Alternative (trigger) workflows & Dark Matter physics cases

Mariana Toscani
Inputs and slides by: Will Kalderon, Antonio Boveia, Caterina Doglioni, the ATLAS TLA team

Sources:
W. Kalderon - Real-time analysis model in ATLAS, HSF/WLCG/OSG workshop (2019)
A. Boveia - Trigger Level Analysis in ATLAS, CHEP (2019)
C. Doglioni - Reduced data formats & real-time analysis, ECHEP Workshop (2019)

A. Boveia - Trigger Level Analysis in ATLAS, CHEP (2019)

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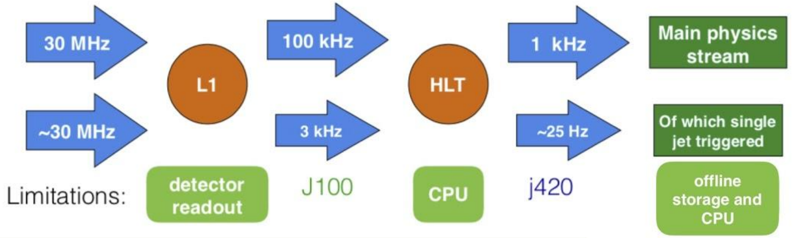
Trigger menu limitations during Run 2

Main menu limitations are **L1 rate** (multi-jet, taus, flavour physics), **HLT CPU** (b-tagging of low-p_T jets), and **HLT rate** (most triggers).

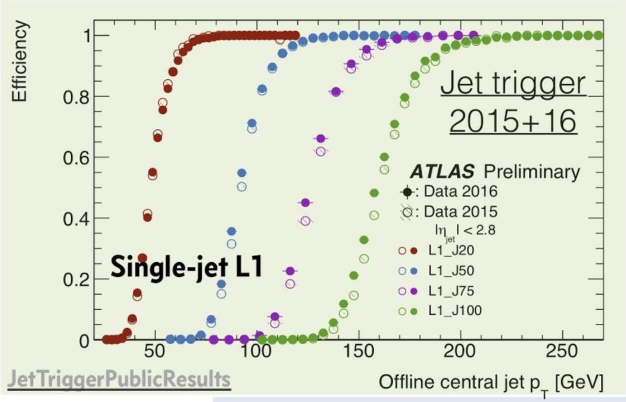


L1

Readout electronics set a hard limit of **100 kHz**.

Peak rate ~**95 kHz**.

Strong production (multi-)jet and flavour-physics triggers would quickly saturate this, without additional requirements (e.g. single-jet p_T thresholds)



HLT CPU

Processing power of HLT farm sets hard limit on what reconstruction can be run

Typically: pre-selection then offline-like (but speed-optimized) reconstruction

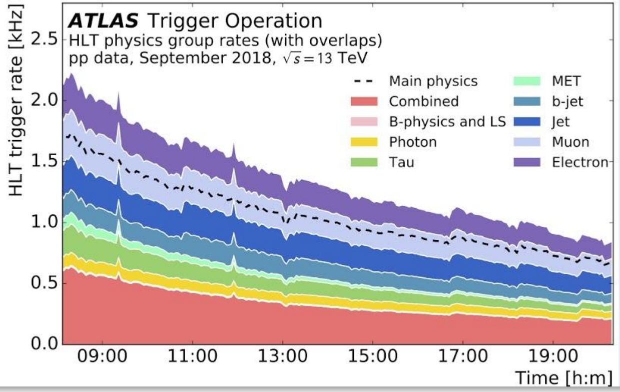
In particular, **tracking is not performed for jet triggers** (and for low-p_T b-jet candidates)

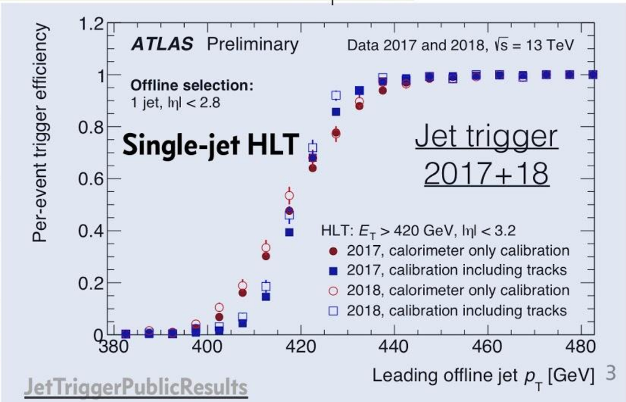
HLT rate

Soft limit of average **1 kHz** from data storage, processing, and maintenance needs

Jet triggers ~15% of total (~150–250 Hz)

Single-jet triggers only unprescaled and fully efficient for offline **p_T>~440 GeV**





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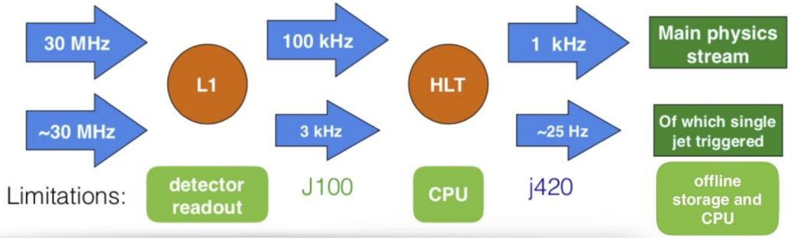
A. Boveia - Trigger Level Analysis in ATLAS, CHEP (2019)

