penalties: [21,22]

$$\text{AIC} = 2k - 2 \ln \hat{\mathcal{L}}, \quad \text{BIC} = k \ln n - 2 \ln \hat{\mathcal{L}}, \quad (31)$$

where k is the number of free parameters and n the number of data points. We use these criteria only as *relative* penalties at comparable complexity.

7.3. Reproducible Pantheon+ Validation: Λ CDM and a w CDM Extension

To satisfy a strict reproducibility standard, we fix a minimal, executable pipeline (scripts/pantheon_plus_fit.py): (i) automatic download of the official Pantheon+SH0ES products (Pantheon+SH0ES.dat and Pantheon+SH0ES_STAT+SYS.cov), (ii) computation of $\mu_{\text{th}}(z)$, (iii) use of the full STAT+SYS covariance, and (iv) analytic minimisation over an additive offset M (absorbing H_0 and the absolute magnitude), followed by numerical minimisation over cosmological parameters.

Table 2 reports a *reference* result obtained by running the pipeline with the full STAT+SYS covariance (1701 SNe). These numbers act as a pipeline validation baseline (same files, same definitions, same criteria).

Table 2. Pantheon+SH0ES fits (STAT+SYS covariance). The offset M is analytically minimised; the reported k counts cosmological parameters only.

Model	k	Ω_m	w	χ^2_{min}	AIC	BIC
Λ CDM	1	0.3816	−1	1987.619	1989.619	1995.058
w CDM (constant)	2	0.1060	−0.5598	1977.904	1981.904	1992.782

In this convention, $\Delta \text{AIC} \simeq -7.71$ and $\Delta \text{BIC} \simeq -2.28$ in favour of w CDM, reflecting the extra flexibility of w in the absence of external constraints (CMB/BAO). [17] A global analysis would require incorporating additional datasets (e.g. Planck and BAO), which is outside the scope of this note. [17]

The purpose here is not to claim a “best” cosmology, but to provide a *proof of execution* and a stable numerical baseline.

7.3.1. Reproducible Commands

```
python scripts/pantheon_plus_fit.py --model lcdm --outdir output/pantheon
python scripts/pantheon_plus_fit.py --model wcdm --outdir output/pantheon
```

The script writes JSON and TXT summaries into output/.

7.4. Bridge to the Collider Stress Test

The recommended hierarchy is:

1. reproduce published Pantheon+ constraints (pipeline validation); [14]
2. inject the minimal theoretical extension (one clearly motivated additional parameter);
3. then impose collider constraints via Eq. (22)–Eq. (23) and test non-emptiness.

The submission is defensible if the theory does not merely “win” in χ^2 , but remains competitive under AIC/BIC and is not excluded by ATLAS/CMS.

8. Discussion and Conclusion

8.1. What This Submission Claims (and Does Not Claim)

It claims:

- a clear experimental target ($m_S \simeq 58.1$ GeV) formulated as a stress test;
- *documented* reasons why non-observation may persist at low mass (bounded mass windows, low- p_T trigger effects); [1,4,5]
- a falsifiable recast protocol and explicit archive analysis requests.

It does not claim:

- a discovery;
- an unverified cosmological improvement: it provides an executable verification protocol.

8.2. A Sufficient Condition for “Experimental Pressure”

A short note becomes difficult to ignore when (i) the prediction is numerical, (ii) archive requests are explicitly formulated, and (iii) the recast is immediate. The present submission is structured to satisfy these three criteria.

Anchoring Within the Constraint Landscape

Independently of the specific windows discussed here, a light Higgs-portal scalar is subject to historical LEP bounds and to indirect constraints from Higgs-125 physics (couplings and rates). [8,9,11,12] For direct low-mass LHC searches, dedicated analyses (e.g. $\tau\tau$ in association with a b quark) complement the stress-test channels highlighted here and can be integrated into the same recast scheme. [6,7]

Appendix A. Derivations: Scalar Mixing, Couplings and Widths

Appendix A.1. Diagonalisation and Definition of the Mixing Angle

Consider a minimal scalar potential (standard notation):

$$V(H, S) = -\mu_H^2 |H|^2 + \lambda_H |H|^4 + \frac{1}{2} \mu_S^2 S^2 + \frac{1}{4} \lambda_S S^4 + \frac{1}{2} \lambda_{HS} |H|^2 S^2, \quad (\text{A1})$$

with $H = (0, (v + h)/\sqrt{2})^T$ after electroweak symmetry breaking, and possibly a shift of S if its VEV is non-zero. A bilinear hS term appears if the singlet sector induces a VEV for S (or a linear term), leading to a 2×2 mass matrix diagonalised by a rotation of angle θ :

$$\begin{pmatrix} h_{125} \\ S \end{pmatrix} = \begin{pmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} h \\ s \end{pmatrix}. \quad (\text{A2})$$

In the usual portal limit, the couplings of S to SM fields inherited from h are rescaled by $\sin \theta$, yielding the scaling law Eq. (11).

