Reconstruction and trigger for B hadron studies in ATLAS Run-3 data

The ATLAS Collaboration

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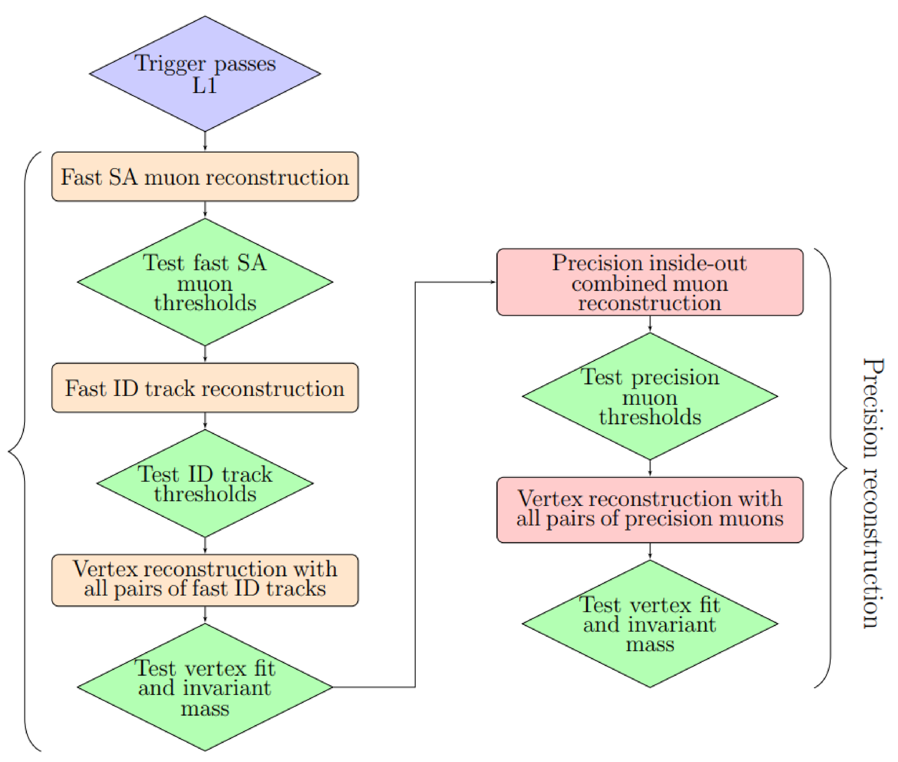
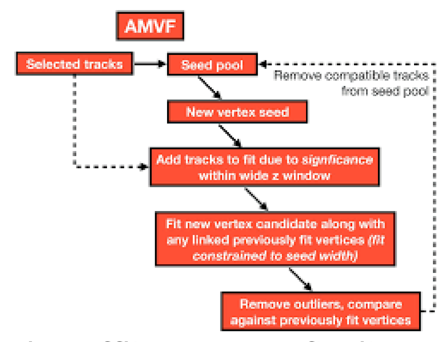
1. Accessing BLS at ATLAS

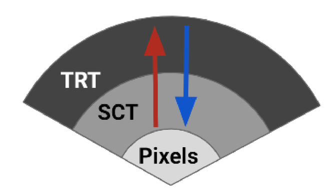
- Triggering and reconstructing for BLS physics at detectors like ATLAS is difficult.
- Physics explorations by ATLAS BLS group exploits samples of low-p_T muons, the luminosity and pileup environment of the LHC makes simplified single and dimuon triggers with these low p_T requirements an infeasible solution.
- To overcome this, BLS triggers are an evolution of standard muon triggers, expanded to include topological cuts, complex vertex reconstruction, and invariant mass assessments.
- In the Level 1 (L1) trigger stage, the BLS program makes strong use of topological triggers, which use a combination of calorimeter data and muon trigger objects to provide topological information and cuts.
- At the second High Level Trigger stage (HLT), the BLS trigger requirements are interlaced into a muon trigger process, performing cuts on vertex fit quality and invariant masses after both the fast and precision reconstruction steps.
- The HLT process also extends muon triggering to use Inner Dectector (ID) tracks to handle complex BLS signatures efficiently, such as B_s^0 and B_d^0.

