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ATLAS
EXPERIMENT

New Techniques for Pile-up Simulation in ATLAS

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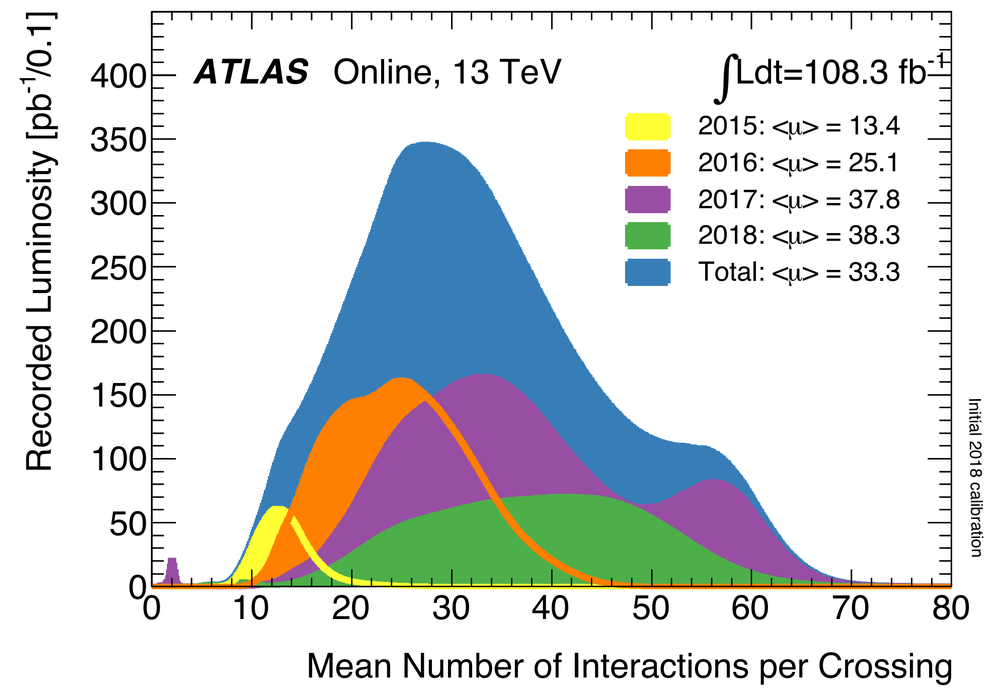
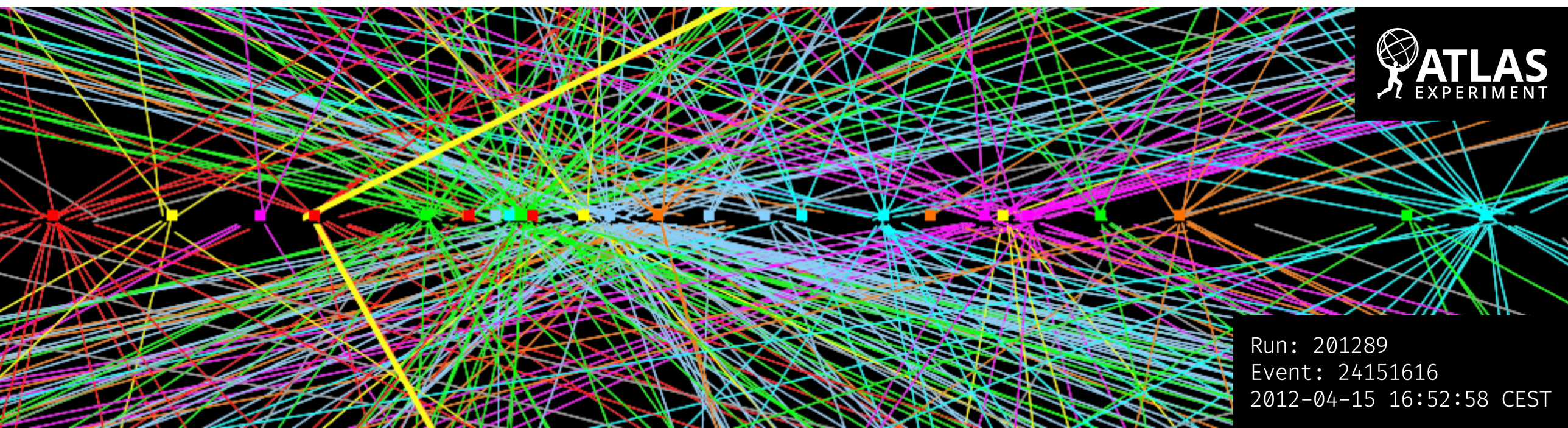
on behalf of the ATLAS Collaboration

