The ATLAS B-physics trigger performance in LHC Run 3 (2022-2023)

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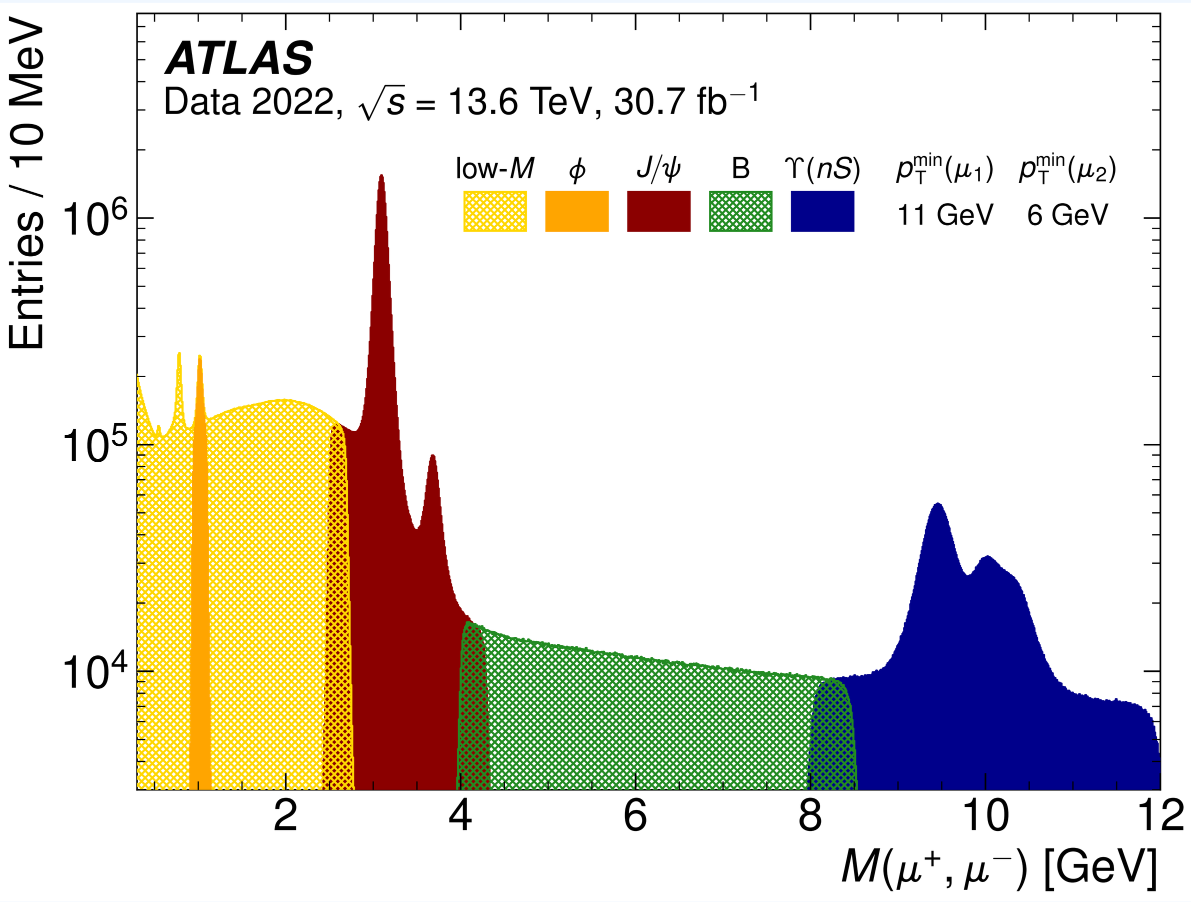
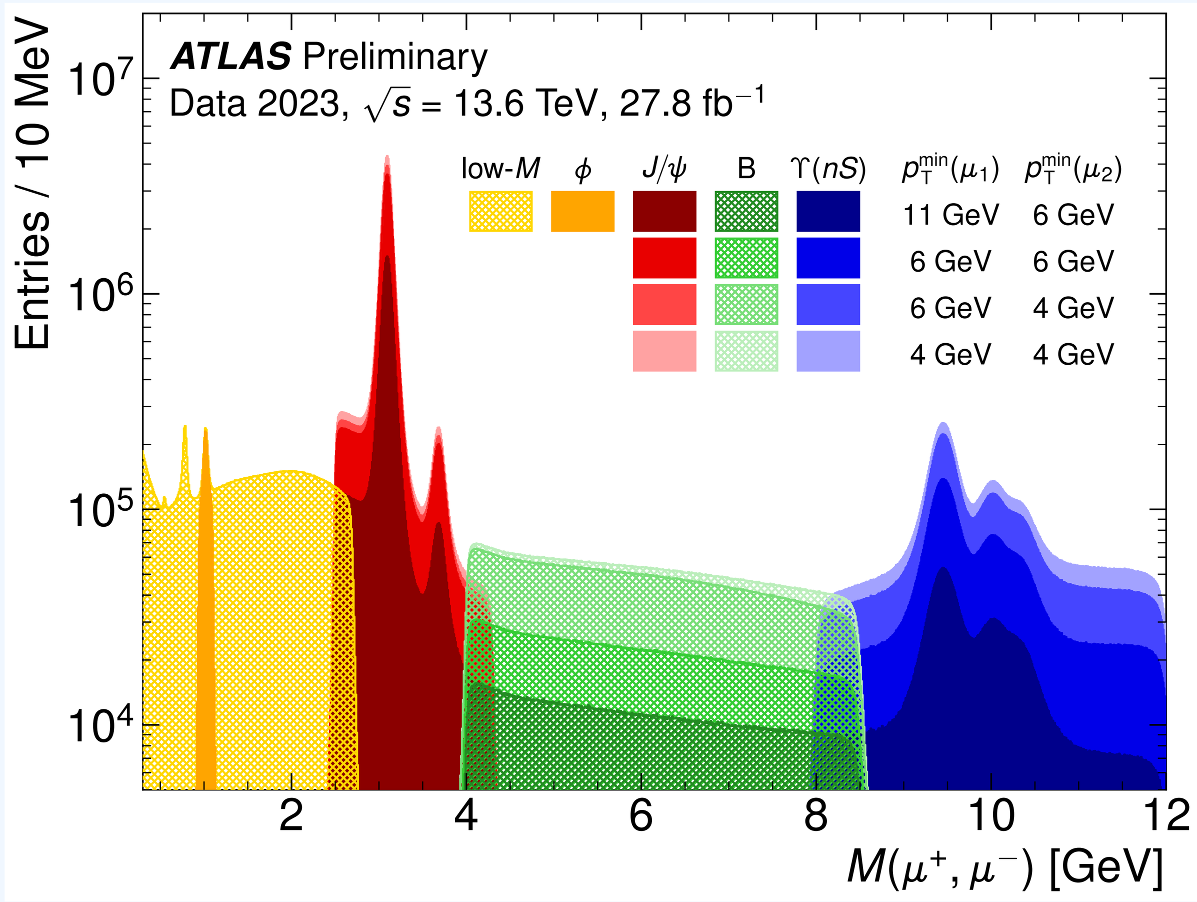
1. Introduction