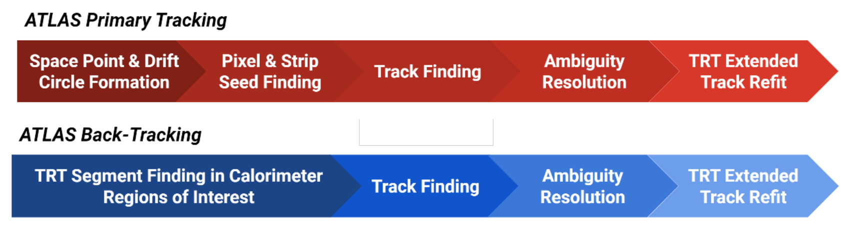


2. Vertex and Tracking Upgrades

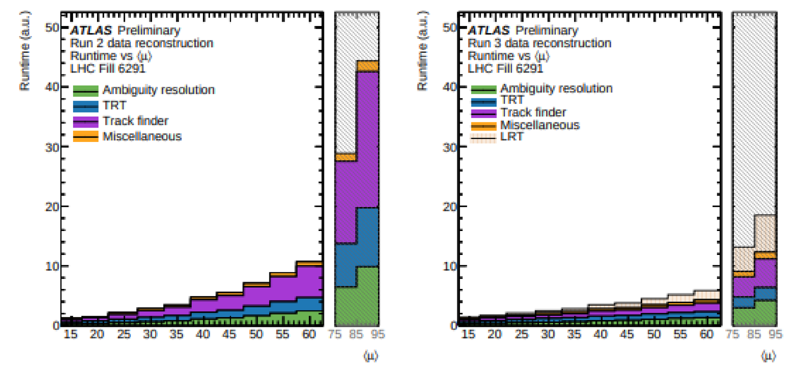
- For tracking, there are higher standards for tracking candidates, earlier stopping for non-viable tracking candidates, and it more successful operation at higher pileup values.
- Overall, in terms of runtime, it performs at twice the speed as the Run 2 algorithm.

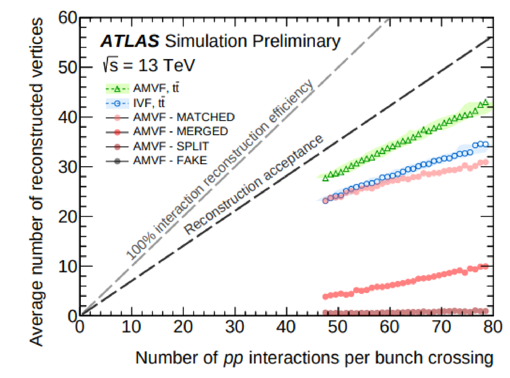






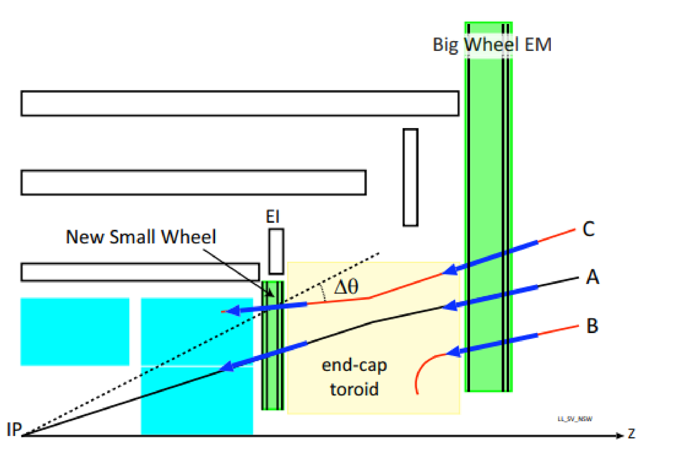
- The offline vertex finding algorithm has been upgraded with a new gaussian density track seed finder, and the new Adaptive Multi Vertex Fitter. This produces a large reduction in tracks per vertex, and it is capable of recovering up to 50% of vertices missed in the old method.
- The online vertex fitting algorithm VKalVrtFitter has also been updated to run in a multithreaded environment for improved performance.