Motivation

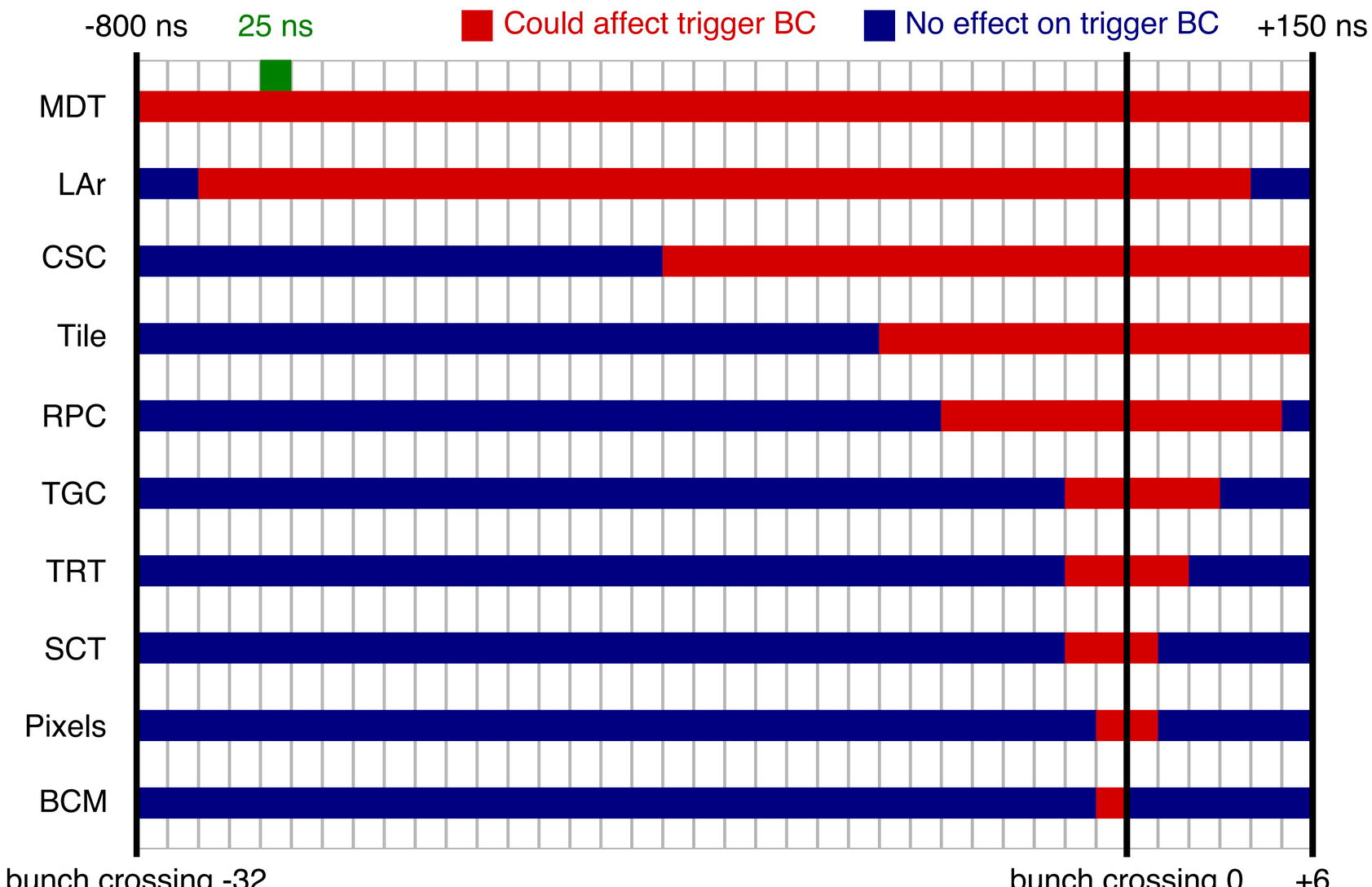
- Pile-up: soft collisions in current and surrounding bunch crossings.
- Number of interactions per crossing (μ) in 2017 up to 80.
- The values expected to increase in Run 3.
- High digitisation CPU requirements directly proportional to μ.





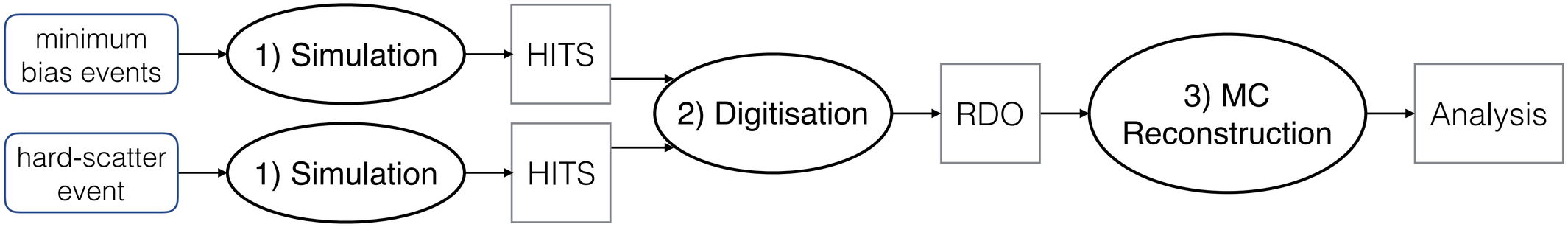
ATLAS Sensitive Time Window

- For each hard interaction and each sub-detector up to 38 surrounding bunch-crossings in time need to be simulated.