W. Kalderon - Real-time analysis model in ATLAS, HSF/WLCG/OSG workshop (2019)

Trigger menu limitations during Run 2



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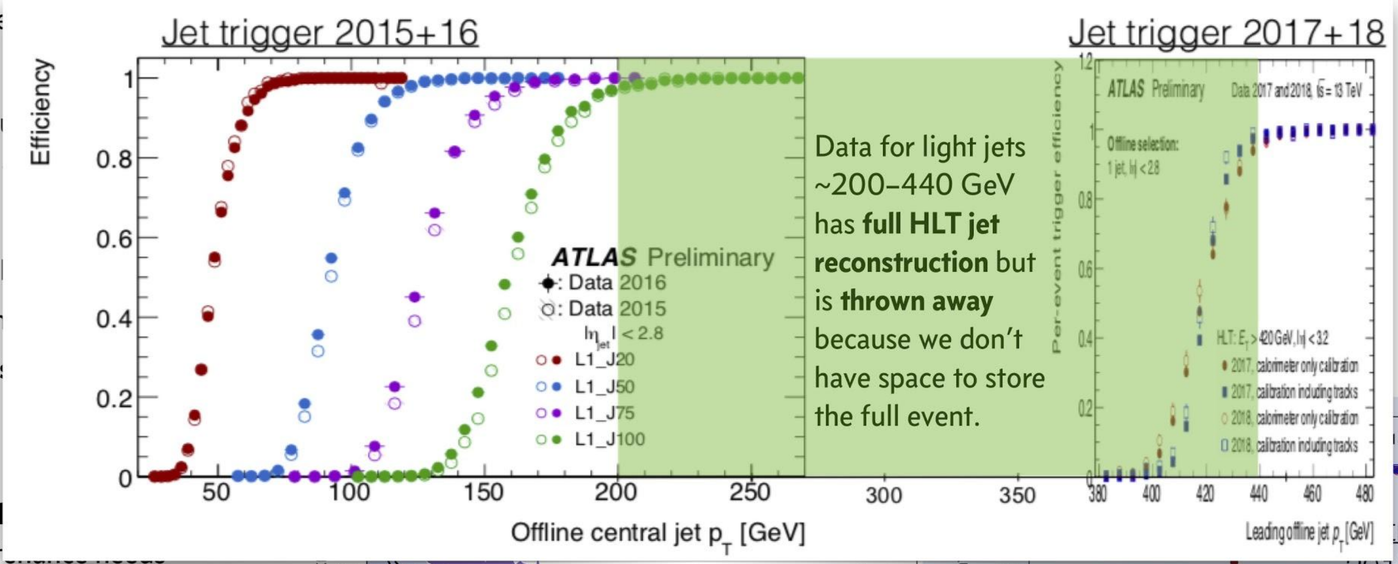
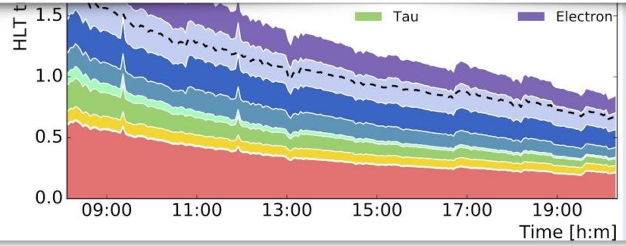
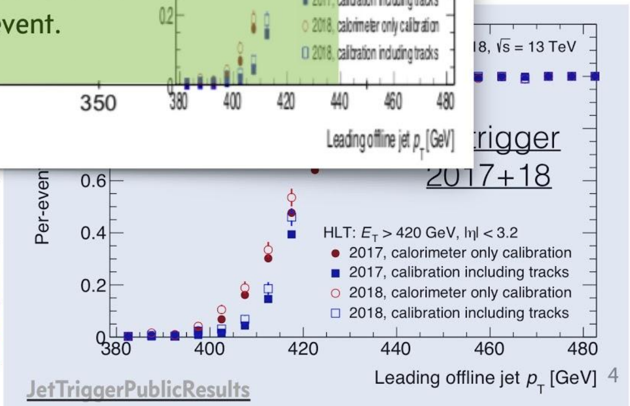
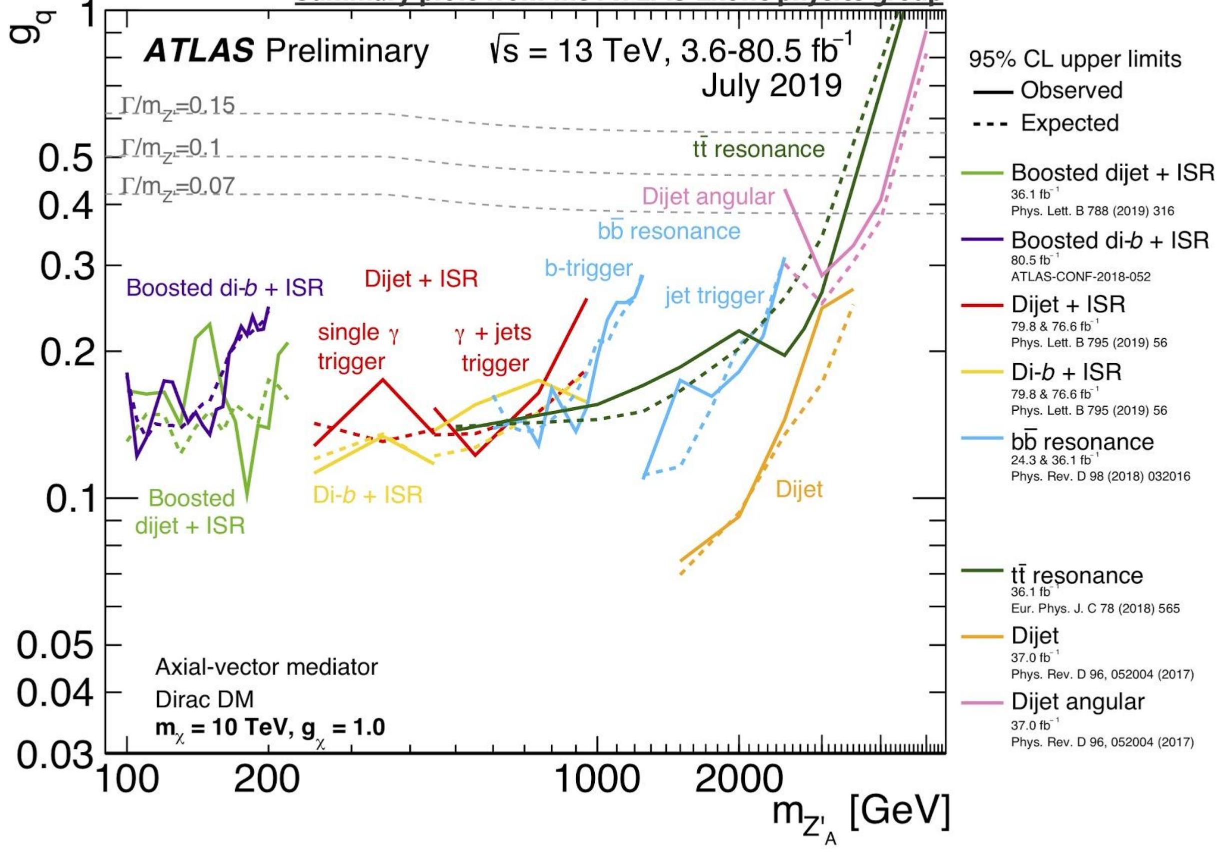






Why bother with "low p_T" jet data?

Summary plots from the ATLAS Exotic physics group



Two-body resonances are a historically fruitful search channel (J/psi, Z, Higgs) and a key component of the ATLAS search program. They are well-covered for most types of decays.

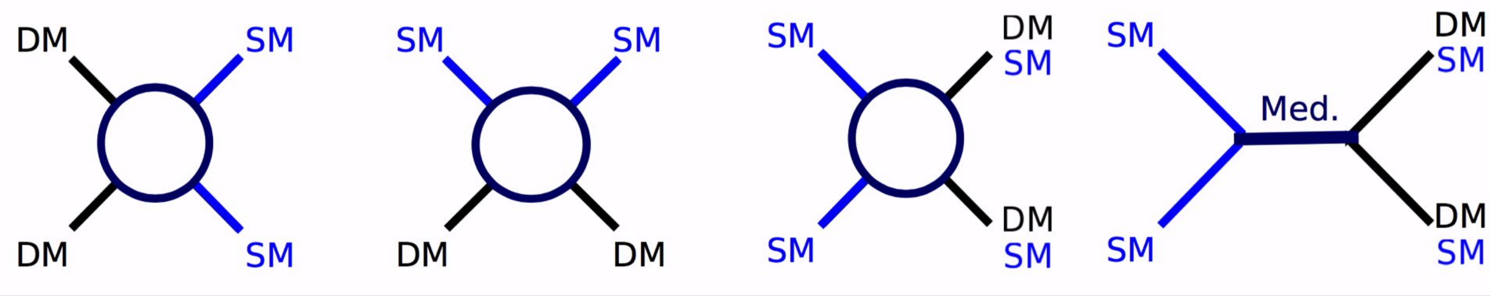
However, the HLT threshold for the single jet trigger (440 GeV) constrains dijet searches to the region $\mathbf{m_{jj}}$>~ **1.5 TeV** (~2x p_T).

