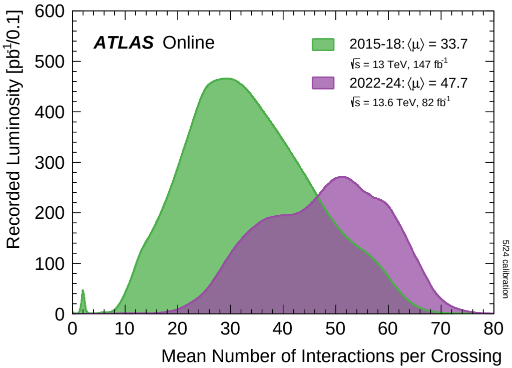
Track and vertex reconstruction performance of the ATLAS detector

G. Gaycken on behalf of the ATLAS collaboration

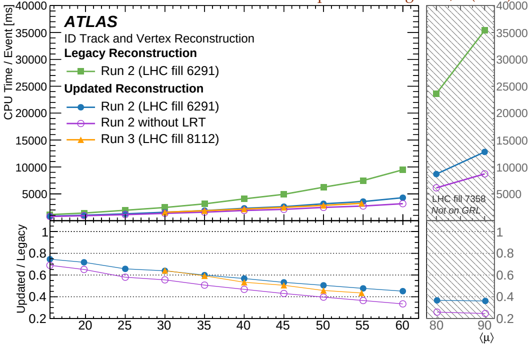
Prague, 2024 July 19

UNIVERSITY OF OREGON

Run 3 interactions per bunch-crossing



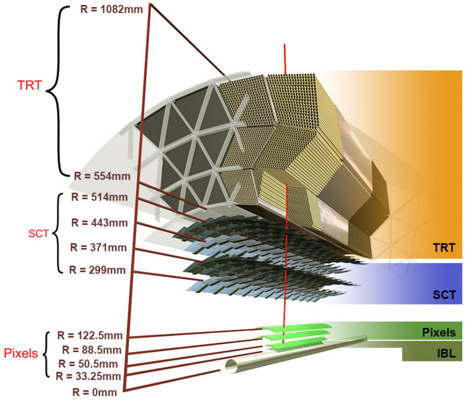
Comput Softw Big Sci 8, 9 (2024).



- Average interactions per bunch-crossing increased from run2 to run3 from ~ 30 to ~ 50
- Processing time per event would have tripled from $\langle \mu \rangle \simeq 30$ to 60

$\rightarrow$ Optimizations were necessary to reduce processing time.

ATLAS Inner detector



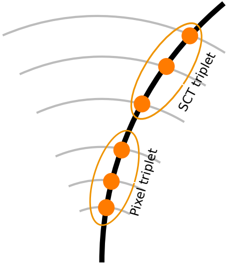
Technologies:

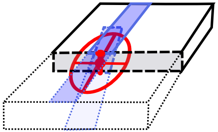
- TRT: stacks of Xe or Ar filled wire tubes
- SCT: $4(2 \times 9)$ barrel(endcap) layers of double sided strip modules with small stereo angle.
- Pixel: $4(2 \times 3)$ barrel(endcap) layers of pixel modules.

Track reconstruction

1. Seed finding (Pixel and SCT)
2. Road building along seed,
3. Trajectory construction by means of Kalman filter (Pixel and SCT),
4. ambiguity resolution,
5. Global χ^2 fit to improve resolution.
6. Extend Si-trajectories into TRT,
7. outside-in trajectory starting from TRT segments in regions of interest seeded by calorimeter clusters.
8. Global χ^2 fit to improve resolution.

triplets of "space" points constructed from pixel or strip clusters





(Strip space point)

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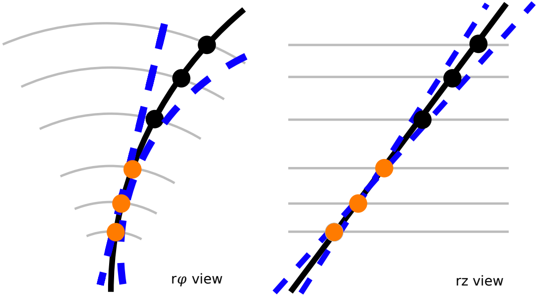