Current Production Pile-up Simulation

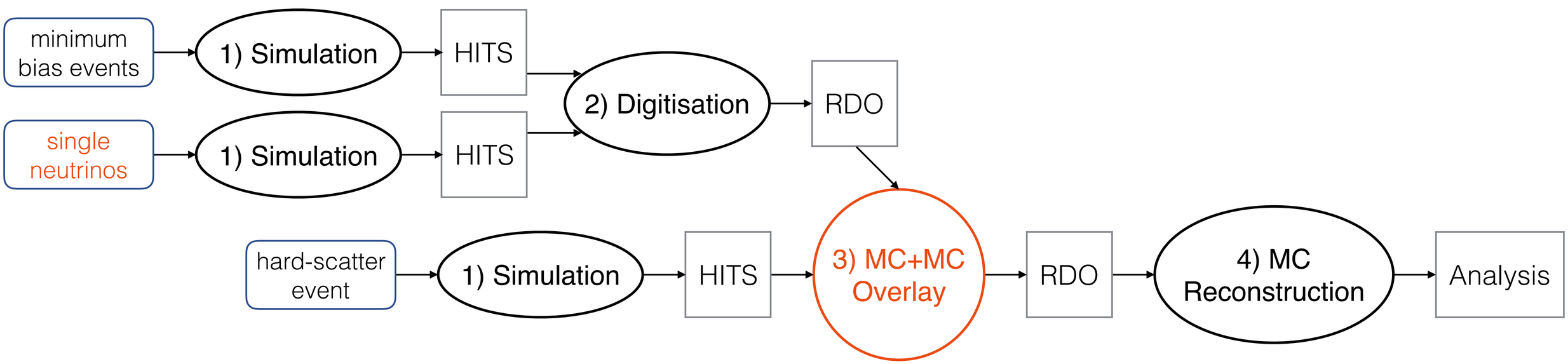
1. Simulation:
   Run the event generation for pile-up for single *pp* interactions.
   Run GEANT4 on each event to simulate detector response (HITS file).
2. Digitisation:
   Combine multiple — thousands! — of random pile-up HITS events with the hard-scatter HITS to get final digital detector signals (RDO file).



- Random pile-up event selection causes large random I/O, damaging hard drives.
- The whole simulation and digitisation takes a lot of time for large μ values.

New Method: MC+MC Overlay

1. Simulate a hard-scatter G4 event with usual configuration.
2. Pre-mixing of pile-up events: Standard pile-up simulation of zero-hard-scatter events (e.g. single neutrinos).
   In the future this step should only require minimum bias events.
3. Digitise simulated hard-scatter event and overlay it on pre-mixed pile-up digits.



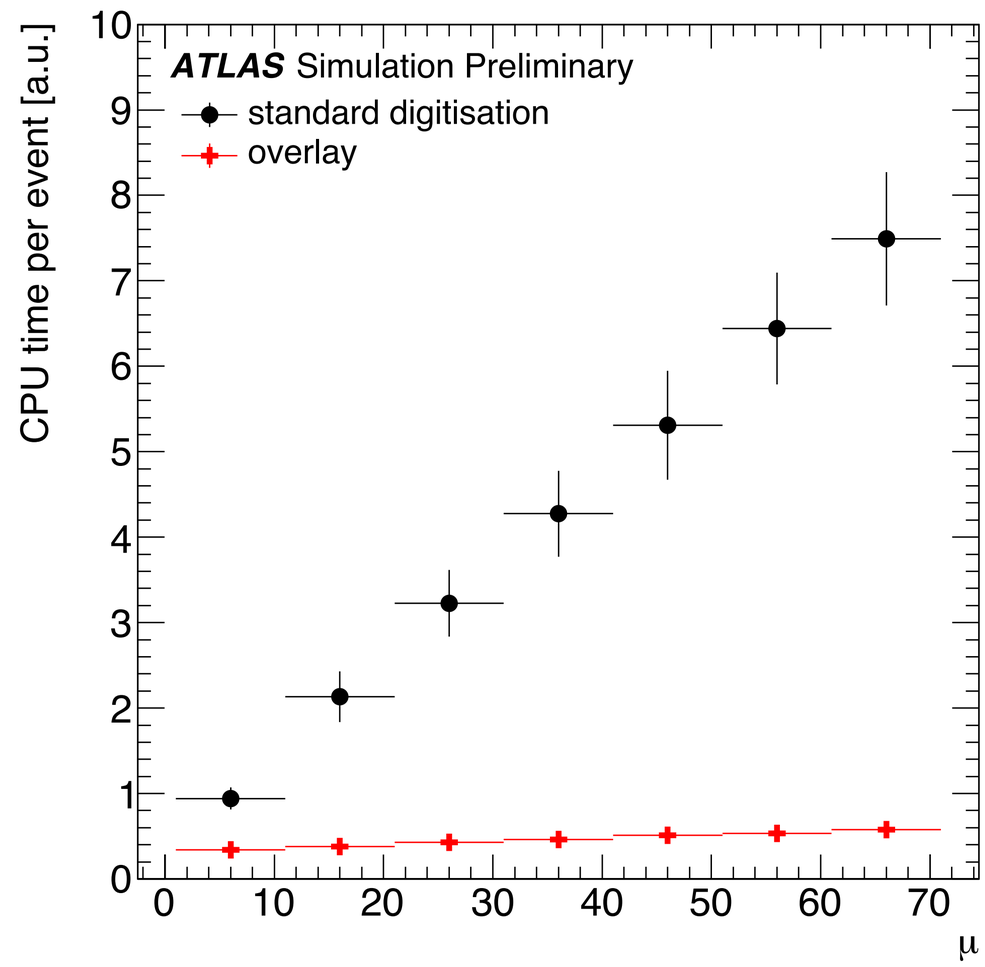
Main Benefits and Drawbacks

Benefits

- The background dataset only needs to be digitised once per campaign.
- CPU and I/O requirements much lower, almost no dependence on μ.