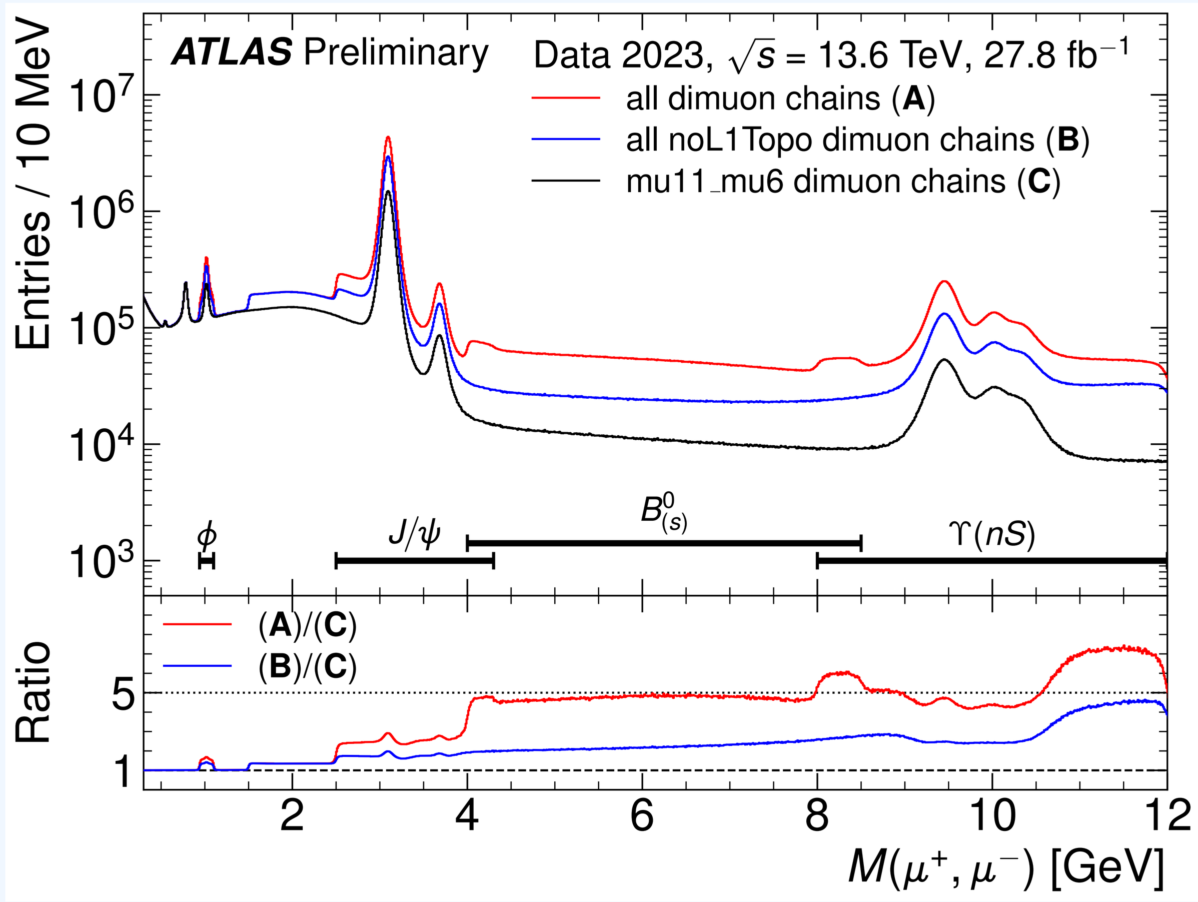
The trigger selection of events for *B*-physics analyses is primarily based on the identification of *b*-hadrons through decays with a muon pair in the final state, however one or more muons or electrons could also be present in specific selections. Examples are decays with charmonium, $B \to (J/\psi \text{ or } \psi')X \to \mu\mu X$, rare decays $B^0_{(s)} \to \mu\mu$, and semileptonic $B \to \mu\mu X$ decays. Decays of prompt charmonium and bottomonium are also identified through their dimuon decays, and are therefore similar to *B*-meson decays, apart from the lack of measurable displacement from the *pp* interaction point. As the BLS topologies are significantly different from the majority of the ATLAS physics triggers, they are recorded to a separate delayed BLS stream.

