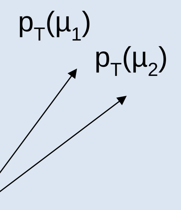
Maximising the ATLAS B physics trigger potential with topological selections

1 B Physics Programme

The **ATLAS B Physics programme** for Run 2 **probes for signs of new physics** and provides **precision constraints of the Standard Model**.

There are four final states (**$B_s \to \mu\mu$, $B_s \to J/\psi\Phi$, $B_d \to \mu\mu K^*$, $\Upsilon(nS) \to \mu\mu$**) that can be considered **prototypical** of the **Run 2 programme** with regards to online event selection. This study maximizes their collection potential by exploiting the ATLAS Level-1 Trigger upgrade.

B Physics Triggers



B Physics signals are typically **detected in ATLAS by triggering on muons** that pass given **transverse momentum (p_T) thresholds**.
In **Run 1**, the **only requirement** of these triggers was that **one or more muons** had a of **p_T greater than 4 or 6 GeV**. The yields for these triggers in Run 2 (thus far) are shown right (Figure 1).

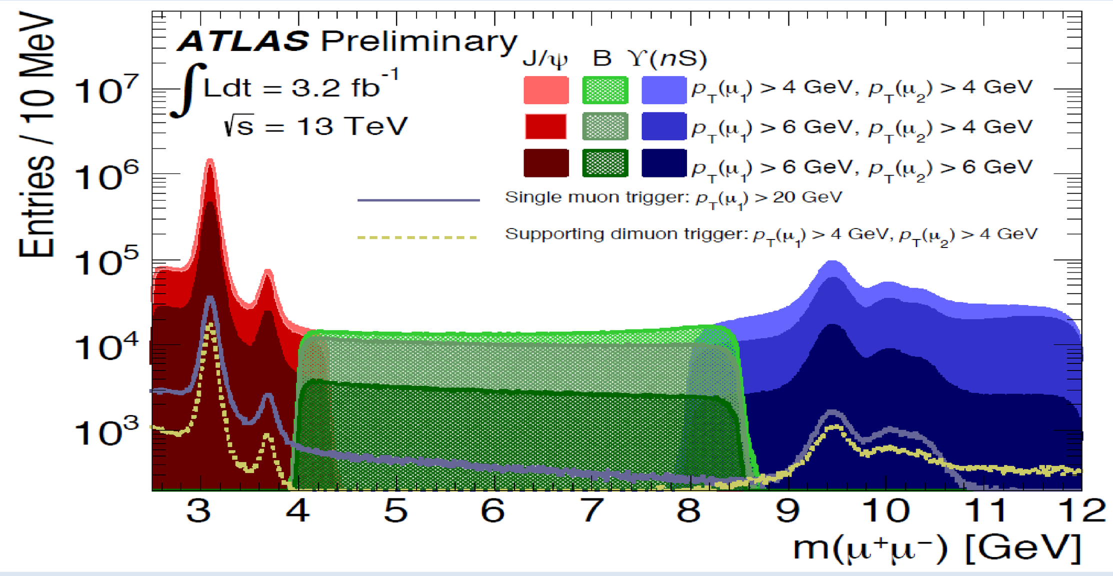


Figure 1: Invariant mass distributions for oppositely charged muon candidate pairs that pass various triggers. The selections on m(μμ) are only required at the High Level Trigger and have **no topological** requirements at Level-1.

Level-1 Bottleneck

During Run 2, the ATLAS detector is expected to record data under unprecedented high luminosity conditions. Due to **bandwidth limitations**, using the existing di-muon selections would impose higher p_T thresholds and/or prescaling lower p_T triggers. This would decrease the available statistics and **hinder the competitiveness of the ATLAS B Physics programme**.

This scenario **can be avoided by introducing new rejection criteria,** and in particular **exploiting newly available topological selections** in the ATLAS Level-1 Trigger.

2 Topological Selections: "L1Topo"

The ATLAS L1Topo system provides the functionality to pair Level-1 primitives and **select events based on their combined kinematic and topological properties**.

Two Level-1 muon (see Figure 2) can be combined in L1Topo to coarsely construct quantities such as the **invariant mass m(μμ)**, **ΔR**, azimuthal Δφ and pseudorapidity Δη differences between the two muons.

Due to the coarse resolution of these quantities at Level-1, the **di-muon selection discrimination** can be **maximized selecting** events based on **m(μμ) and a** secondary **correlated quantity**.