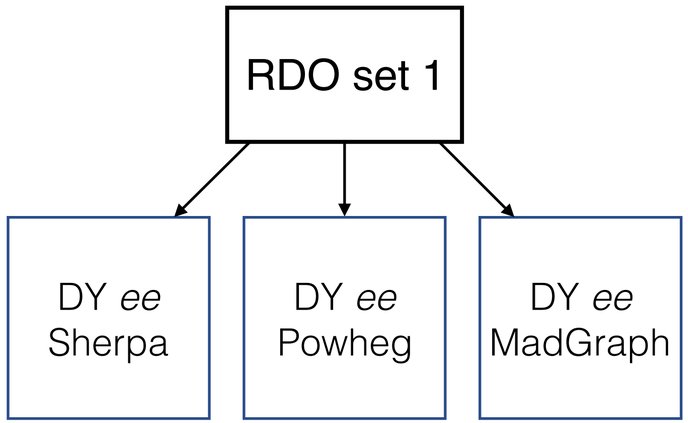
Drawbacks

- Effect of two sub-threshold signals from different events causing a signal above threshold to be lost (mostly affecting Inner Detector).
- Different datasets can have the identical set of merged pile-up events — the effects still need to be investigated.

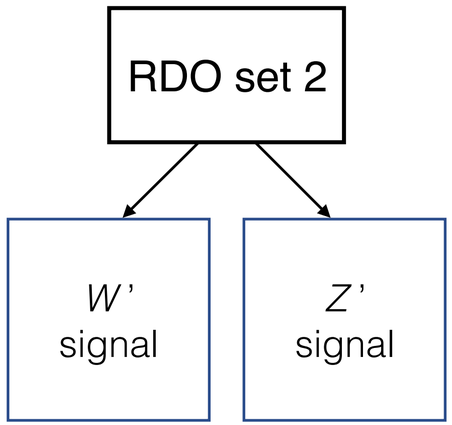


Reuse of the Pile-up Events

- Pre-digitising the pile-up RDOs is only beneficial if they are reused.
- Bookkeeping is needed to ensure unique pile-up events for related samples.
- Related samples grouped in the Production System.

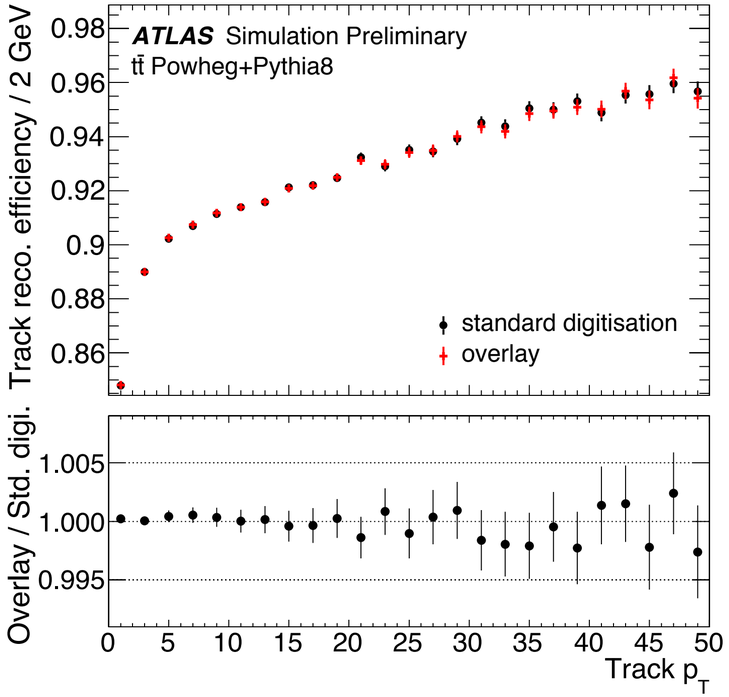


- Still approximately 1 billion pre-mixed RDOs will be needed — 4 PB of disk per copy, 2-3 needed copies globally.
- Current pileup simulation requires 80 copies of 40 TB — 3.2 PB in total.
- As only one input file is needed it can be requested and copied on demand.



Reaching the Desired Physics Performance

Requirement: MC+MC overlay should give statistically compatible results to the standard digitisation