As *B*-mesons are very light, the resulting muon momenta are rather soft. To control the input rate to the high level trigger (HLT), most of the *B*-physics triggers require two muons at Level-1. Their rate is substantially reduced compared to single-muon L1 triggers. The Level-1 topological trigger can be used for the subsequent background rejection. It combines information about several L1 objects into topological information about the event. In the case of *B*-physics additional requirements for the invariant mass $M_{\mu\mu}$ and the opening angle $\Delta R_{\mu\mu}$ calculated for the L1 muons allow us to reduce L1 rate for the dimuon chains with soft p_T thresholds. At the HLT, muons are reconstructed using the same algorithms as for the pure Muon chains with the additional requirement that the combined muons have opposite charges and form a good vertex (where a fit is performed using the ID track parameters) within a certain invariant mass window.

2. Dimuon trigger chains







Invariant mass distribution for oppositely charged muon candidate pairs that pass various high level triggers (HLT).
Events are selected by dimuon triggers, with objects passing p_T thresholds of 4, 6 or 11 GeV. Pairs of opposite-sign muons are fitted to a common vertex, using the inner detector track parameters, with a $\chi^2 < 20$ per degree of freedom. The invariant mass of each pair is calculated using the offline track parameters refitted by the vertexing, and a PDG muon mass hypothesis. Different colors correspond to triggers selecting muon pairs in specific invariant mass ranges, namely $\phi(1020)$ meson (0.94–1.1 GeV), charmonium (2.5–4.3 GeV), *B*-hadron (4–8.5 GeV), and bottomonium (8–12 GeV). Not all ranges are continuous due to not all mass ranges being available for all selections. Muons are required to have pseudorapidity $|\eta| < 2.3$ and to pass "Medium" offline quality criteria [1]. They are also required to match the objects responsible for firing the trigger (ΔR between inner detector tracks of the offline and HLT muons is required to be < 0.01). The events are recorded into a dedicated stream for B-physics and Light States that is not reconstructed offline promptly, but as available resources allow. Data quality requirements are imposed, notably on the performance of the MS and ID system. Left plot was taken from [2], right plot from [3].

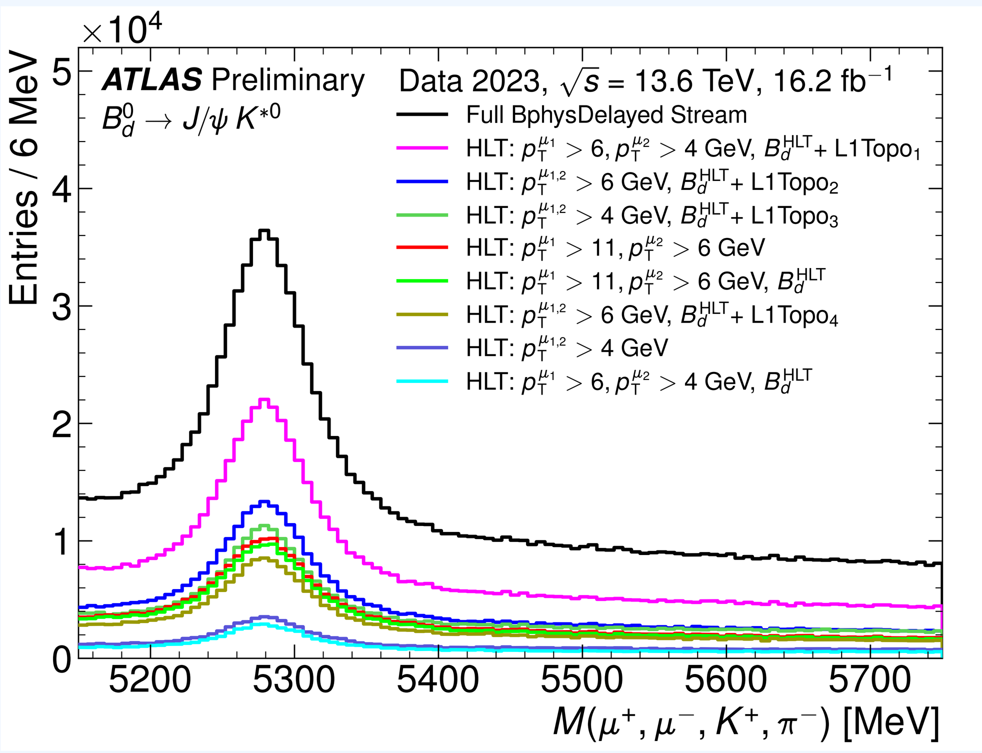
Data recorded with and without L1Topo.
Black line **(C)** corresponds to the dimuon triggers with one object passing a p_T threshold of 6 and the other 11 GeV. Blue line **(B)** adds contributions from various dimuon triggers with objects passing p_T thresholds of 4 or 6 GeV (no L1Topo algorithm applied for L1 muon objects). Red line **(A)** shows pairs from events where any of dimuon chains was active (including those seeded from L1Topo). So that, the difference between red and blue curves is due to events recorded with L1Topo seeds. The non-physical bump around 8.5(4) GeV is due to the overlap of HLT chains for bottomonium(charmonium) decays and chains for rare *B*-hadron decays seeded from independent L1 items with and without L1Topo algorithms correspondingly.