The electroweak–TeV scale is special! The W, Z, Higgs, and top are all found there. We must study it as thoroughly as we can. Not even SM-like couplings (few * 0.01) are reached by the most sensitive search.

With a variety of alternate triggering strategies or more narrowly targeted searches, ATLAS can cover a wider range of dijet masses, but with **much less statistical power** than the full data would allow.

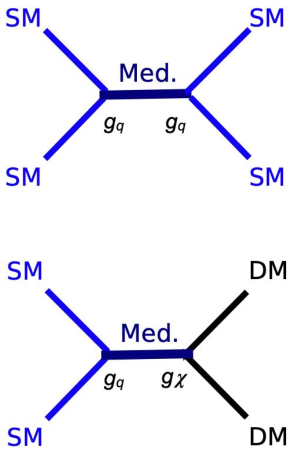
We have to do better!

Low-mass resonances and dark matter: a simplified picture



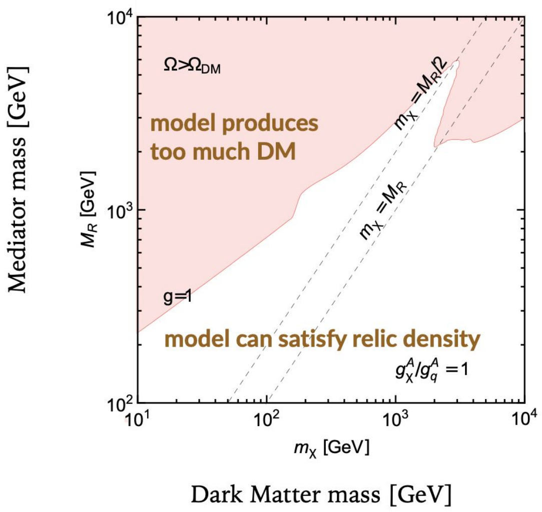
Indirect Detection | Direct Detection | Particle Accelerators (colliders & extracted beam lines)

DM complementarity
(and access to DM mediator decays by LHC experiments):
part of the reason why TLA happened in ATLAS



$$g \equiv (g_q^A\, g_\chi^A)^{1/2}$$

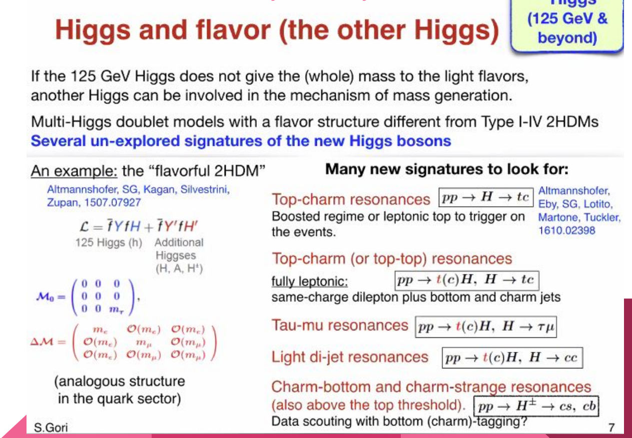
Example from arXiv:1503.05916



We now know that vector and axial vector models are very simple / rather constrained by direct detection…
See e.g. arXiv:1807.02503

…let the search for **scalars** continue?

Stefania Gori's talk yesterday



Trigger-level analysis

To generically probe the entire range of EW–TeV dijet resonances with the full statistical power of the data, we need to work around all three trigger limitations (L1, HLT CPU, HLT rate).

This can only be done within the trigger itself, i.e. trigger-level analysis (TLA).

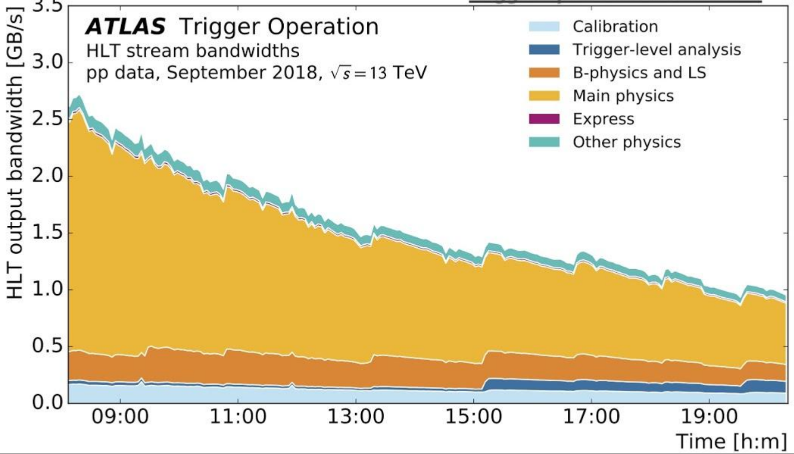
Difference between L1 and HLT thresholds (200–440 GeV, shown earlier) suggests a first step for Run 2: improve (already good) and **analyze the HLT jet reconstruction at the L1A rate**; throw out the full data.

This technique also employed at LHCb (turbo stream) and CMS (data scouting).

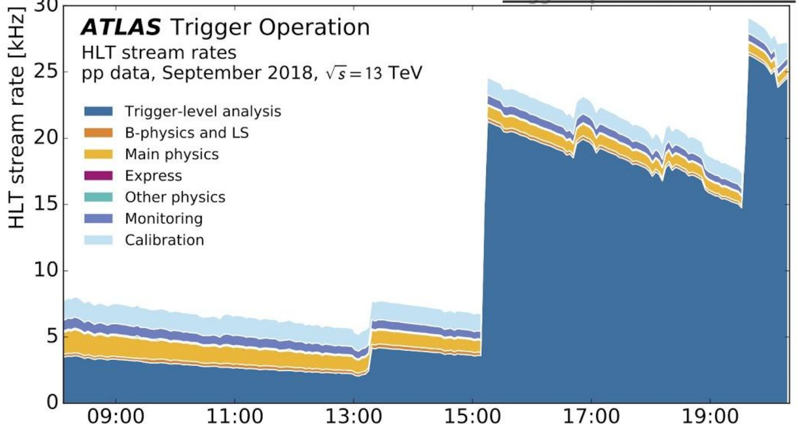
TLA stream records **only HLT objects** (jet four-vectors, jet ID and calibration variables, etc.) for **specific L1A**.

Throw out other information (e.g. **no tracking information kept** in Run 2, but **0.5% of full event** size.)