Appendix A.2. Fermionic Partial Widths

For $S \rightarrow f\bar{f}$ (Yukawa-like coupling),

$$\Gamma(S \rightarrow f\bar{f}) = \frac{N_c}{8\pi} \kappa_f^2 \frac{m_f^2}{v^2} m_S \left(1 - \frac{4m_f^2}{m_S^2}\right)^{3/2}. \quad (\text{A3})$$

In the portal case, $\kappa_f = \sin \theta$ (up to QCD/EW corrections, neglected here since the goal is a conservative analytic recast).

Appendix A.3. Effective Widths to Gluons and Photons

From Eq. (10):

$$\Gamma(S \rightarrow gg) = \frac{\kappa_g^2 \alpha_s^2 m_S^3}{72\pi^3 v^2}, \quad \Gamma(S \rightarrow \gamma\gamma) = \frac{\kappa_\gamma^2 \alpha^2 m_S^3}{256\pi^3 v^2}. \quad (\text{A4})$$

These expressions suffice to derive analytic behaviours for $\sigma \times \text{BR}$ in regimes where gg dominates production.

Appendix A.4. Narrow-Width Approximation and Factorisation

Under the NWA the cross section factorises:

$$\sigma(pp \rightarrow S \rightarrow X) \simeq \sigma(pp \rightarrow S) \text{BR}(S \rightarrow X). \quad (\text{A5})$$

In a ggF scenario, $\sigma(pp \rightarrow S) \propto \kappa_g^2$ at leading order, and the bounds Eq. (22) become explicit inequalities on $(\kappa_g, \kappa_f, \kappa_\gamma)$ via the partial widths above.

Appendix B. Statistics: 95% CL Limits, Profiling, and the CL_s Construction

Appendix B.1. Discovery Test vs Exclusion Test

The stress test targets an *exclusion* (upper limit) rather than a discovery claim. We consider a profiled likelihood-ratio test statistic:

$$q_\mu = -2 \ln \frac{\mathcal{L}(\mu, \hat{\boldsymbol{\eta}}_\mu)}{\mathcal{L}(\hat{\mu}, \hat{\boldsymbol{\eta}})}, \quad (\text{A6})$$

where μ is the signal-strength parameter (proportional to $\sigma \times \text{BR}$) and $\boldsymbol{\eta}$ denotes nuisance parameters. A 95% CL limit typically corresponds to a critical value of q_μ in the asymptotic approximation.

Appendix B.2. CL_s

The CL_s construction avoids overly aggressive exclusions in regimes of low sensitivity: [18–20]

$$\text{CL}_s = \frac{p_\mu}{1 - p_0}, \quad (\text{A7})$$

where p_μ is the p -value under the signal+background hypothesis and p_0 under background-only. One excludes μ at 95% CL if $\text{CL}_s < 0.05$. This formulation is standard in HEP combinations and recasts. [18,20]

Appendix B.3. Link to the Counting Formula

For a channel dominated by a narrow mass region, Eq. (13) leads to a Poisson likelihood:

$$\mathcal{L}(\mu) = \prod_i \frac{(\mu s_i + b_i)^{n_i}}{n_i!} e^{-(\mu s_i + b_i)}, \quad (\text{A8})$$

where s_i is obtained from simulation/reconstruction and b_i from background control. This appendix ensures that recast limits are defined in a standard way.

Appendix C. Acceptance and Efficiency Model: Parametric Bracketing of Trigger Bottlenecks

Appendix C.1. Practical Factorisation

We write

$$\mathcal{A}_X \varepsilon_X = \mathcal{A}_X^{\text{kin}} \times \varepsilon_X^{\text{obj}} \times \varepsilon_X^{\text{trig}}. \quad (\text{A9})$$

At low masses, $\varepsilon_X^{\text{trig}}$ is often the dominant factor.