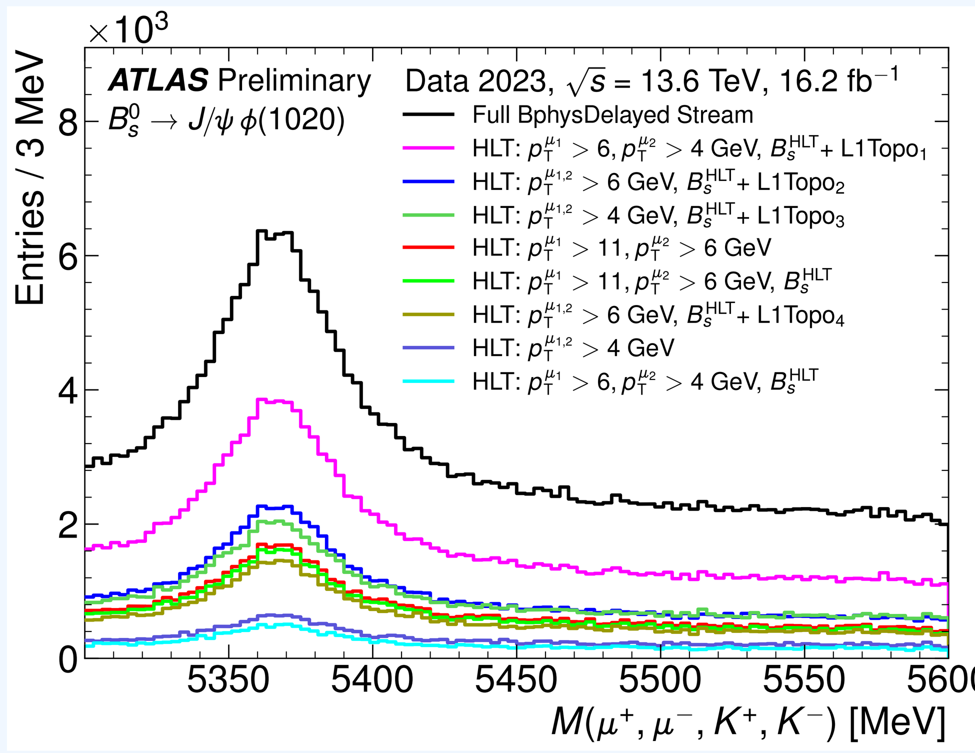
3. Semileptonic decays, such as $B^0 \to \mu\mu K^{*0}(\to K^+\pi^-)$