TriggerOperationPublicResults

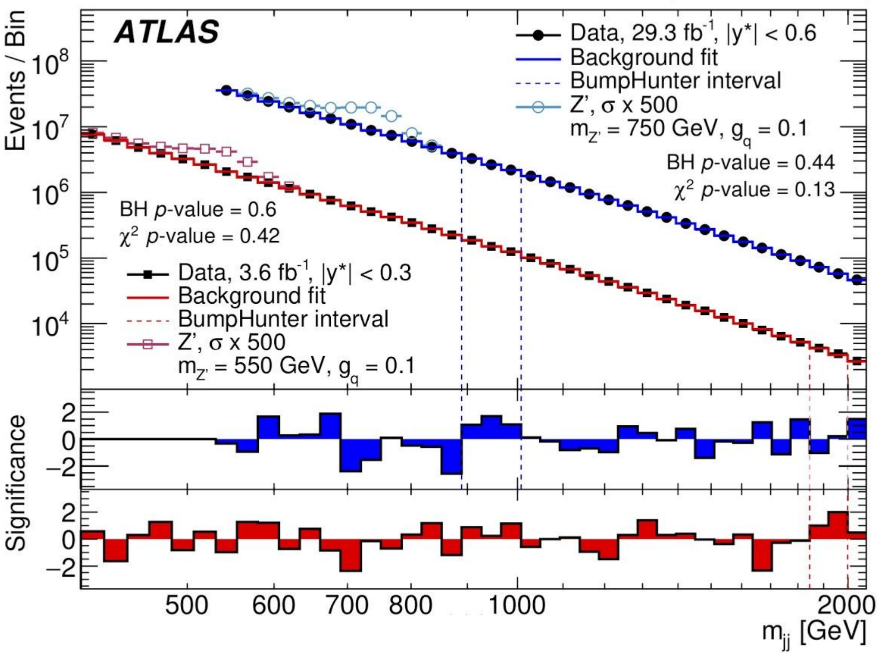


TriggerOperationPublicResults

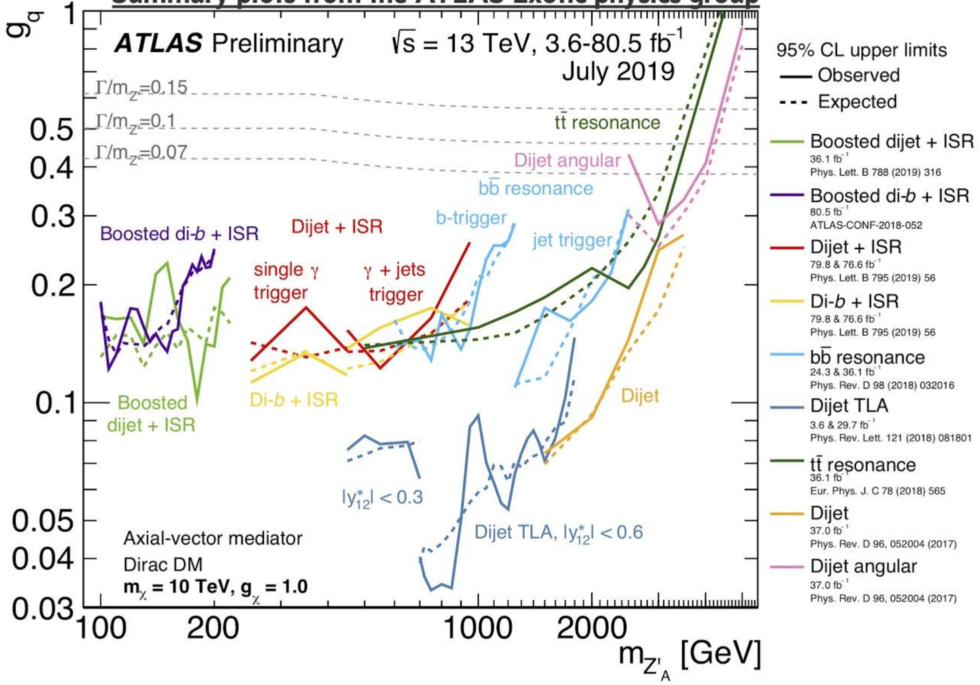


TLA results from first 1/4 of Run 2

PRL 121 081801



Summary plots from the ATLAS Exotic physics group



Analysis of **two mass ranges** with different L1 triggers (75 & 100 GeV) and different angular (y*) cuts.

Factor of **2–5x improvement in coupling** limits (roughly 1–2 orders of magnitude in cross section).

Does not yet use strategies for other trigger limitations.

Watch for improved results with **the full Run 2 dataset!**

Even weaker-coupled resonances: motivations

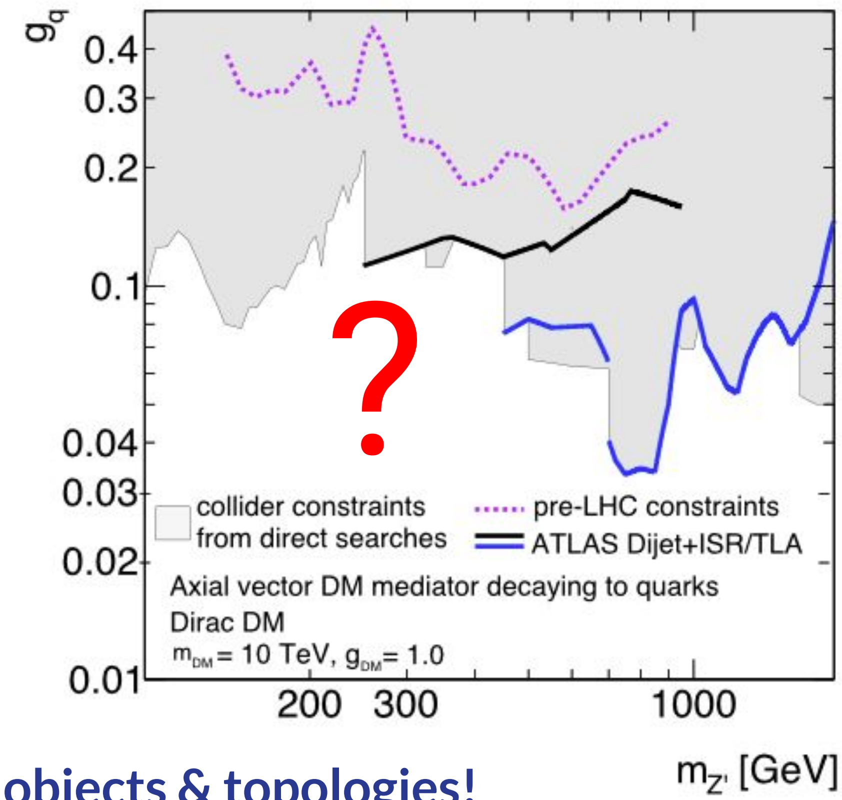
Current set of dijet resonance searches don't yet reach **electroweak-scale couplings**

No reason to stop searching now:

- Many Z'-like models are still viable and motivated
  (see e.g. https://arxiv.org/abs/1807.02503 for "evolved DM simplified model Z's ")
- If a resonance is found, theories will appear
  (think of what happened for the 750 GeV diphoton excess)

TLA remains a flagship analysis for low-mass Z's:

- Extremely high statistics → great to test robust solutions
- But luminosity scaling is not fast, and we're still L1-limited...



→ in Run-3, we need to be more creative with triggers/TLA objects & topologies!

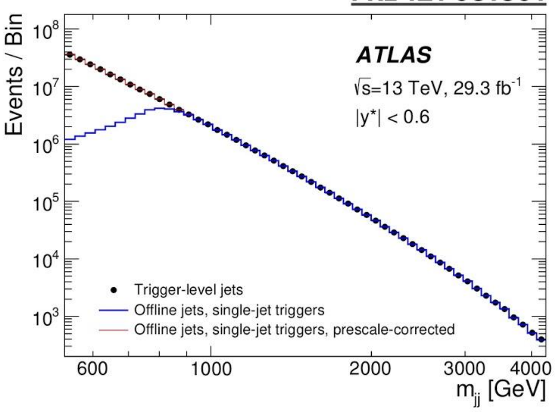
Challenges of TLA in Run 2

Huge background and small signal **requires very precise control** of all aspects of the analysis.

