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Topological Level-1 Trigger used in Run-2 for $B^0_{(s)} \rightarrow \mu\mu$ searches

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**.
- Four final states ($B_s \rightarrow \mu\mu$, $B_s \rightarrow J/\psi\Phi$, $B_d \rightarrow \mu\mu K^*$, $\Upsilon(nS) \rightarrow \mu\mu$) have been considered **prototypical** of the **Run 2 programme**.
- This study maximises their collection potential by exploiting the ATLAS Level-1 Trigger upgrade.

B-Physics triggers

- **B-Physics signals** are triggered with **muons** passing given **transverse momentum (p_T) thresholds**.
- In **Run 1**, the **requirement** was: **one or more muons** with **p_T > 4 or 6 GeV**.
- Yields for these triggers in Run 2 (2015 data) are shown right (Figure 1).

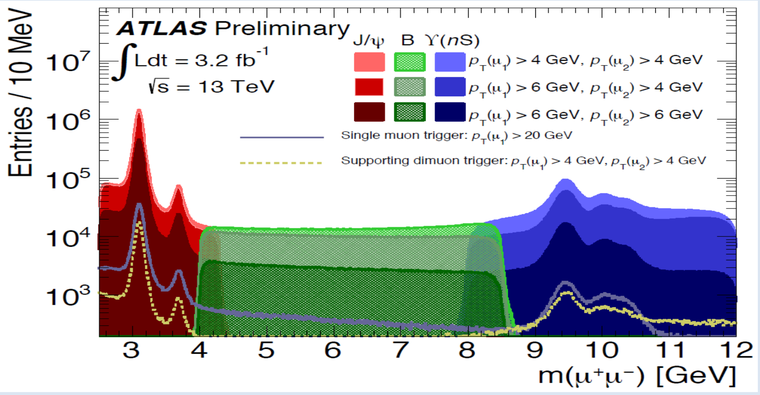


Figure 1: Invariant mass distributions for oppositely charged muon candidate pairs that pass various triggers. The selections on m(μμ) are only required at the High Level Trigger and have **no topological** requirements at Level-1.

Level-1 bottleneck

- During Run 2, the ATLAS detector is expected to record data under unprecedented high instantaneous luminosity conditions.
- **Bandwidth limitations,** with existing di-muon selections would impose higher p_T thresholds and/or pre-scaling lower p_T triggers
- Decrease the available statistics limiting the competitiveness **of the ATLAS B-Physics programme**.
- To cope with this: **introduce new rejection criteria based on the newly available topological selections** in the Level-1 Trigger.

2 Topological selections: "L1Topo"

- **The ATLAS L1Topo system** uses Level-1 primitives to **select events based on their kinematic and topological properties**.
- Possibility to use two Level-1 muon objects (see Figure 2) to build kinematical quantities (with Level-1 resolution):
  - **Invariant mass m(μμ)**,
  - **Angular distances** (**ΔR**, Δφ and Δη) between the two muons.
- **Goal:** define cuts on these quantities to maximise S/B for the B-physics channels considered.

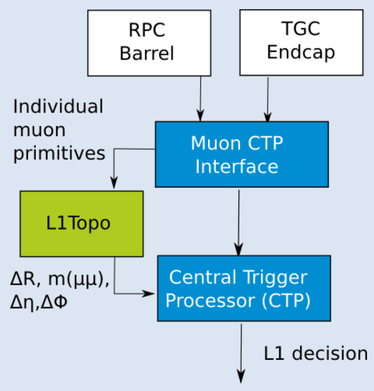


Figure 2: Highly simplified overview of the Level-1 trigger with only the subsystems most pertinent to B Physics.

3 B-Physics L1Topo optimisations

- Best S/B discrimination power achieved using **m(μμ) and ΔR**
- The prototype signals were modelled with simulated MC samples
- Background evaluated using a high pile-up minimum bias run at √s = 8 TeV (see Figure 3).
- The **optimisation** in **m(μμ) and ΔR** was **repeated for multiple background rejection levels**, providing a comparison with existing di-muon only triggers (Section 5).

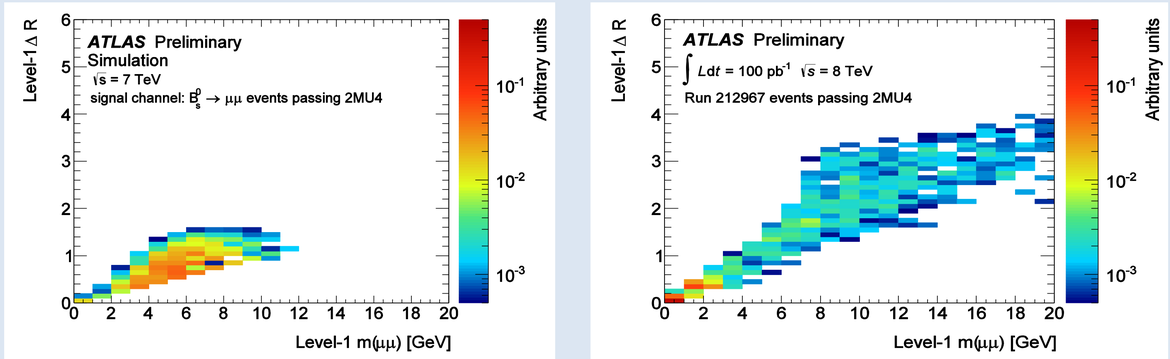
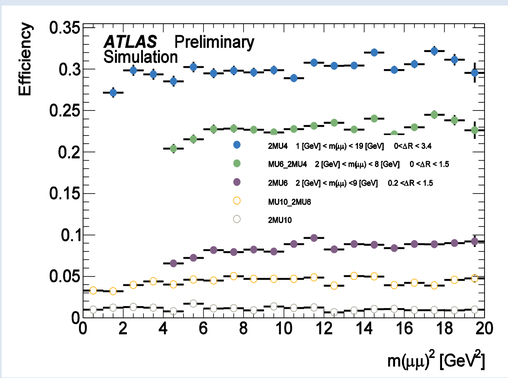