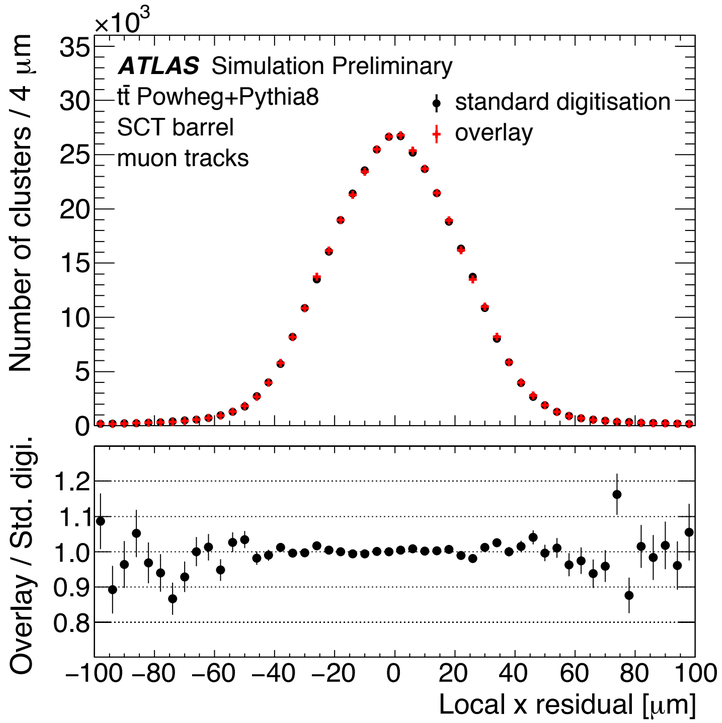
Implementation overview

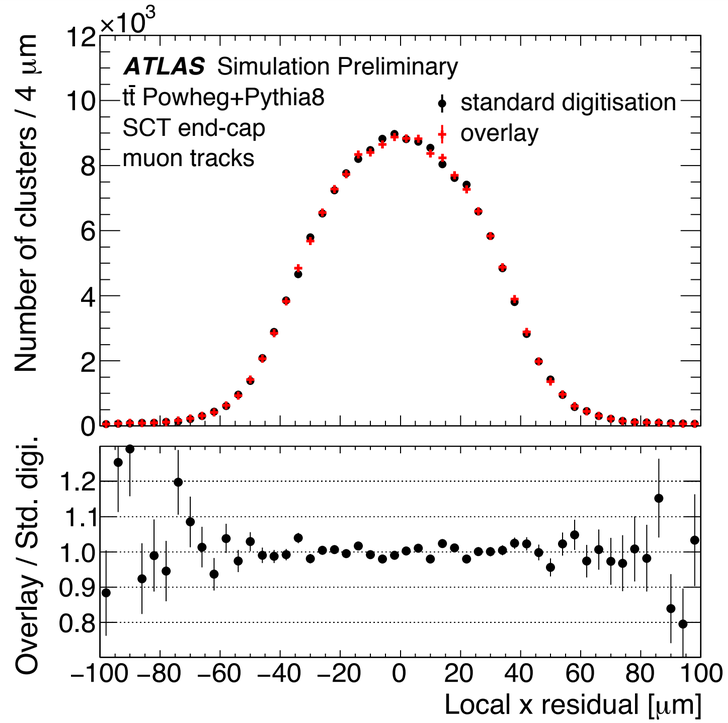
- Based on data overlay currently used for heavy-ion collisions simulation.
- Proper event information and metadata propagation.
- Pre-mixed digits stored as floats (e.g. tile calorimeter).
- Should be transparently integrated in the digitisation and reconstruction chain.

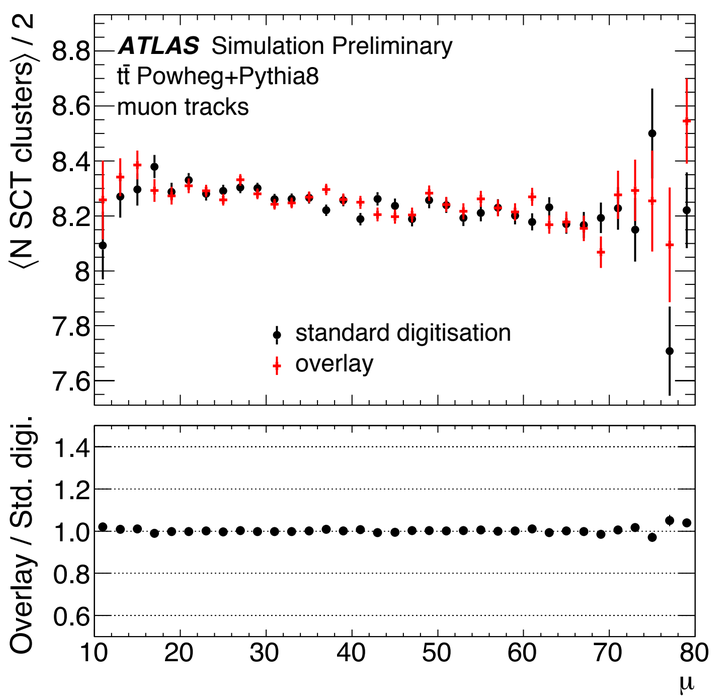
Status: Close to nominal physics performance, fixing the last remaining issues.

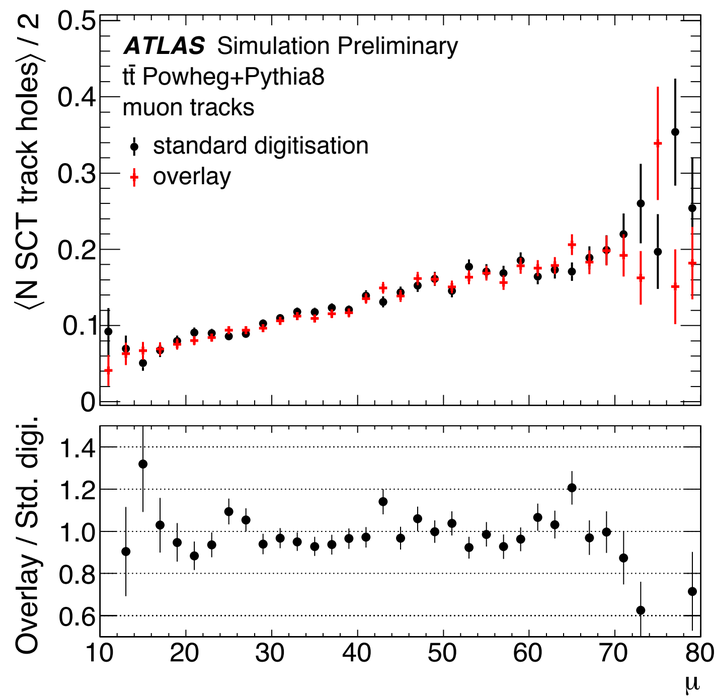
More performance plots:
ATLAS SIM-2018-002