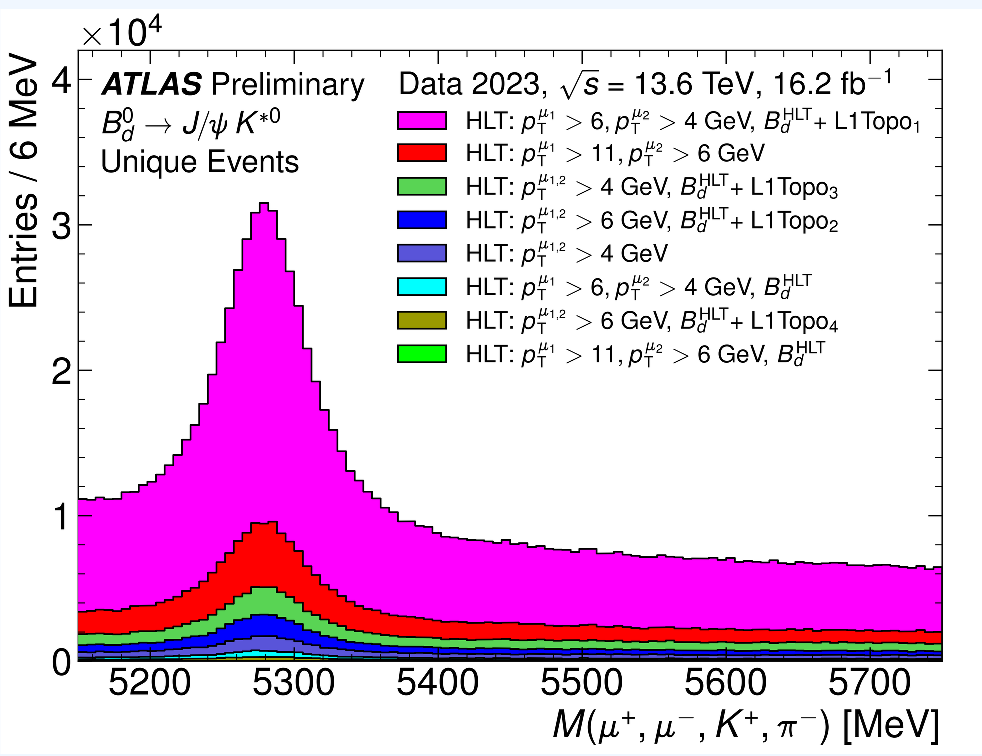
For semileptonic decays, searches for additional InDet tracks and a combined vertex fit are performed, assuming a few exclusive decay hypotheses:

