pBSM Topical Meeting: Heavy Resonances

Date: October 7, 2025
Indico: https://indico.cern.ch/event/1588457/

Key Takeaways (Post-Meeting Summary)

> *Will fill in after the meeting (summary of the most important outcomes and decisions.)* **Detailed real-time minutes at the end of the document / agenda.**

Your input goes here!

[Ben Allanach, Theory]: Z' searches for di-leptons could be favoured by the b->s l l vertex inferred from comparing experiment to state-of-the-art Standard Model predictions. Currently, the c-quark contributions to the non-local charm-loop contribution are well constrained in the EOS framework, but there is a clear need for estimating the size of various (excited and non-excited) D-meson contributions on top of this. Nevertheless, such scenarios work and have TeV-scale Z' particles and so provide a nice sand-box where one cannot merely tune the Z' to be too weakly coupled or too massive to contribute, if it is to explain the b->sll anomalies. Many of the models are based on a **third family baryon number** symmetry (plus some leptonic part) eg 3B_3-L, which predicts Z' -> ttbar or b bbar.

Xanda in the chat: the spin 0 case more realistic (non vanilla) frameworks are the extended Higgs sectors, that are mostly on the Higgs LHC WG3
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG3

Community Interest & Contact List

Add your name and email if you want to be kept informed, participate in future meetings, or help organize community efforts.

Name	Email	Institution / Role	Interest (Participation, Organization)
Ben Allanach	ben.allanach.work@gmail.com	University of Cambridge / Professor	Participation
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Jonas Würzinger	jonas.wuerzinger@cern.ch	TUM / postdoc	Participation

Minutes & Key Points

1. Opening and Meeting Goals

Second topical meeting of the Prompt BSM Working Group, dedicated to **Heavy Resonance searches** (focus on spin-1).

Goals of the topical meeting series:

- Brainstorm what has been done so far, identify next steps and perspectives.
- Form task forces to agree on:
    - Data preservation & reinterpretation
    - Uncertainties
    - Results presentation
    - Benchmarks and model synchronization
- Collect inputs and define guidelines to be summarized in a **public document**.

Upcoming topical meetings:

- **Oct 31, 2025** – pMSSM
- Later: VLF, LQ, HNL.

Action Items:

- Add names to shared Google Doc to join the Heavy Resonance task force.
- Subscribe to **lhc-pbswg@cern.ch** mailing list.
- Contact conveners if interested in contributing to specific task forces.

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2. Theoretical Overview - Andrea Thamm

Focus: theory motivation and simplified modeling of heavy spin-1 resonances, covering both heavy vector triplets (HVTs) and heavy vector singlets (HVSs).

Key points:

- **Motivation:**
    - Spin-1 resonances arise in many extensions of the SM:
        - *Weakly coupled* models (e.g., Z', W' extensions).
        - *Strongly coupled* models (e.g., composite Higgs, technicolor).
    - Simplified models provide a unified framework to compare theory and experiment.
- **Simplified Heavy Vector Triplet (HVT) Model:**

    - Parameters: coupling to gauge bosons (cH), to fermions (cF), and effective gauge coupling (gV).
    - Benchmarks:
        - *Model A:* weakly coupled extended gauge sector.
        - *Model B:* strongly coupled composite Higgs scenario.
    - Enables translation of ATLAS/CMS limits into general coupling space.
- **Production and Decay:**
    - *Drell–Yan* and *Vector Boson Fusion (VBF)* considered.
    - VBF can dominate for large masses and small fermion couplings ($cF \lesssim 0.05$).
    - Defined VBF benchmarks for diboson and dilepton final states.
    - Highlighted complementarity between Drell–Yan and VBF searches and need for expanded VBF coverage.
- **Heavy Vector Singlets (HVS):**
    - Similar framework with additional couplings; applicable to neutral and charged states.
    - Benchmark “Model C” introduced (extended U(1) gauge sector).
    - Branching ratios shift between quark and bosonic final states depending on the coupling regime.
    - For strongly coupled cases, VBF may again dominate.
- **Outlook:**
    - Simplified models remain powerful tools for reinterpretation and cross-experiment comparison.
    - Encouraged experiments to explore **VBF production modes** and **broaden coupling scans** (both larger gHgHand smaller cF).
    - Collider probes complement electroweak precision constraints.