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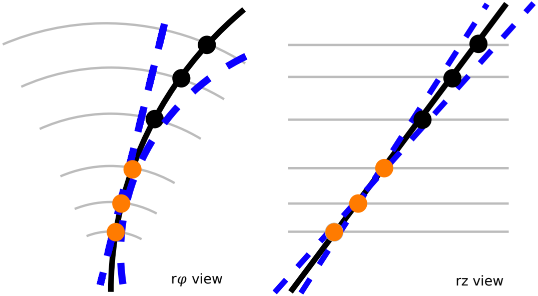

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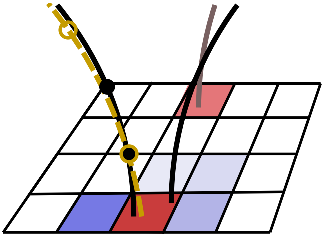

- *NN to estimate number of particles traversing shared clusters, position and uncertainty;*
- *keep unambiguous or tracks with highest score*

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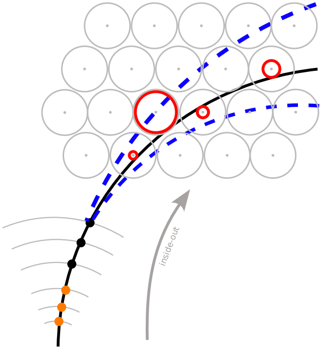

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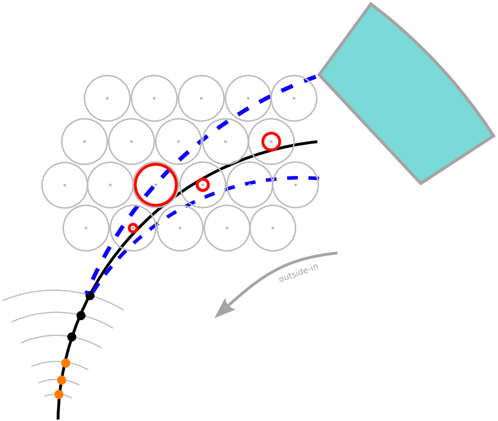

Improvements for Run 3

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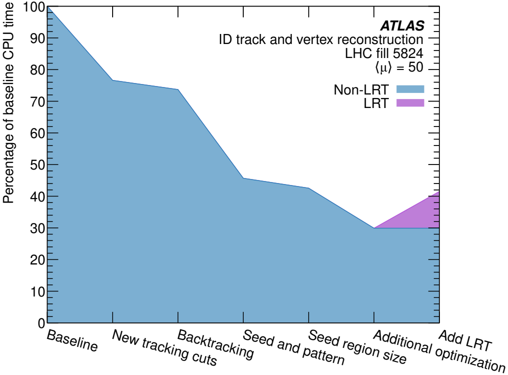

- require more Si-hits, and tighter impact parameter cuts for Si-seeded tracks
- Improved regions of interest for outside-in track search.
- Tighter cuts on seed impact parameters, cuts widened depending on deviation from straight line in the r-z plane; forth "confirmation" space point,
- Form triplets using smaller angular regions.
- Tighter cuts on TRT precision hits; code optimisations.

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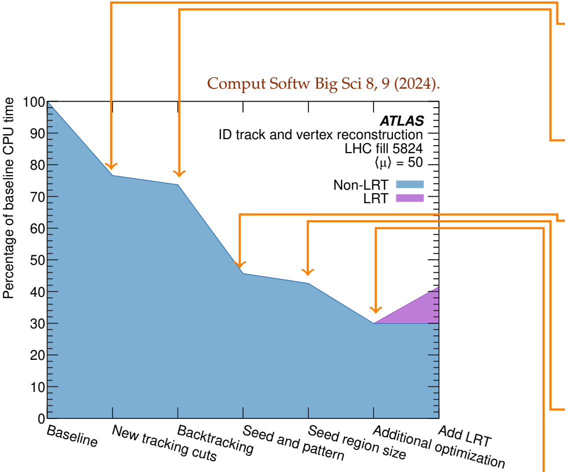

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Track reconstruction efficiency