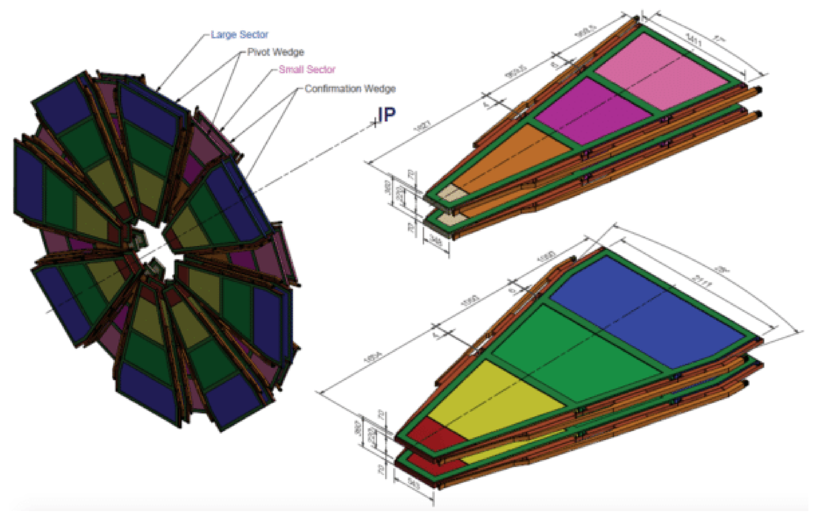




3. The New Small Wheel

- The largest part of the ATLAS Phase-I upgrade consisted of the inclusion of the Muon New Small Wheels (NSW)
- These included two new detector technologies small strip TGC (sTGC), and MicroMegas (MS), the latter of which has never been produced at this scale for HEP experiment.