Physics Performance: Tracking — SCT



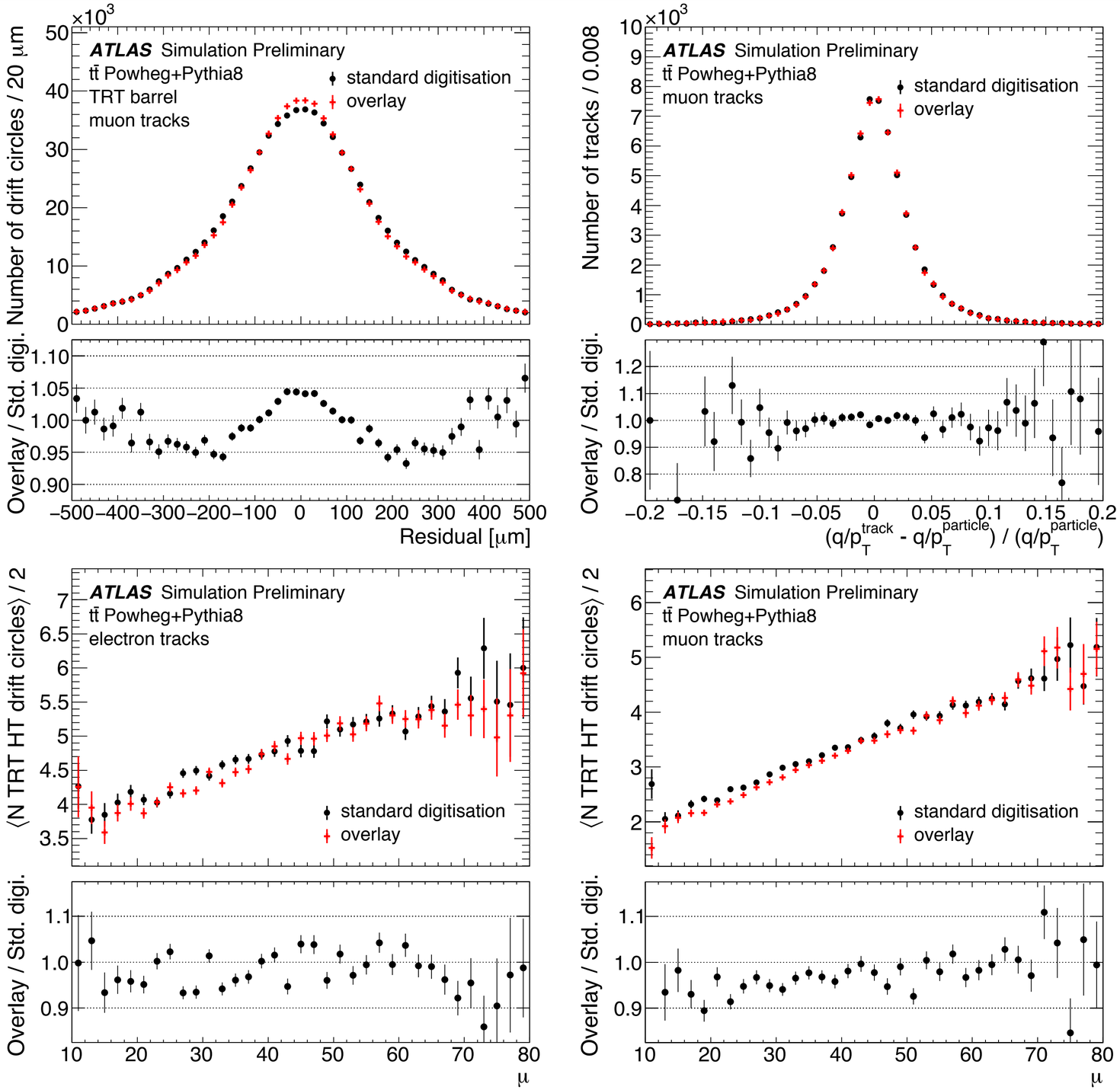






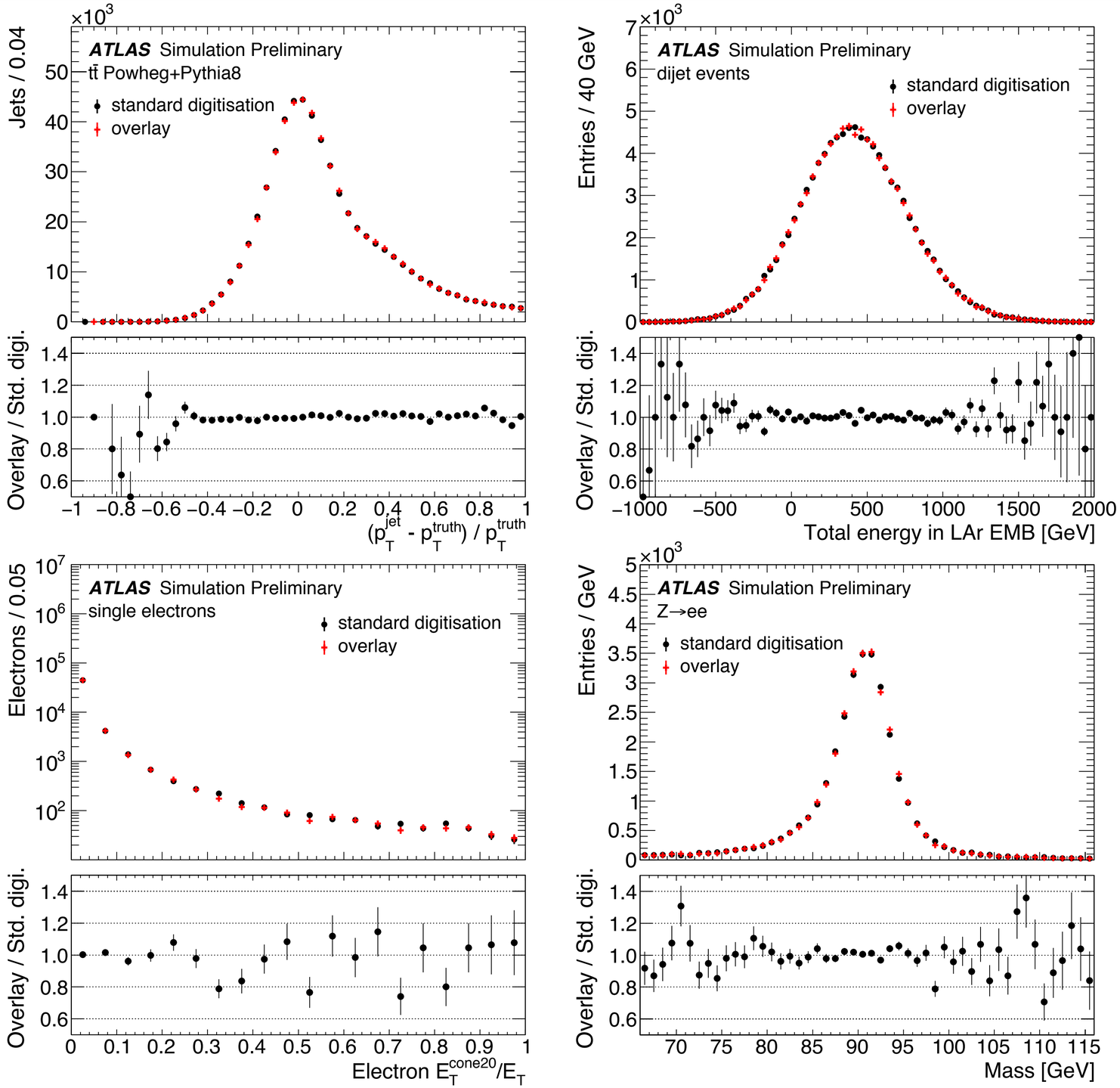
- SCT particularly sensitive to pileup from from earlier bunch crossings.
- Explicit read-out requirement of no hit in the channel in the previous bunch-crossing.
- Solution: All digits are stored regardless of the hits.

Physics Performance: Tracking — TRT



- Energy deposits information stored with courser granularity in pre-mixed events.
- TRT high-threshold drift circles incorrect: the energy in the tube for the hard-scatter and pile-up can not be added.