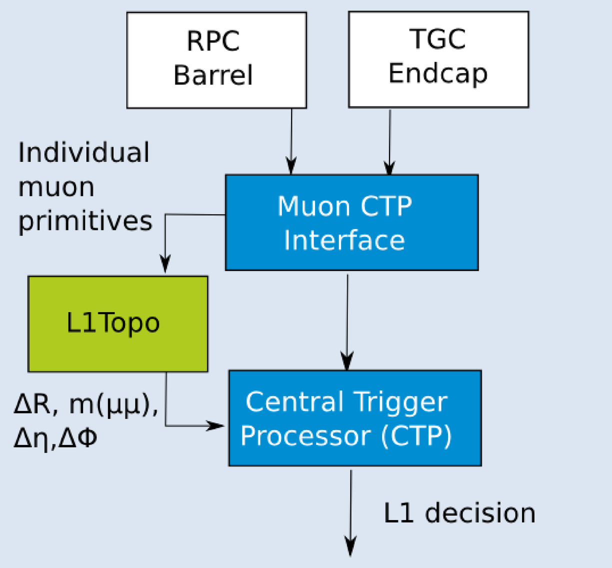


Figure 2: Highly simplified overview of the Level-1 trigger with only the subsystems most pertinent to B Physics.

3 B Physics L1Topo Optimizations

L1Topo selections were optimized by **maximizing the signal to background ratio**. **Rectangular selections** in **m(μμ) and ΔR** were chosen as they **provided the best discrimination power**. The prototype signals were modelled with simulated MC samples, while the background was realistically evaluated with a high pile-up minimum bias run (see Figure 3). The **optimization** was **repeated for multiple background rejection levels**, providing a comparison with existing di-muon only triggers (section 5).

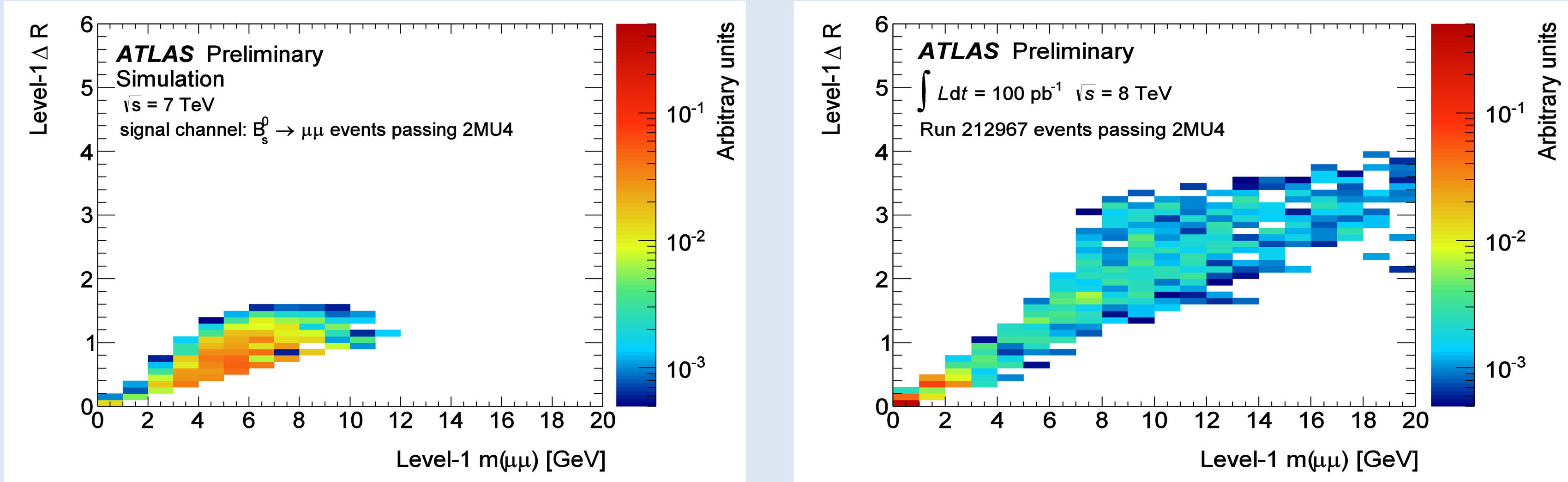
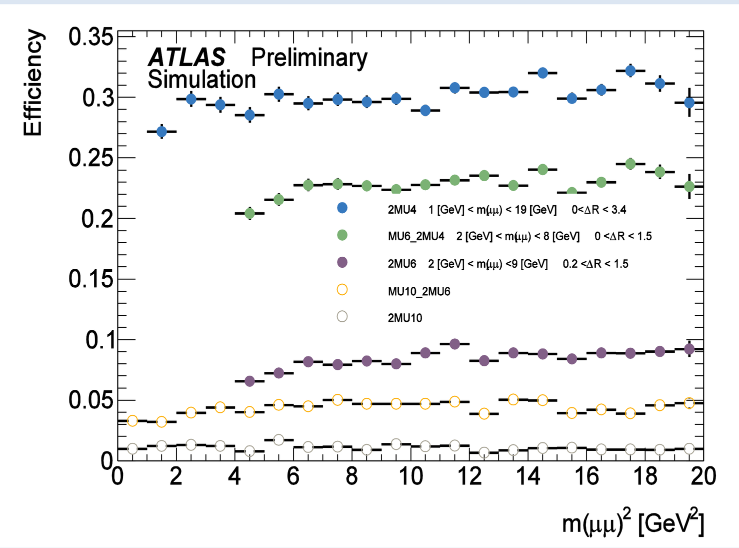