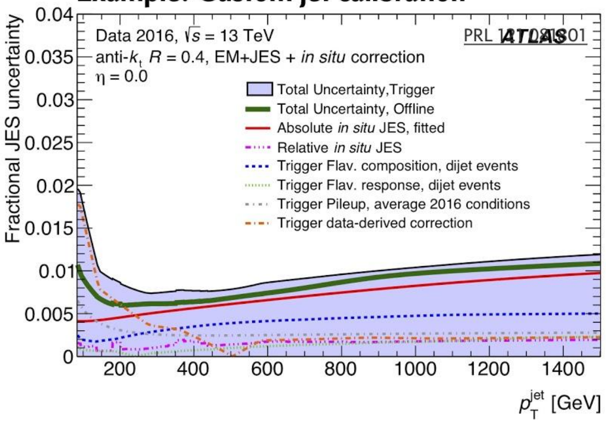
Partial-event data requires a **separate data handling pipeline** (non-standard reconstruction, data cleaning, HLT object calibrations, etc.)

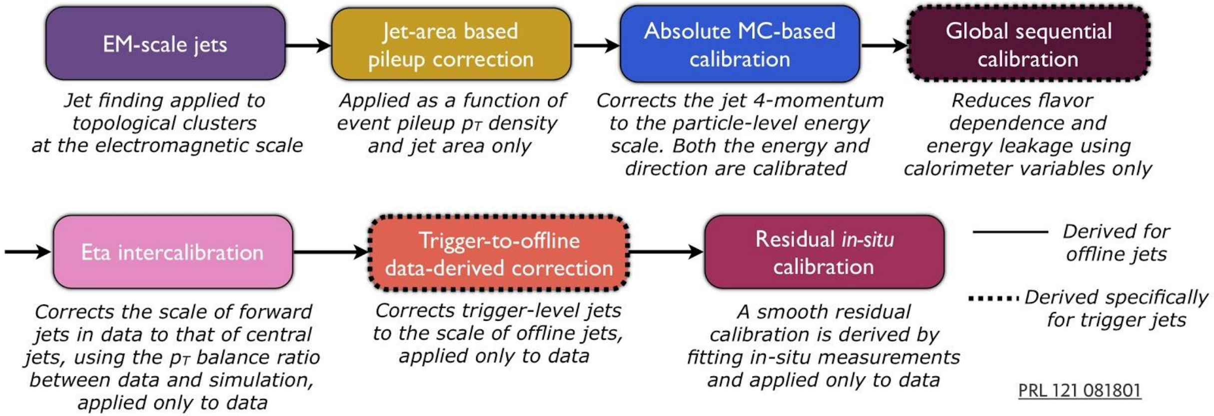
Without tracking, pile-up suppression is difficult for low-p_T jets.

PRL 121 081801

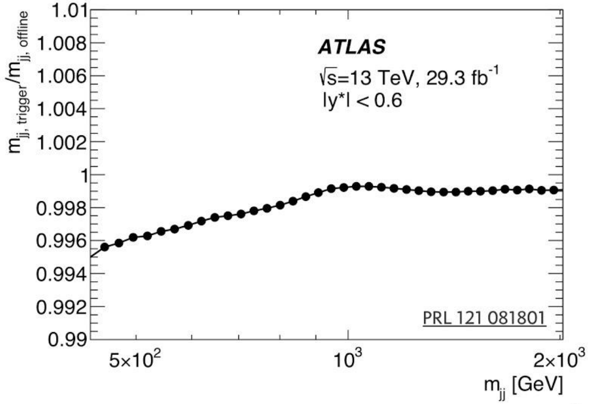


Example: Custom jet calibration

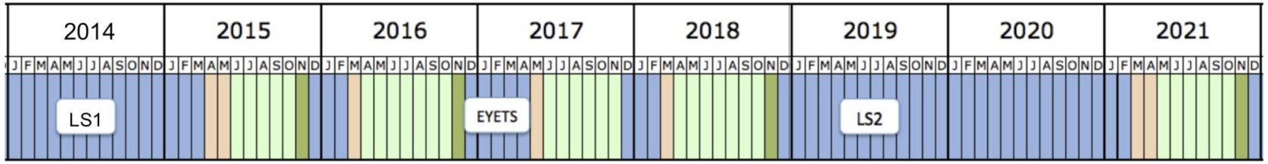




PRL 121 081801



Trigger-level analysis in Run 2



TLA implemented in 2013–2014 see Eur. Phys. J. C (2017) 77:317

First TLA result with L1_J75 (3/fb)

Substantial work on HLT iet calibration

First TLA publication with L1_J75 and L1_J100 (30/fb) see PRL 121 081801

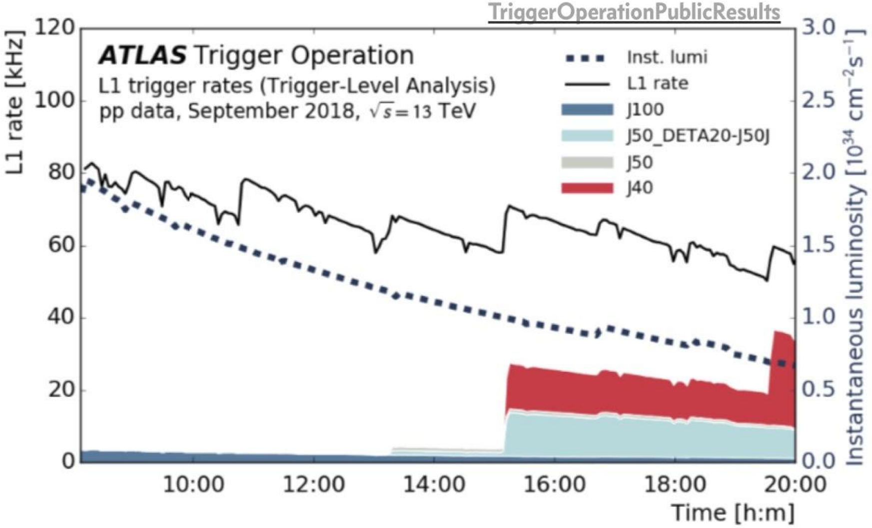
Final Run 2 jet calibrations and analyses underway + Run 3 preparations

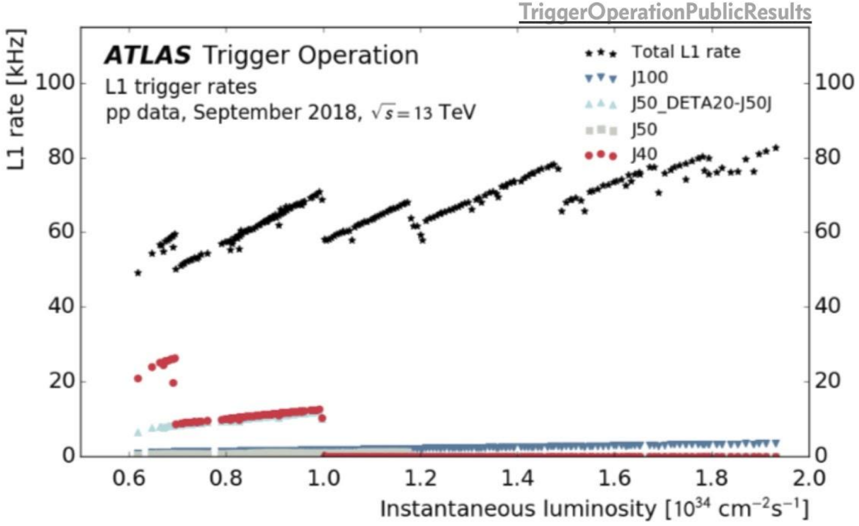
L1 rate remains most significant limitation

Two initial strategies explored for L1 limits: topological trigger and end-of-fill.