- Solution: A detector occupancy based correction to the HT hits in the TRT.
- Tuned separately to electrons and non-electrons.
- Lower weight of the TRT tracks fits in high pile-up — remaining differences only affecting the fit quality.

Physics Performance: Calorimeters



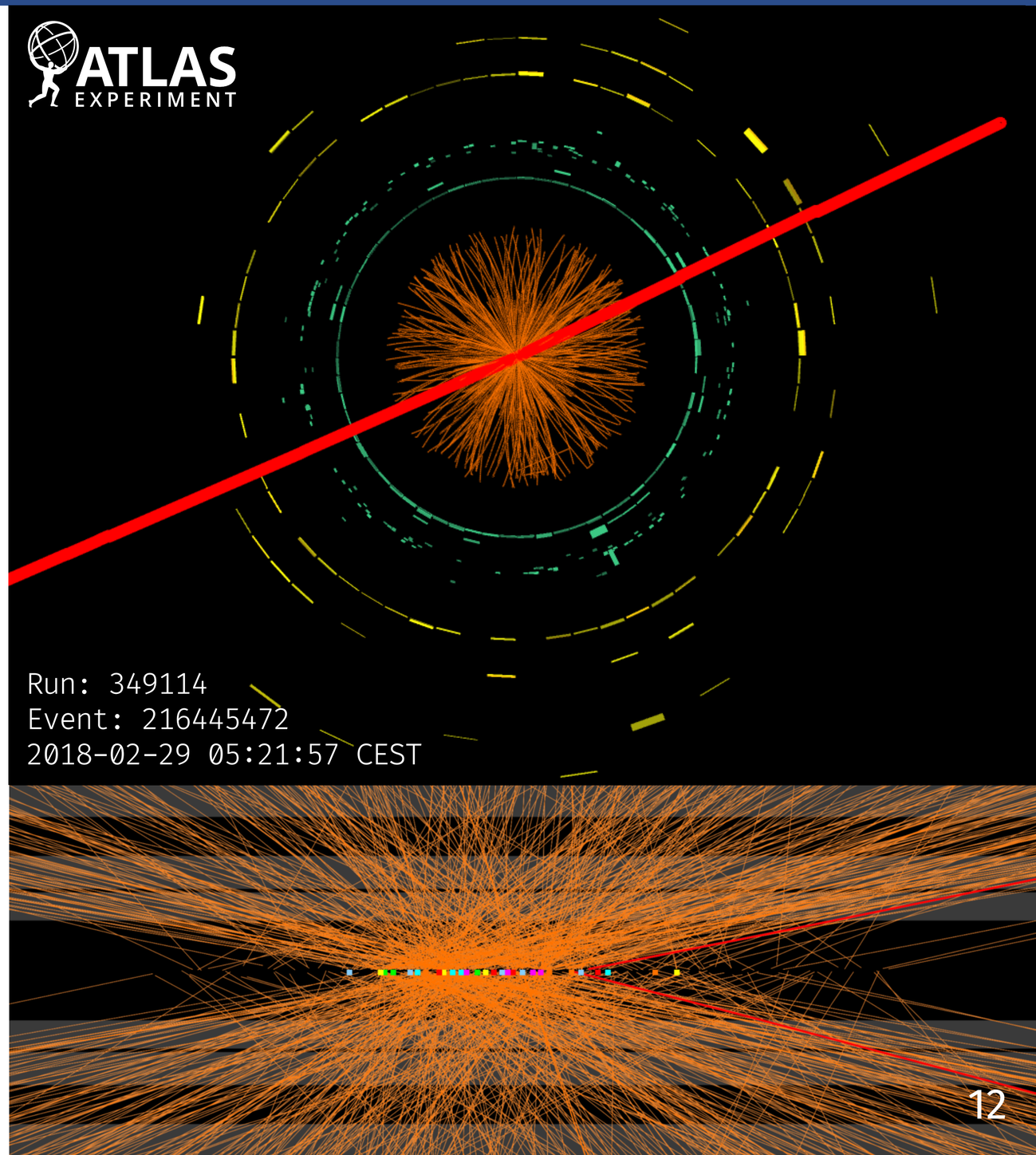
- Liquid argon and tile calorimeter overlay performed on the digit level.
- Tile digits as float improving precision.
- Good overall agreement for jets and electrons.