Figure 3: Normalised distributions of ΔR and invariant mass, as reconstructed with the granularity of L1Topo. Simulated $B^0_s \rightarrow \mu\mu$ events (left) and run 212967 events (right) that pass the Level-1 2MU4 trigger are shown. The largest portion of background events reside in the low m(μμ)-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

4 $B^0_d \rightarrow \mu\mu K^*$: optimisation improvements



- The **optimisations** from Section 3 **do not preserve the low m(μμ) region**
- Some measurement, such as $B_d \rightarrow \mu\mu K^*$ analysis can be compromised(see Figure 4).
  - Sensitive to **low m(μμ)** region where the **minimum bias background is large** (see Figure 3 right)
- **Specific trigger items have been developed** 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 $(m(\mu\mu)^2)$ for simulated $B_d \rightarrow \mu\mu K^*$ events passing various di-muon L1 triggers. For each selection, the efficiencies are normalised, per $m(\mu\mu)^2$ bin, to the number of events in that bin passing offline reconstruction. While topological selections are inefficient at low $m(\mu\mu)^2$, Higher p_T di-muon triggers still preserve this region.

5 L1Topo Menu for B-Physics

- The **B-Physics menu** (see Table 1 and Figure 4) was **constructed from the optimised selections described in Section 3**.
- **Several levels of background rejection available** based on expected Run2 luminosity conditions
- **Impact:** using **same trigger thresholds**, the **signal** yield is **improved by a factor of 3-5 under high-luminosity conditions.**

Level-1 muon thresholds	Topo cut $m(\mu\mu)$ [GeV]	Topo cut ΔR	Background rejection	Signal efficiencies $B^0_s \rightarrow \mu\mu$	Signal efficiencies $B^0_s \rightarrow J/\psi\phi, J/\psi \rightarrow \mu\mu$	Signal efficiencies $\Upsilon(1S) \rightarrow \mu\mu$
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

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

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

The optimisations 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 normalised with respect to the Level-1 2MU4 trigger.

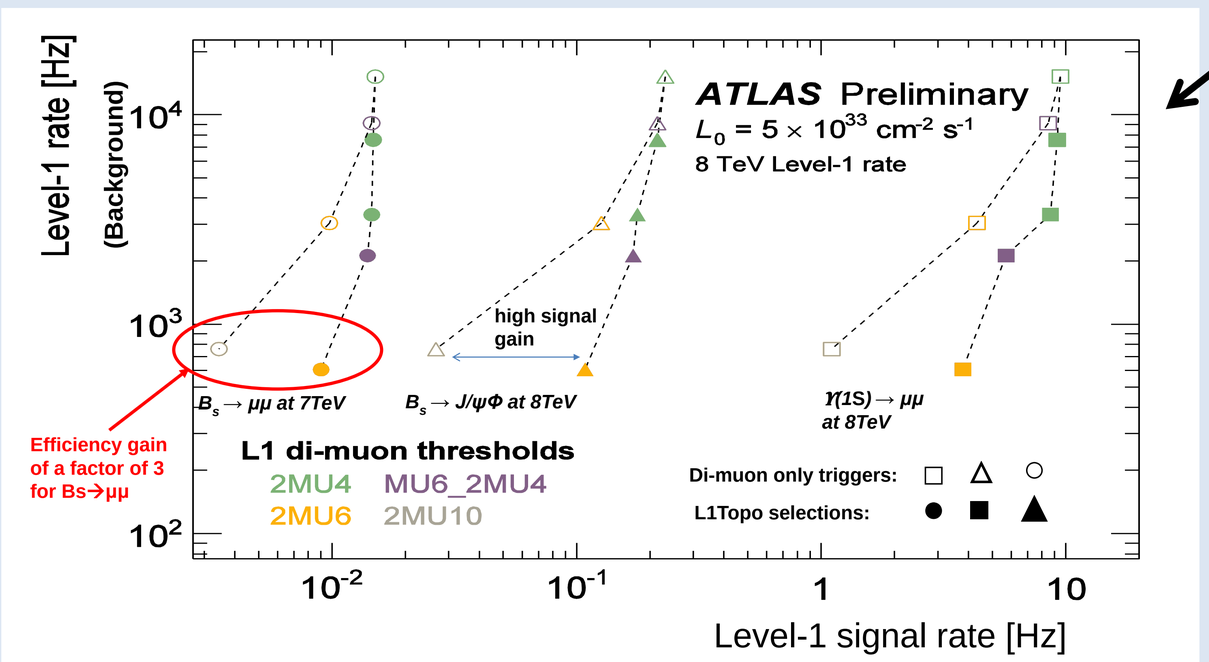


Figure 5: Estimated Level-1 background and signal rates, at a L = 5×10^{33} $cm^{-2}s^{-1}$ the Run 2 B Physics L1Topo. The $B_s \rightarrow \mu\mu$ signal yield was scaled up by 10^3 for visual clarity. An additional correction by a factor of 1.5–2 is to be applied on the x-axis in order to scale the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

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
  - An **optimised menu** for three prototypical B-physics channels has been **built**
  - **Menu items available for several background rejection levels** matching the instantaneous luminosity conditions expected in Run 2
  - **Gain up to a factor of 3 for Bs→μμ channel**
  - **Specific items** have been prepared also for channels **focusing on low m(μμ) region** (such as $B^0_d \rightarrow \mu\mu K^*$) based on higher p_T di-muon triggers

U. De Sanctis (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