Discussion and Q&A

- **Daniel Hayden (ATLAS):**
    - Asked whether **Randall–Sundrum (RS)** models mapped onto the HVT framework could allow interpreting **spin-2** limits using **spin-1** parameters.
    - **Franceschini:** clarified this is **not directly possible** — spin-1 and spin-2 simplified models remain distinct; while some parameter analogies exist, bounds cannot be sharply transferred without assumptions that are not testable elsewhere.
- **Mihail Chizhov (Sofia):**
    - Noted that **SU(2) doublet vectors** *can* couple to quarks via higher-order (non-renormalizable) operators.
    - **Thamm:** agreed, clarifying that her talk is restricted to **dimension-4 (renormalizable)** terms; such effective couplings are possible but **suppressed** by the high energy scale.
    - Chizhov added these could appear in **heavy-quark associated production (ttH-like)** processes.

    - Thamm requested the relevant papers for reference and agreed to add this caveat to her slides.
- **Chizhov (follow-up):**
    - Questioned why **exclusion plots start at 1 TeV** and not lower masses.
    - **Thamm:** replied that below ~500 GeV the simplified model loses validity and lower-mass regions are already experimentally constrained; noted that most LHC analyses start at a few hundred GeV.
    - **Franceschini:** added that literature often omits references for sub-TeV limits, and urged experiments to **document lower-mass coverage** explicitly for clarity.
- **Daniel Hayden (follow-up):**
    - Asked about the **upper and lower bounds of coupling scans**: whether it is meaningful to go beyond gH=3 or down to very small cF values (~0.01).
    - **Thamm:**
        - Large couplings ($g_H \lesssim 4\pi$) are **physically motivated** in strongly-coupled models (e.g., composite Higgs).
        - Very small fermionic couplings are also relevant, since models exist with **near-zero cF**; both ends of parameter space are interesting to probe experimentally.

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3. ATLAS Overview - Daniel Hayden

Presentation summarized the **ATLAS heavy resonance combination** and ongoing efforts to harmonize interpretations across spin hypotheses (spin-1, spin-0, spin-2)

Main Points:

- Reviewed ATLAS combinations of bosonic (VV/VH) and leptonic final states:
    - **8 TeV (36 fb^{-1}, 2018)** – first full combination across spin-0/1/2 interpretations.
    - **13 TeV (139 fb^{-1}, 2024)** – extended to τ, top, and jet channels; focused on **spin-1 (HVT)** interpretation with first exploration of **VBF production**.
- Emphasized potential of **combined fits across channels** to reveal smaller excesses or rule out fluctuations.
- Shared mock coupling scans (cF–cH planes) for exclusion sensitivity at 4–5 TeV masses.
- Discussed previous ATLAS–CMS coordination, including:
    - Exchange of VBF generation jobOptions for consistent sample production.
    - Cross-checks of cross-sections and PDF/theory uncertainties.
    - No combined paper yet, but ongoing interest in readiness for a discovery scenario.

- Highlighted desire to publish likelihoods and correlation matrices to allow reinterpretation; constrained by legacy format of 2024 workspaces.
- Proposed further model extensions: adding VLQ couplings, additional Higgs, or other spin frameworks (0, 2).
- Briefly outlined prospects for EFT-based reinterpretations of resonances (SM ↔ BSM EFT transition).