Figure 3: Normalised distributions of ΔR and invariant mass, as reconstructed with the granularity of L1Topo. Simulated $B^0_s \to \mu\mu$ events (left) and run 212967 events (right) that pass the Level-1 2MU4 trigger are shown. The largest portion of background events reside in the low m(μμ)- ΔR region while the majority of the $B^0_s \to \mu\mu$ signal is situated in higher regions. This demonstrates how rectangular cuts can be used to improve rejection power.

4 $B_d^0 \to \mu\mu K^*$: Optimization Improvements



The **optimizations** from section 3 **do not preserve the low m(μμ) region** to which the $B_d \to \mu\mu K^*$ analysis is highly interested (see Figure 4).

The large amount of background in this region (see Figure 3 right) means it is **not possible to keep the background rejection** sufficiently **high without sacrificing the low m(μμ) events**.

Low mass events are kept by complementing topological selections with higher p_T di-muon triggers (such as MU10_2MU6 and 2MU10).

Figure 4: Trigger efficiencies binned in the di-muon invariant mass squared (m(μμ)^2) for simulated $B_d \to \mu\mu K^*$ events passing various di-muon L1 triggers. For each selection, the efficiencies are normalized, per m(μμ)^2 bin, to the number of events in that bin passing offline reconstruction. While topological selections are inefficient at low m(μμ)^2, higher p_T di-muon triggers still preserve this region.