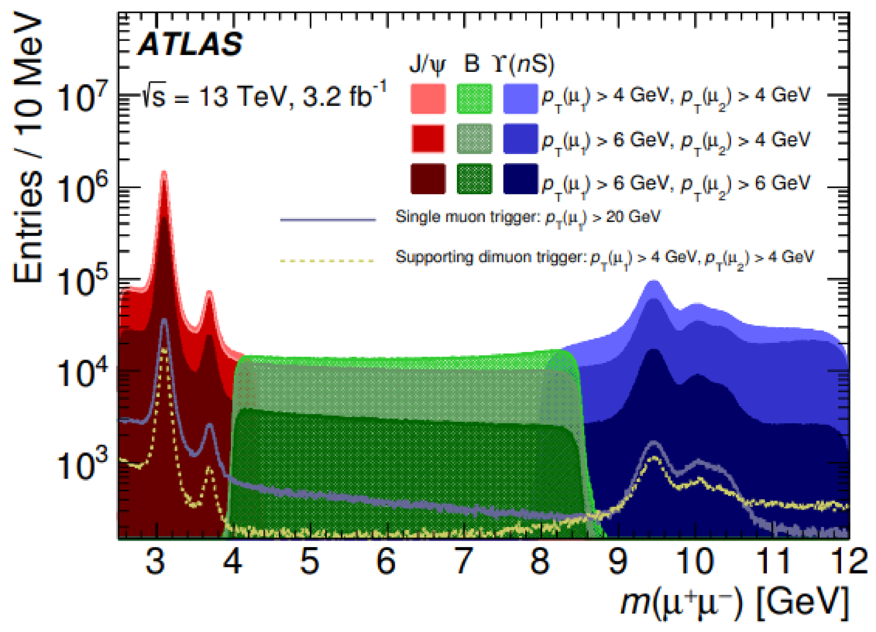


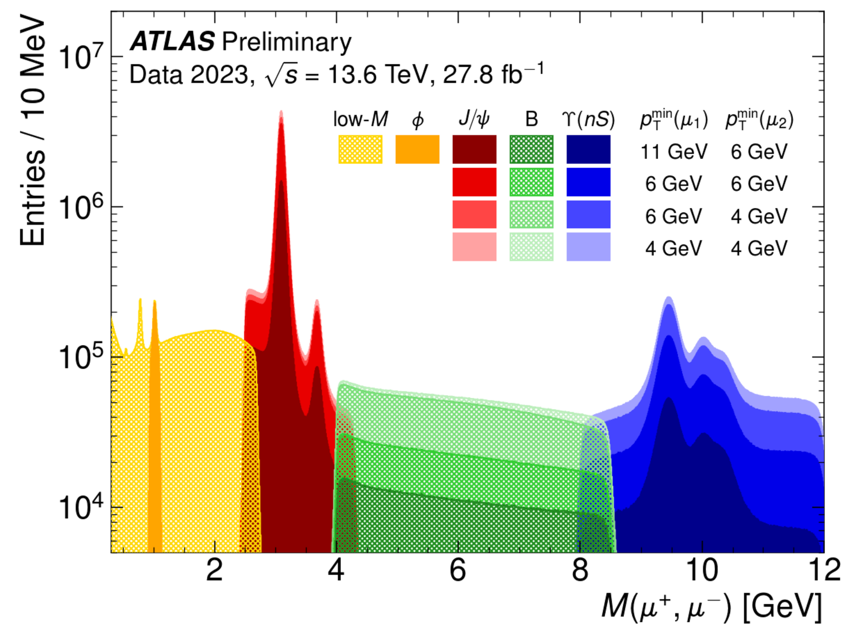


- The NSW system is located in the forward regions and is designed to use fast detector systems to solve a number of problems;
  - Reducing the high fake rate of low p_T muons, without increasing the p_T threshold.
  - Reduced tracking efficiency in forward regions due to rate limits of old detector losing high quality muon candidates.
  - Increasing luminosity and flux as the LHC moves towards High-Luminosity ranges.
- Improvements on all these fronts are of relevence to BLS.

4. The BLS di-muon Mass Region

- Despite the busy pileup conditions from the luminosity at the LHC, the full BLS region can be reconstructed.
- This is assisted by L1Topo, allowing the lower-p_T threshold triggers to operate in these conditions.

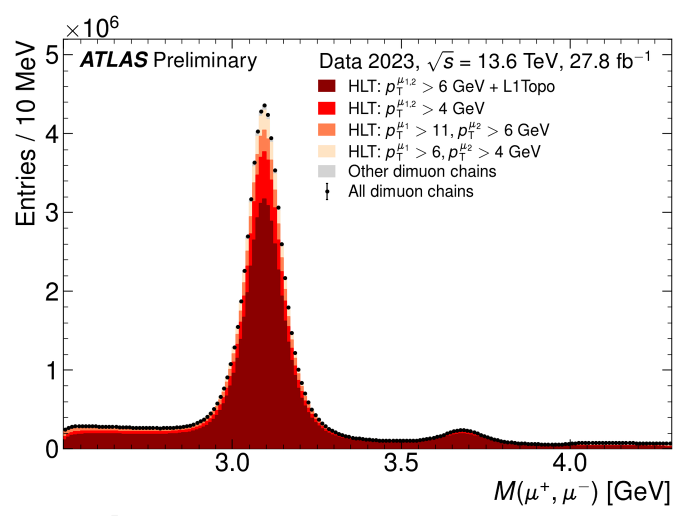


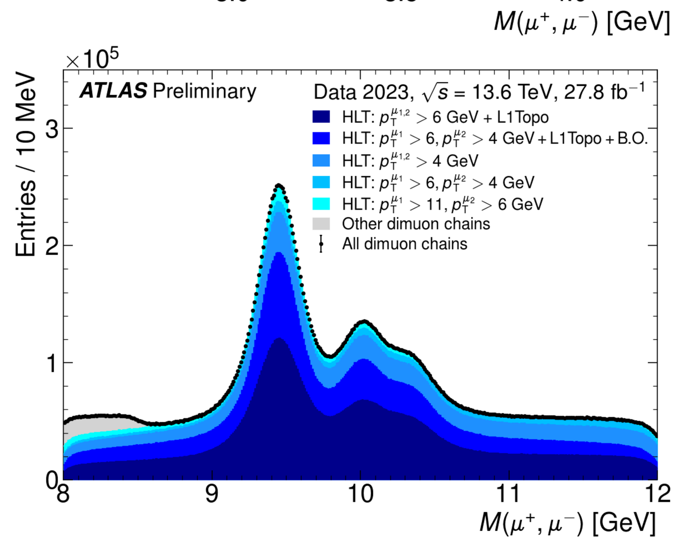


- Along with this, the BLS menu maintains the ability to have flexible muon p_T thresholds allow the sensitivity to dimuon signatures to be adjusted to match luminosity conditions.
- A key example of this is the lowering of thresholds at the end of an LHC fill.