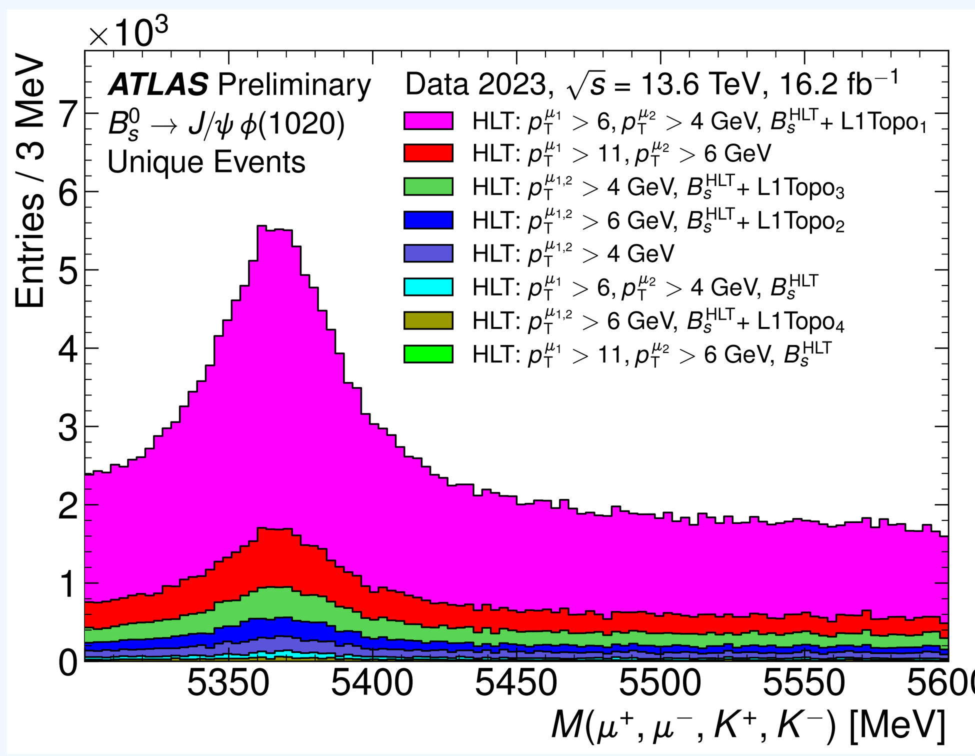
1. Dimuon + 1 track
   - ✓ $B^+ \to \mu^+\mu^- K^+$,
   - ✓ $B_c^+ \to J/\psi(\to \mu^+\mu^-)\pi^+$.
2. Dimuon + 2 tracks
   - ✓ $B_s^0 \to \mu^+\mu^-\phi(\to K^+K^-)$,
   - ✓ $B_d^0 \to \mu^+\mu^- K^{*0}(\to K^+\pi^-)$,
   - ✓ $\Lambda_b^0 \to P_c^+(\to J/\psi p)K^-$ for pentaquark and tetraquark searches.
3. Cascade decays for B_c:
   - ✓ $B_c^+ \to J/\psi D_s^+(\to \phi\pi^+)$, hadron tracks are fitted to the common vertex, the combined momentum of D^+/D_s^+ candidate is constrained to point to the dimuon vertex,
   - ✓ $B_c^+ \to J/\psi D^+(\to K^-\pi^+\pi^+)$, same topology as for the previous decay, D^+ candidate should have $L_{XY} > 0$ w.r.t. dimuon vertex,
   - ✓ $B_c^+ \to J/\psi D^{*+}(\to D^0(\to K^-\pi^+)\pi^+)$, muons and pion from D^{*+} decay are fitted to the common vertex, D^0 is refitted to point to the D^{*+} decay vertex,
   - ✓ $B_c^+ \to J/\psi D^0(\to K^-\pi^+)X$, partial reconstruction: we omit pion from D^{*+}.

The mass spectra of $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi$ candidates reconstructed using the dedicated stream for B-physics and Light States from a partial 2023 dataset. The candidate yields from different trigger selections are also shown (top). Events overlapping with other triggers listed have been removed giving priority to the chains yielding the larger samples. This provides information about the unique events the triggers are recording (bottom). The legend is ordered so that the largest subsample is first. Various L1Topo algorithms make additional requirements for invariant mass $M_{\mu\mu}$ and the opening angle $\Delta R_{\mu\mu}$ calculated for the L1 muons. Namely, L1Topo$_1$ requires $M_{\mu\mu} \in [2, 9]$ GeV, $\Delta R_{\mu\mu} \in [0, 1.5]$ and it also requires opposite charge muons if the charge information is available (two L1 muons from TGC, $|\eta_\mu| > 1.05$); L1Topo$_2$: $M_{\mu\mu} \in [2, 9]$ GeV, $\Delta R_{\mu\mu} \in [0.2, 1.5]$; L1Topo$_3$: $M_{\mu\mu} \in [2, 9]$ GeV, $\Delta R_{\mu\mu} \in [0, 1.5]$; L1Topo$_4$: only $\Delta R_{\mu\mu} \in [0, 1.5]$.









4. References

[1] G. Aad *et al.* [ATLAS], "Muon reconstruction and identification efficiency in ATLAS using the full Run 2 *pp* collision data set at $\sqrt{s} = 13$ TeV," Eur. Phys. J. C **81**, no.7, 578 (2021)
[2] The Run-3 ATLAS Trigger System, CERN-EP-2023-299
[3] B Physics Trigger Public Results, TWiki link.

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