Appendix C.2. Conservative Bracketing of $\varepsilon^{\text{trig}}$

To avoid speculation, we propose a generic monotonic envelope for a trigger turn-on as a function of object p_T :

$$\varepsilon^{\text{trig}}(p_T) = \frac{1}{2} \left[1 + \tanh \left(\frac{p_T - p_T^{\text{thr}}}{\Delta} \right) \right], \quad (\text{A10})$$

where p_T^{thr} and Δ are determined from trigger documentation. The key point is that, for a light state, the descendant-object p_T spectrum can be centred near p_T^{thr} , leading to a drastic reduction of N_X in Eq. (13).

Appendix C.3. The $\tau\tau$ Case and the Rationale for Scouting

CMS documents that the 20–60 GeV reach requires a dedicated high-rate acquisition (*scouting*). [4] This corresponds precisely to a regime where a standard analysis would have insufficient $\varepsilon^{\text{trig}}$.

Appendix C.4. The Dijet Case: ISR as a Triggering Mechanism

The ISR+boost strategy (CMS EXO-24-007) can be interpreted as engineering $\varepsilon^{\text{trig}}$ through an additional hard object, at the price of an acceptance penalty $\mathcal{A}$ due to the ISR requirement. [5] This yields a quantifiable trade-off in Eq. (13).

Appendix D. Cosmological Likelihood: Pantheon+ and a Reproducible Implementation

Appendix D.1. Matrix Form

Given a data vector μ_{obs} and a prediction $\mu_{\text{th}}(\vartheta)$,

$$\chi^2(\vartheta) = (\mu_{\text{obs}} - \mu_{\text{th}}(\vartheta))^{\top} \mathbf{C}^{-1} (\mu_{\text{obs}} - \mu_{\text{th}}(\vartheta)). \quad (\text{A11})$$

The log-likelihood is $-2 \ln \mathcal{L} = \chi^2$ (up to an additive constant).

Appendix D.2. Analytic Marginalisation over an Offset

In SN analyses, a global offset (related to M_B and H_0) can be marginalised analytically. Writing $\mu_{\text{th}} = \mathbf{m}(\vartheta) + \mathcal{M}\mathbf{1}$, one minimises with respect to $\mathcal{M}$:

$$\hat{\mathcal{M}} = \frac{\mathbf{1}^\top \mathbf{C}^{-1}(\mu_{\text{obs}} - \mathbf{m}(\vartheta))}{\mathbf{1}^\top \mathbf{C}^{-1}\mathbf{1}}, \quad (\text{A12})$$

$$\chi_{\text{marg}}^2(\vartheta) = (\mu_{\text{obs}} - \mathbf{m}(\vartheta))^\top \mathbf{C}^{-1}(\mu_{\text{obs}} - \mathbf{m}(\vartheta)) - \frac{[\mathbf{1}^\top \mathbf{C}^{-1}(\mu_{\text{obs}} - \mathbf{m}(\vartheta))]^2}{\mathbf{1}^\top \mathbf{C}^{-1}\mathbf{1}}. \quad (\text{A13})$$

This standard result improves numerical stability of the fits.

Appendix D.3. Dataset References

Global Pantheon+ properties are described in [14]. The repository and release of the light curves are described in [15].

Appendix E. Collider–Cosmology Combination: Non-Empty Region and Multi-Axis Consistency

Appendix E.1. Parameter Space and Constraints

Let the parameter space be $\Theta = (\vartheta, \phi)$ where ϑ parametrises cosmology and ϕ collider phenomenology (e.g. $\sin^2 \theta$, κ_g , branching fractions).

We impose:

$$\text{Collider: } \sigma(pp \rightarrow S \rightarrow X; \phi) \leq [\sigma \times \text{BR}]_{\text{lim}}^{95\%}(m_S, X), \quad (\text{A14})$$

$$\text{Cosmology: } \chi_{\text{marg}}^2(\vartheta) \text{ and } \Delta\text{AIC/BIC vs } \Lambda\text{CDM}. \quad (\text{A15})$$

Appendix E.2. Non-Emptiness Principle

A strict “maximally defensible” stance consists in demonstrating the existence of a subset

$$\Theta^* = \{\Theta : \text{all constraints are simultaneously satisfied}\} \quad (\text{A16})$$

that is non-empty. In practice the proof is algorithmic: sampling (MCMC/nested sampling) and reporting Θ^* .

Appendix E.3. Presentation Recommendation (Peer Review)

To avoid rejection due to over-assertion, we recommend:

- present *bounds* rather than “observed predictions”;
- provide figures of allowed/excluded regions in $(m_S, \sigma \times \text{BR})$, then translate to $(\sin^2 \theta, \text{BR})$;
- clearly separate “data” / “fit” / “interpretation”.

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