5. J/ψ and Υ

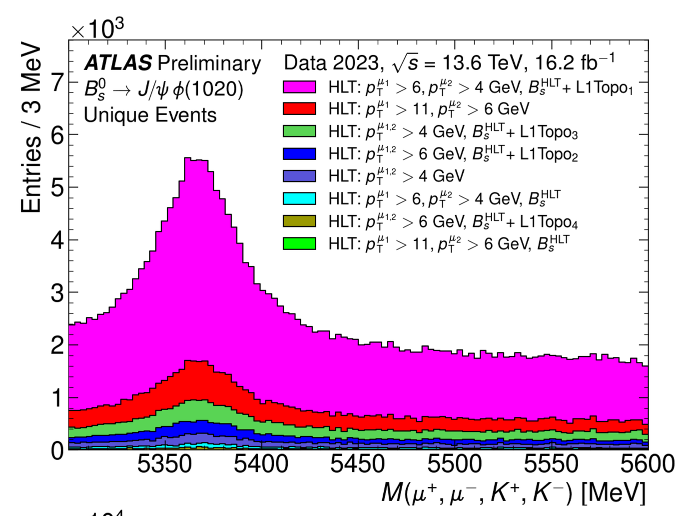
- Triggering on J/ψ and Υ distributions is greatly assisted by the use of the L1 Topological trigger (L1Topo), without these constraints the low-p_T thresholds alone would be too high rate and require high prescales..
- For the offline reconstruction specific requirements are imposed alongside the trigger; muons in the dimuon pairs are required to be of opposite sign (OS), have their tracks fitted to a common vertex with a $\chi^2 < 20$ per degree of freedom, and have $\Delta R = \sqrt{(\Delta\phi^2 + \Delta\eta^2)} < 0.01$ between their offline ID tracks, and the muon processed in the HLT.
- Invariant mass calculations are performed using PDF mass hypothesis of the muon, and the offline track parameters.
- In the trigger cases with L1 Topo, different requirements are applied for the J/ψ and the Υ, stemming for the invariant mass of the target reconstruction particle. The J/ψ reconstruction rejects candidate events when outside of $2 < M_{\mu\mu} < 9$GeV, and for Υ the same is done for the range $8 < M_{\mu\mu} < 15$GeV. Opening angle is similarly controlled for J/ψ and Υ with $0.2 < \Delta R_{\mu\mu} < 1.5$ and $\Delta R_{\mu\mu} < 2.2$, respectively.