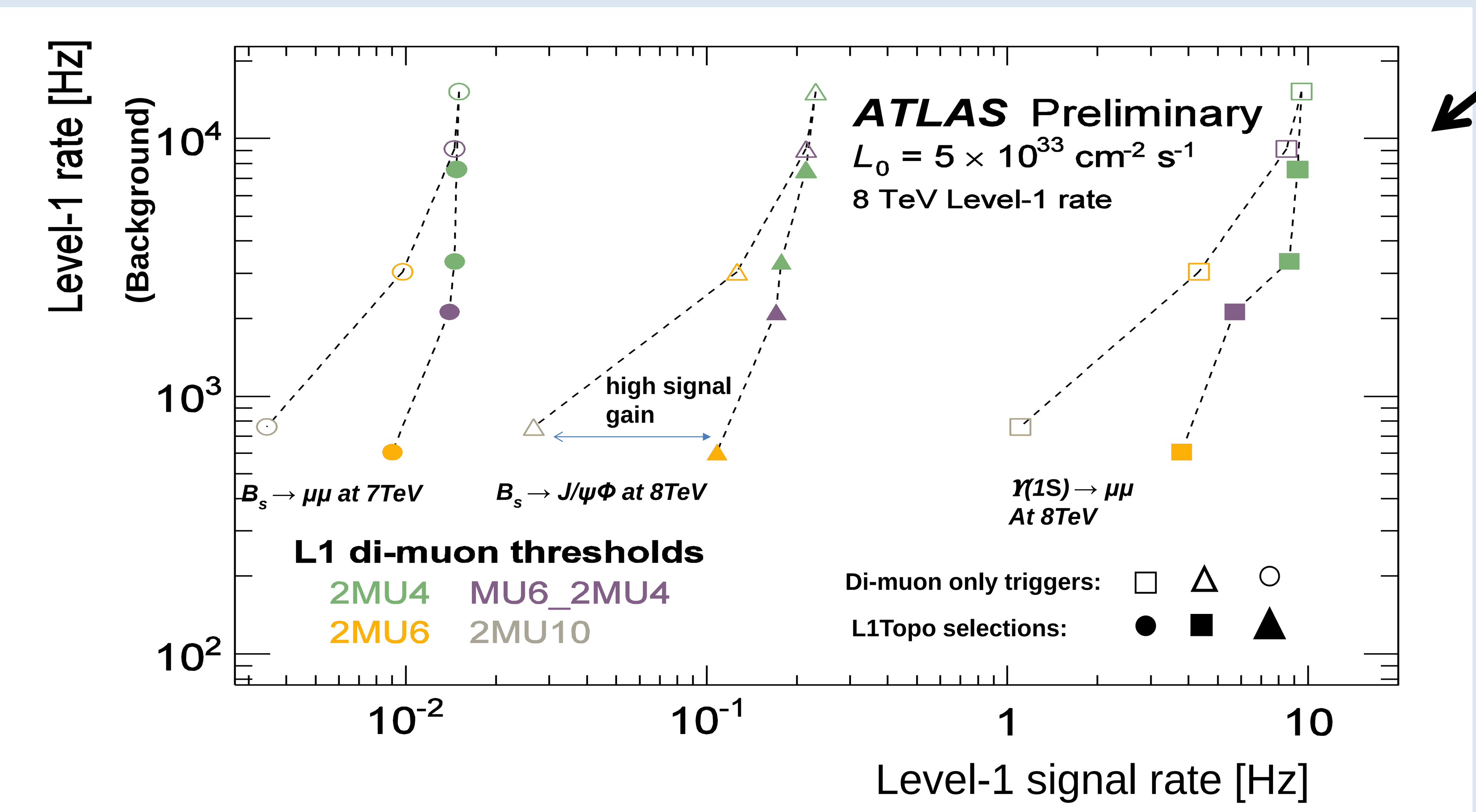


Figure 5: Estimated Level-1 background and signal rates, at a L = 5x10^{33} cm^{-2}s^{-1} the Run 2 B Physics L1Topo. The $B_s \to \mu\mu$ signal yield was scaled up by 10^3 for visual clarity. An additional correction by a factor of 1.5–2 is to be applied on the x-axis in order to scale the 7/8 TeV simulated signal samples to the centre of mass energy in Run 2 (13TeV)[1].

5 L1Topo Menu for B Physics

The B Physics menu (see Table 1 and Figure 4) was constructed from the optimized selections described in section 3. The selections target increasing levels of background rejection. This provides a set of working points that match the range luminosity of conditions expected in Run 2. It is a comparable scheme to the existing set of di-muon triggers but **for high luminosities it improves the signal yield by a factor of x5– x10.**

Level-1 muon thresholds	Topo cut m(μμ) [GeV]	Topo cut ΔR	Background rejection	Signal efficiencies $B^0_s \to \mu\mu$	Signal efficiencies $B^0_s \to J/\psi\phi, J/\psi \to \mu\mu$	Signal efficiencies $\Upsilon(1S) \to \mu\mu$
2MU4	–	–	0.00 (baseline)	1.00	1.00	1.00
MU6_2MU4	–	–	0.40	0.97	0.93	0.89
2MU4	1–19	0–3.4	0.50	0.98	0.93	0.97
2MU4	2–8 7–14	0–1.5 0–2.4	0.78	0.97 –	0.77 –	– 0.75
2MU6	–	–	0.80	0.65	0.55	0.46
MU6_2MU4	2–8 8–13	0.0–1.5 0.0–2.2	0.86	0.93 –	0.74 –	– 0.60
2MU10	–	–	0.95	0.23	0.17	0.12
2MU6	2–9 8–13	0.2–1.5 0–2.2	0.96	0.60 –	0.47 –	– 0.40

$B_s \to \mu\mu$ and $B_s \to J/\psi\Phi$ selection **Logical OR** $\Upsilon(1S) \to \mu\mu$ selection = Background rejection that determines B Trigger rate

Table 1: Optimized L1Topo menu (blue) along with di-muon only triggers (red), sorted in ascending levels of background rejection.

The optimizations in section 3 were performed separately for each physics channel. The background rejection column is for the logical OR of all selections in a given row and can be used to determine the trigger rate in Figure 4.

All the efficiencies/ rejections are normalized with respect to the Level-1 2MU4 trigger.

6 Conclusions

- ATLAS Run 2 B Physics programme is dependent on statistics
  - At higher luminosities the potential statistics would be reduced due to bandwidth limitations
    - ➢ New strategy needed
- The new strategy provided was developed using topological selections
  - These selections target background rejection levels that should match the various luminosity conditions expected in Run 2
  - The strategy is well optimized for three prototypical channels
  - The remaining ($B^0_d \to \mu\mu K^*$) channel is well optimized for overall signal but…
    - ➢ higher p_T di-muon triggers must be used to recover the low m(μμ) events

O.J Winston (University of Sussex) on behalf of the ATLAS collaboration

[1] ATLAS B-physics studies at increased LHC luminosity, potential for CP-violation measurement in the B s → J/ψφ decay. Technical Report ATL-PHYS-PUB-2013-010, CERN,Geneva, Sep 2013

ATLAS EXPERIMENT