L1Topo processor allows angular cuts (pseudorapidity difference) to suppress main search background (t-channel dijet production).

Opportunistic **end-of-fill triggers** with lower L1 thresholds, in special situations using the majority of the L1 bandwidth.





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Challenges for current/future TLA

- Physics objects used for TLA need to be **identified, reconstructed and calibrated** as well as possible → what does this mean for analysis models?
  - Risk of turning storage limitations into CPU limitations?
  - Lack of information may reduce performance / signal discrimination
- **Difficult** (not impossible) to calibrate ATLAS & CMS physics objects ”in real time”:
  - Quasi-online calibration already happens in ATLAS/CMS for certain things (e.g. luminosity, beamspot, cells)
  - Some calibration steps depend on the presence of rare objects → limited statistics
- **MC statistics** will **never** be enough for final analysis
  - Forces to think about alternative solutions!
  - Background estimation techniques need to be data-driven & robust against signal

- Your event numbers may overflow as some runs collect more events than MAX_INT

Conclusions

There is a lot of potential in **trigger** and **non-standard workflows** to probe **uncovered phase space** and **non-standard signatures** - for dark matter and more!

- Trigger Level Analysis: reconstruct objects in real-time to save smaller events
  - Di-object resonances - Z’ or dark photons or [insert your favourite model here]
- Partial event building: keep regions with full detector information alongside trigger level analysis
  - Dark sector signatures involving jets (& already used for muons)
- Delayed stream: save lower threshold triggers and reconstruct full events during a long shutdown
  - Has been used in 2012 for hadronic signatures including resonance searches

Work ongoing to improve on Run-2 results, beyond luminosity gains:

- Better online calibration (benefits entire physics program) for lower pT TLA objects
- More specialized reconstruction algorithms
- More TLA objects in addition to jets

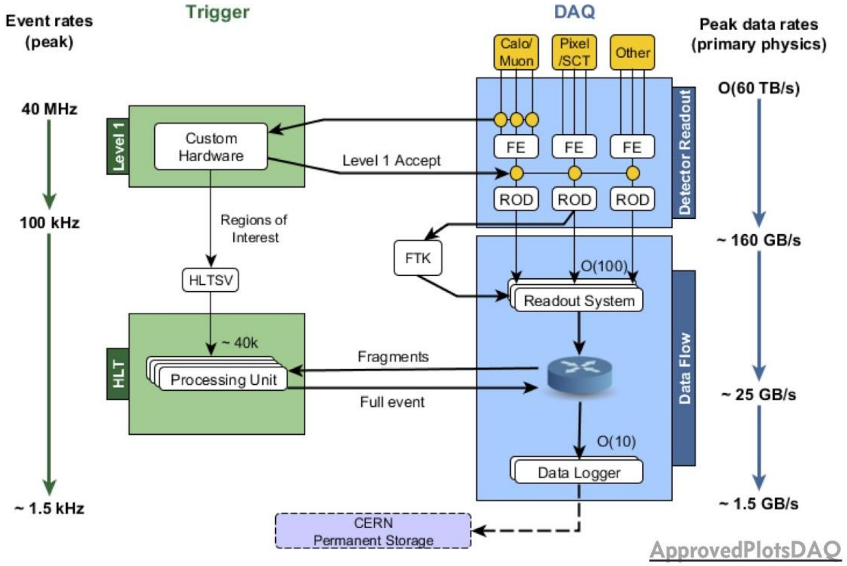
Backup slides

A. Boveia - Trigger Level Analysis in ATLAS, CHEP (2019)

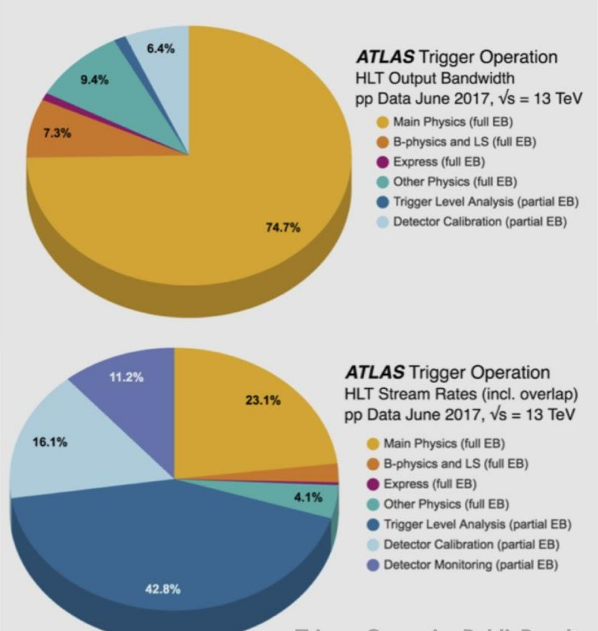
Overview of ATLAS trigger system during Run-2

The trigger system for ATLAS during Run 2 consisted of a **L1 hardware system** (accepting 100 kHz) and an **HLT software system** (accepting ~1 kHz of physics triggers).

Along with other **upgrades** to the L1 system, it also featured a **L1Topo processor** (allowing topological algorithms such as selection on angular distance between two L1 jets) and an **upgraded CTP** (providing e.g. more room for topo- and analysis-specific L1 items).



ApprovedPlotsDAQ



TriggerOperationPublicResults

ATLAS trigger menu largely driven by inclusive triggers generically useful to many analyses and recorded in a **"main" stream**. Average **1 kHz** and **1 MB/event**.

Additional **flavour physics streams**: dedicated triggers, can use delayed/custom reconstruction, or partial-event readout (e.g. only subdetectors in 1.5X1.5 area around a track satisfying pre-selection). Non-PE stream averages **200 Hz** and **1 MB/event**.