Conclusions and Future Plans

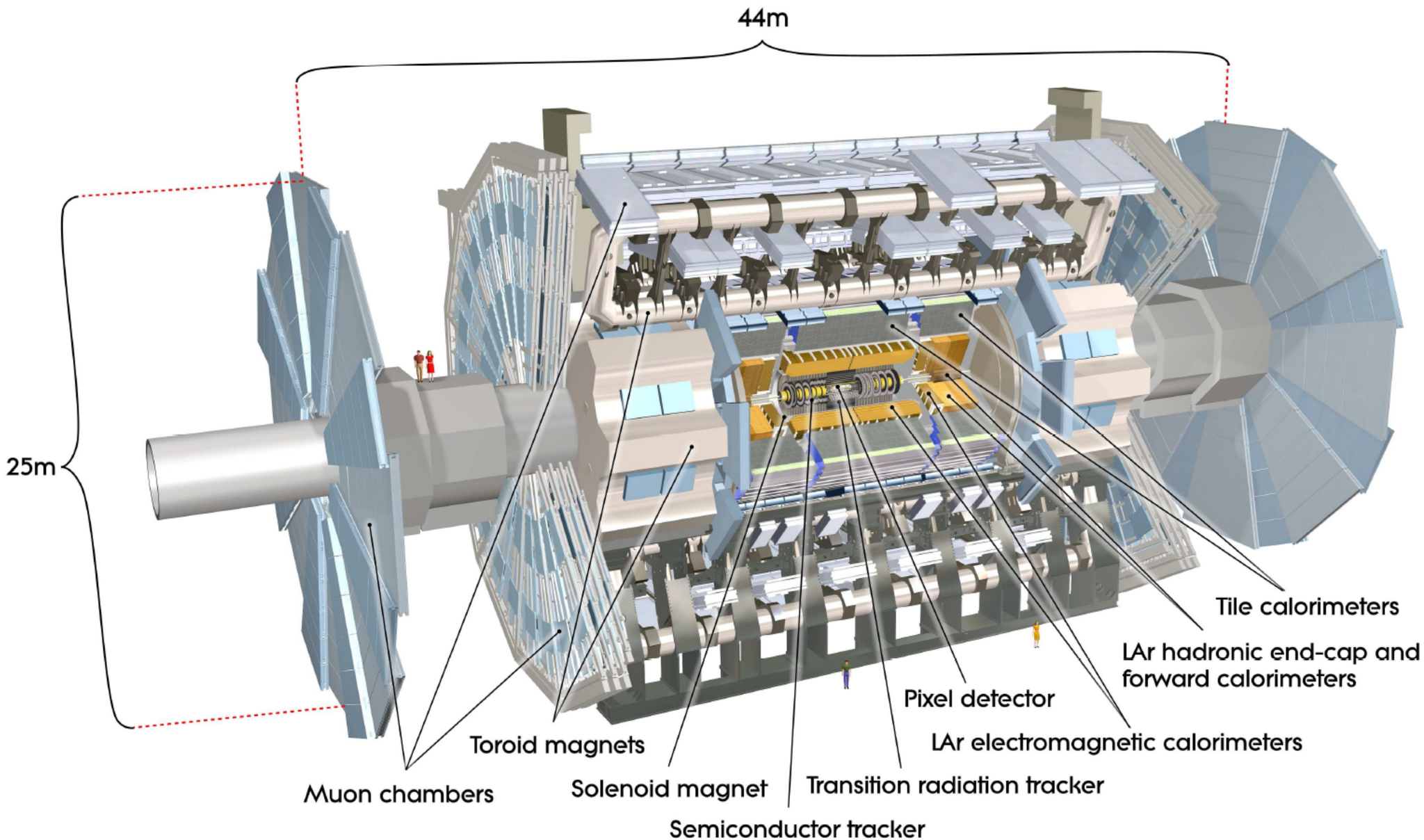
- MC+MC overlay a promising method of pile-up simulation.
- Helping ATLAS computing cope with high pile-up conditions.
- Computing requirements much lower.
- Close to being validated for physics — could be used by the end of the year.

Future

- Making the code thread-safe.
- Data overlay for *pp* collisions?
- Integration with ATLAS Fast Simulation.



ATLAS Detector



Physics Performance: Additional Tracking