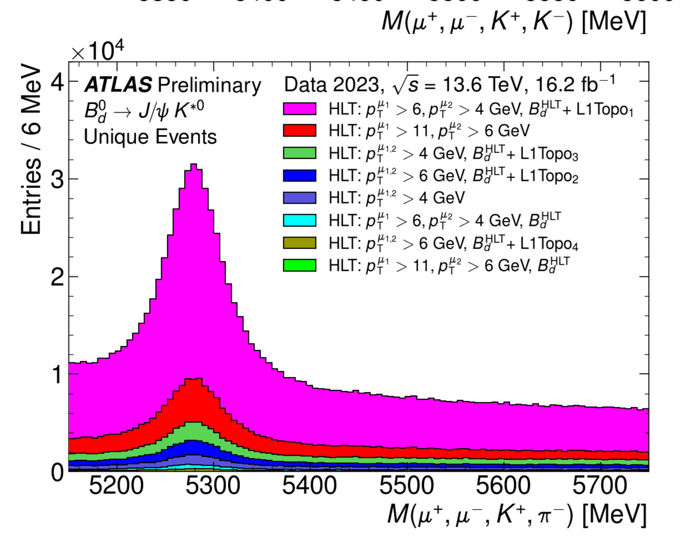




6. B_s^0 and B_d^0

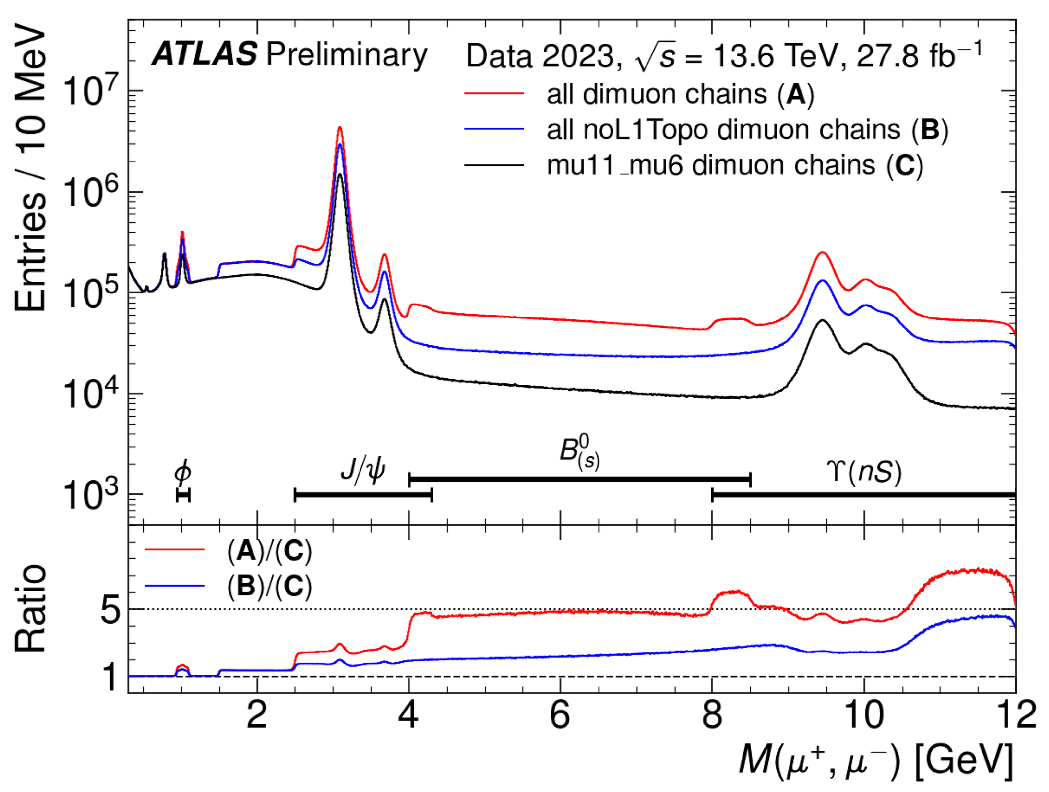
- The capabilities of the BLS trigger system extend to more complex signatures than the dimuon, by expanding upon the requirements of a typical dimuon trigger.
- These signatures include the decays $B_s^0 \to J/\psi\phi$ and $B_d^0 \to J/\psi K^{*0}$
- For the B_s^0 and B_s^0 mesons, the BLS trigger system can be expanded to produce completely reconstructed candidates, online at HLT level.
- To complete these HLT level B candidates, the BLS trigger extends beyond the muon system to use charged hadron tracks.
- When a dimuon candidate for the J/ψ decay is built, for these chains tracks within a certain region of an interest are used to build the $B_{d,s}^0$.
- Further enhancement comes from L1Topo items, typically requiring close-by muons from the dimuon pair, and OS information where available.
- The ATLAS BLS trigger menu expands to a large range of signatures with similar combinations of tracks and muons ($B \to \mu\mu + X$) this includes $B_c \to J/\psi\pi$ and $\Lambda_b \to J/\psi pK$, and multiple other signatures for B_c, B_s, and B^+.





7. L1 Topo, new chains and Large Radius Tracking.

- The utility of the L1Topo system can be demonstrated in isolation, an important fraction of the trigger yield across all ranges can be attributed to L1Topo, when comparing the range when produced with chains without the L1Topo cuts.
- Alongside the Run 3 upgrades, the BLS trigger menu has now expanded to now include dielectron triggers.
- Although still novel, these are allowing the expansion of ATLAS B-physics into new areas.
- One area of particular note is the measurement of $R(K^*)$
- Some BLS work also utilises Large Radius Tracking (LRT), a step ran after the main track reconstruction, designed to pick up tracks with high displacement commonly associated with BSM physics searches.



$$R(K^*) = \frac{\mathcal{B}(B \to K^*\mu\mu)/\mathcal{B}(B \to K^*(J/\psi \to \mu\mu))}{\mathcal{B}(B \to K^*ee)/\mathcal{B}(B(\to K^*(J/\psi \to ee))}$$

8. Conclusion

- The BLS physics program is supported by an advanced trigger system, a precise and able trigger menu and a comprehensive reconstruction system, and an upgraded detector.
- These features allow a multitude of analyses in a region essential for a complete physics program, ranging from $R(K^*)$ measurements, to Gluon transverse momentum dependent parton distribution function measurements.

References

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