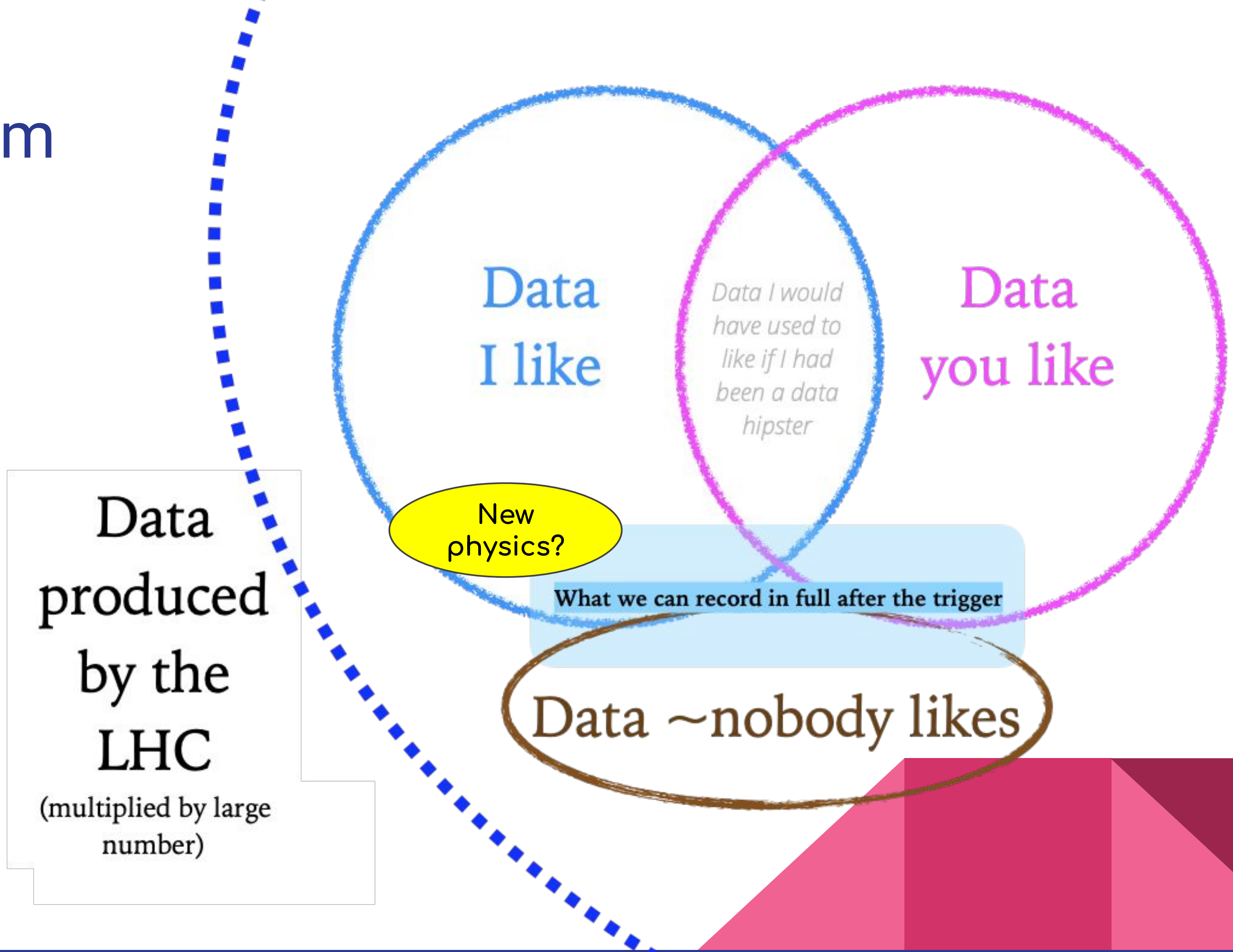
Trigger-Level Analysis stream: stores HLT reconstruction only. Discussed in this talk. Recorded up to **26 kHz** peak rate at an average **5 kB/event**.

In 2018, 32 streams total: about half with full event information, half with partial event building (PEB).

The usual problem

If we don't trigger on new processes (that we may or may not know about), we can't discover them!

Note: we're safe if events from these new processes are already in one of the existing unprescaled inclusive trigger streams, but that's often not the case...

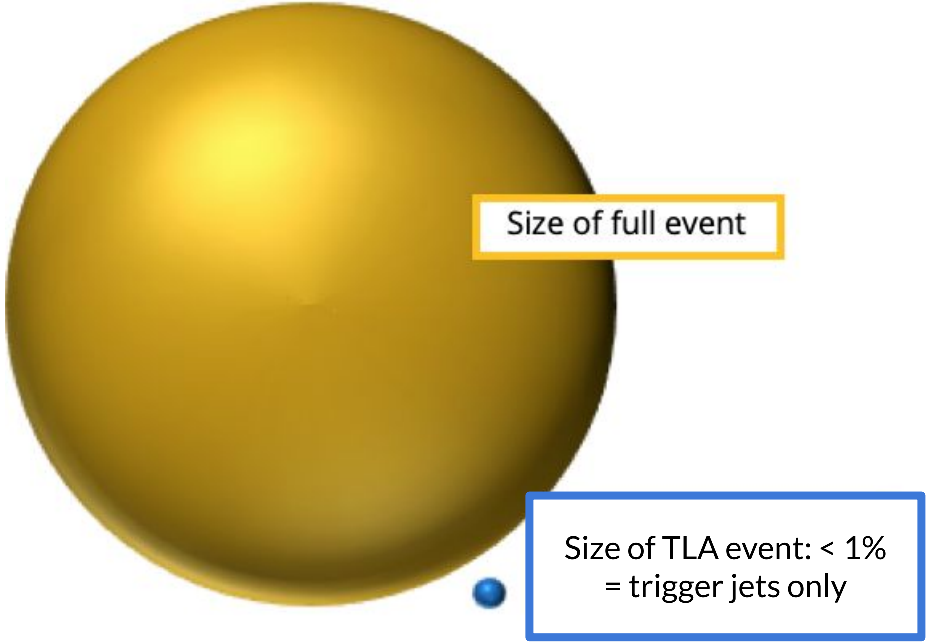


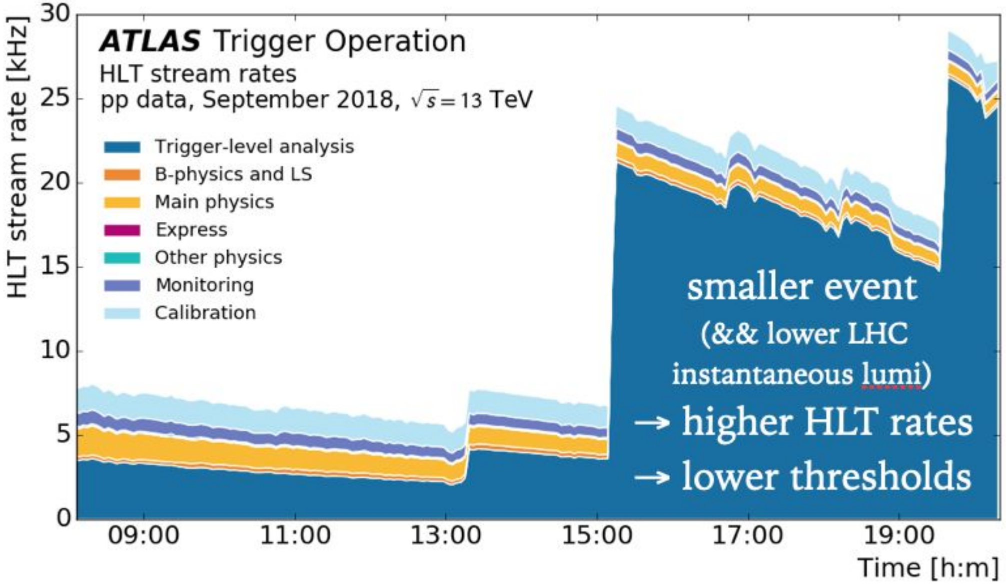
E. Tolley's talk, March P&P week

Trigger Level Analysis & Partial Event building: why?

My analysis is **limited by HLT** and I have *relatively* simple objects/backgrounds
- use **TLA**, see e.g. Phys. Rev. Lett. 121, 081801 (2018)

Nice feature of TLA: helping improve performance of HLT objects, which benefits everyone in ATLAS!