Discussion and Q&A

- Haleem: For VBF studies, should Model C be extended to enable leptonic couplings (e.g., to electrons), or should there be a separate benchmark with both gauge and leptonic couplings on?
  Hayden: Prior work looked at near-zero fermionic coupling and where leptonic sensitivity enters; VBF still tends to be more competitive at high gHgH. If one turns down bosonic couplings too much, VBF production turns off; suggests theory guidance to define a motivated benchmark with nonzero leptonic couplings.
- Hayden (clarifying VBF reach): To see VBF "closing in" on small cF regions, ATLAS found they needed to go to lower masses (~1 TeV) and likely scan beyond gH=3; plans to zoom to smaller couplings in low-mass plots.
- Gustavino: Asked whether VBF is the best approach both for higher masses (small couplings) and to probe lower masses; raised trigger threshold concerns and whether very low masses are already ruled out.
  Hayden: At 3 TeV already quite constrained; they looked at 1 TeV but would need to "zoom in"; ATLAS can go sub-TeV, but the practical floor needs study.
- Franceschini: Noted much of the older literature isn't expressed in the HVT language; suggested "archaeology & translation" to map prior constraints into current parameter spaces.
- Hayden (follow-on): Mentioned overlaying electroweak precision constraints (shown earlier in theory talk) as additional context on coupling planes.

Takeaways / Next steps (from discussion):

- Consider a leptonic-enabled VBF benchmark if theory can motivate it (interplay of production vs decay when gH is small).
- For VBF coverage, extend scans to higher gH and zoom low-mass planes to smaller cF values.
- Document/translate relevant sub-TeV constraints from older literature into the HVT parameter space.

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4. CMS Overview - Andrea Malara

Scope:
CMS presented a Run-2 heavy-resonance combination, “just made public last week,” combining 16 channels; orthogonality across channels was enforced (some channels excluded) and both DY & VBF production were considered.

- Dileptons: Combination improved sensitivity by ~20–50% relative to single channels; earlier 2–3σ tensions in dileptons were reduced to just above ~2σ (around the ~3 TeV region).
- Dijets: Overall sensitivity dominated by the inclusive dijet search; other sub-channels help recover low-mass coverage up to ~1 TeV.
- Dibosons (VV/VH): All-hadronic channel strongest at high mass; 1-lepton modes add modest gain between ~2–4 TeV.
- VBF coverage: In the combination, VBF interpreted only for diboson channels; no VBF results yet for dilepton/dijet. Sensitivity suggests (re)study of the VBF parameter space.

Coupling scans & non-universality: CMS performed 2D scans (fermion vs. Higgs couplings), explored non-universal fermion couplings, and a third-generation-only benchmark; showed complementarity between light-flavor and $t\bar{t}t\bar{t}$ constraints, with some regions entirely excluded at 95% CL.

Discussion and Q&A (after CMS presentation)

- Mihail Chizhov: Asked whether production via heavy quarks could be relevant for the searches shown.
    - Pointed out that in some models, new vector bosons (such as the V′) may couple to third-generation quarks, leading to processes like associated production with $t\bar{t}$ or $b\bar{b}$ pairs.
    - Suggested that these couplings could significantly affect the phenomenology and might deserve to be considered within the simplified model.
    - Cited examples from his earlier works on non-universal gauge interactions and possible “chiral” vector couplings, emphasizing that such effects could manifest even when the HVT formalism assumes universality.
    - He further noted that some of these diagrams could mimic standard Drell–Yan or VBF topologies in the experimental reconstruction.
- Andrea Malara: Responded that the current CMS combination did not include such processes explicitly.
    - Clarified that the combination followed the standard HVT parameterization assuming fermion universality, but that CMS had indeed tested non-universal couplings (different light- vs heavy-flavor couplings) in specific scans.
    - Confirmed that associated production with heavy quarks was *not part of the official signal modeling* but could, in principle, be reinterpreted later if corresponding simulated samples were produced.

    - Mentioned that some channels involving top or bottom final states (e.g., $W' \to tb$, $Z' \to t\bar{t}$) were part of the combination, covering part of that phenomenology indirectly.
- Roberto Franceschini: Thanked Malara for the clarification and added that such interactions could be discussed in future task-force meetings, particularly if theory colleagues provide benchmarks for third-generation-specific couplings.
    - Highlighted that CMS results with non-universal couplings are already an important step forward compared to previous combinations.
    - Emphasized the value of making cross-experiment comparisons for these cases, since ATLAS had explored similar setups.
- Giuliano Gustavino: Supported the idea of exploring extended benchmarks including heavy-quark–associated production, noting that these could connect collider searches more closely to models explaining flavor anomalies.
    - Proposed following up with a joint ATLAS–CMS–theory benchmark table to align interpretations.