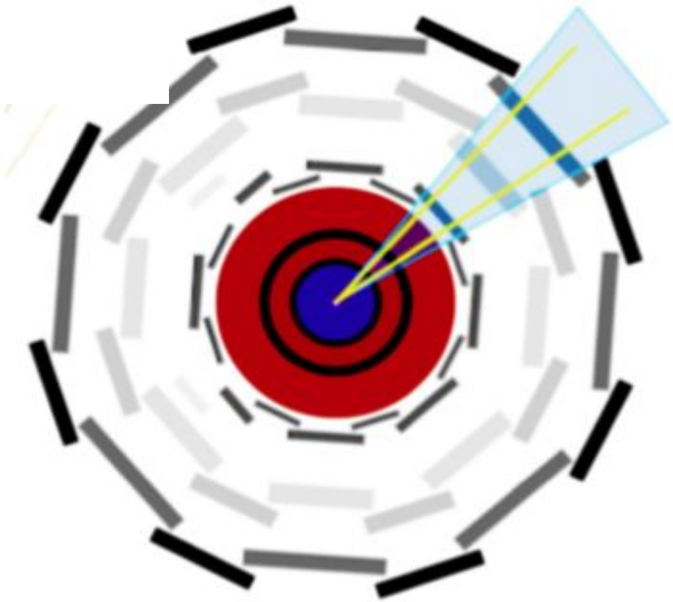


Who to contact: your group's trigger liaisons, Trigger menu (W. Kalderon and M. Owen), code writers (TJ Khoo, R. Bielski, CD, A.Boveia), the TLA team

Trigger Level Analysis & Partial Event building: why?

My analysis is **limited by HLT** and I have *relatively* **simple objects**/backgrounds
- use **TLA**, see e.g. Phys. Rev. Lett. 121, 081801 (2018)

My analysis is **limited by HLT** and I have more **complicated objects** (but not too many)
- use TLA + Partial Event Building to look into region of interests and reconstruct complex objects later, while keeping a small enough event size



Adapted from H. Russell's poster

E. Tolley's talk, March P&P week

Trigger Level Analysis & Partial Event building: why?

My analysis is **limited by HLT** and I have *relatively* **simple objects**/backgrounds

- use **TLA**, see e.g. Phys. Rev. Lett. 121, 081801 (2018)

My analysis is **limited by HLT** and I have more **complicated objects** (but not too many)

- use TLA + Partial Event Building to look into region of interests

I have a TLA going and I am sure I'll **discover something**

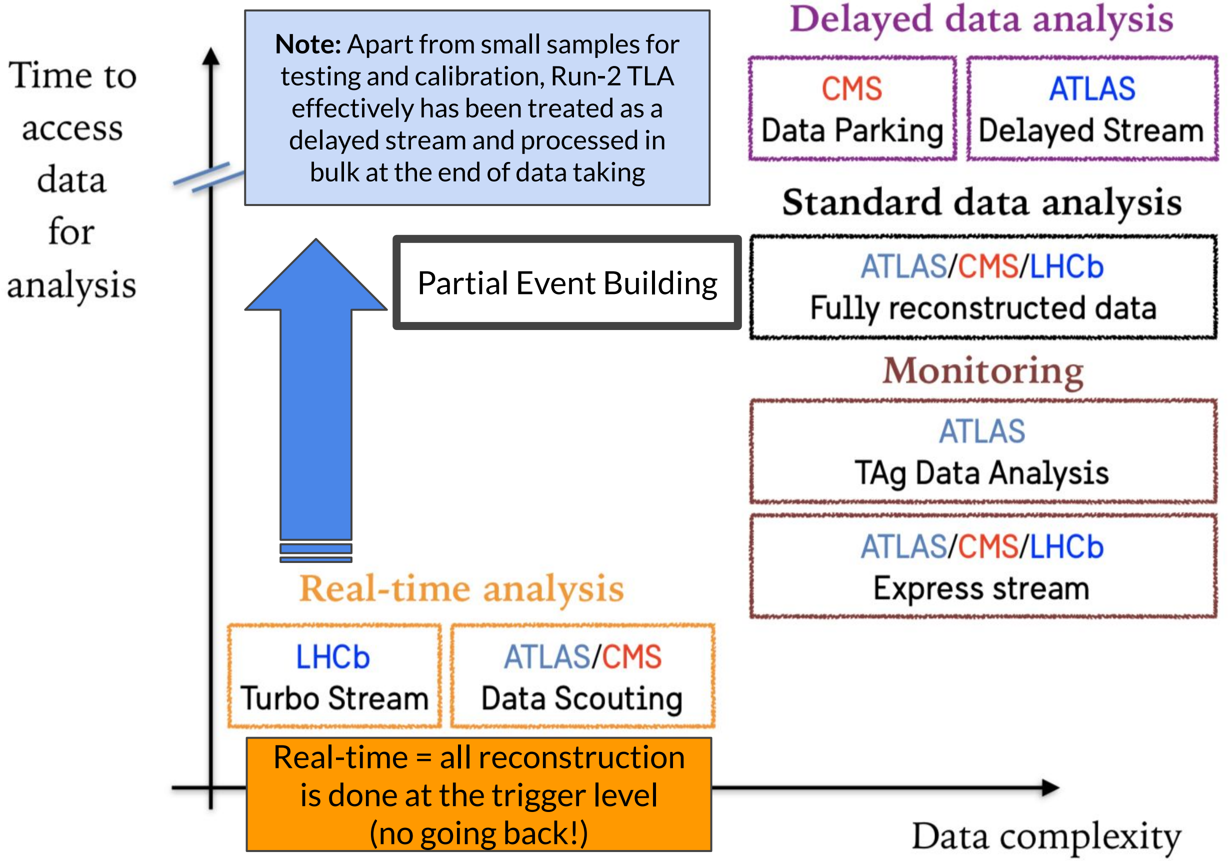
- use TLA + PEB to keep more raw data behind the objects

My analysis is limited by HLT but I need the full event
(and I don't mind when I get it)

- use **delayed stream** (see earlier slides)

Simplified diagram from 2015 talk:
Real-time data analysis in ATLAS, CMS and LHCb

When do you need the data reconstructed?



HEP Software Foundation + Institut Pascal organized a cross-experiment discussion on PEB - gory details are here.

Who to contact: Trigger menu, W. Kalderon and M. Owen, TLA team for experience

Overcoming limitations

L1 to HLT limited by:

- detector readout (prior to L1)
- network bandwidth

→ This is a hard limit: need to have a suitable L1 for any alternative workflow

HLT to offline storage rate limited by:

- network bandwidth
- storage for written events

→ Write less than the whole event:
 - Trigger objects only (**Trigger Level Analysis, or TLA**)
 - Customize raw data in regions of interest (**PEB**)

- CPU in HLT farm needed to run reconstruction of trigger objects

→ Keep raw information and reconstruct later at Tier-0 (normally done for full events, a reason for doing PEB)

- CPU at Tier-0 needed to run prompt reconstruction of events

→ Save the RAW data and delay the reconstruction:
- Delayed stream (can also do with PEB)

Note: coordination needed to avoid "breaking the bank" (nothing is completely resource-free!)

Who to contact: Trigger menu, W. Kalderon and M. Owen, TLA team for experience