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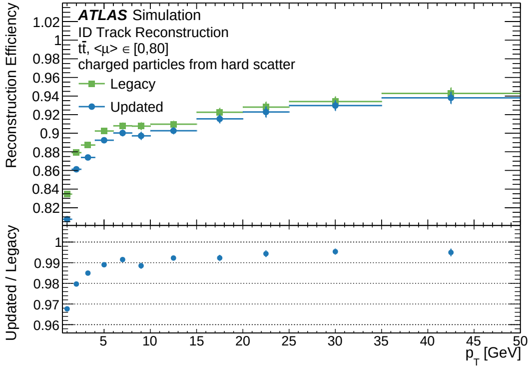

- after optimisation / re-tuning: only slightly lower track reconstruction efficiency,
- predominantly at low p_T

Track reconstruction fake rate

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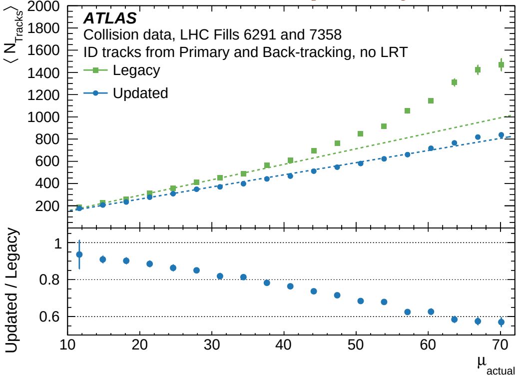
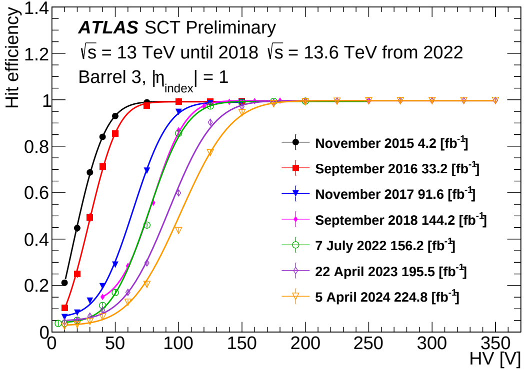


- number of tracks expected to be linear function of average interactions per bunch crossing (μ).
- Deviation from linearity measure of number of “fake” tracks.
- Efficiency loss wrt. Run 2 reconstruction, but
- now very low fake rate, and
- above $\langle\mu\rangle \simeq 50$, Run 2 reconstruction produces for about every extra track also a “fake” track.

Future inefficiencies from aging detectors?

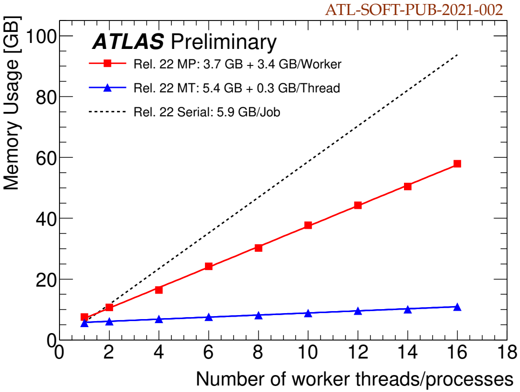
IDET-2024-001



- According to projections SCT can maintain hit efficiency till end of Run 3.
- Same likely true for Pixel.
- Likely radiation damage can be compensated by optimisation of detector operation.

(for Pixel → S. Tsuno, Jul 18)

Processing model



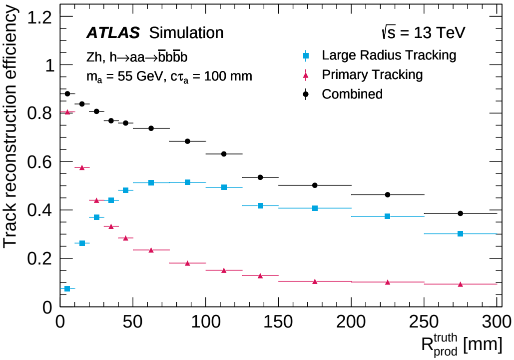
- For Run 3, changed processing model from "multi processing" to "multi threading".
- More memory shared, less memory consumed per core.
- Can do more while staying within the limit of 2 GB/core imposed by grid site configuration.

Extra tracking pass

faster track reconstruction and less memory constraints allowed for an additional tracking pass: **Large radius tracking**

- algorithms similar to primary track reconstruction pass, but
- limited to unused hits, SCT seeds only,
- tighter cuts on p_{T}, but
- relaxed impact parameter cuts to accommodate signatures of typical long-lived-particle scenarios.

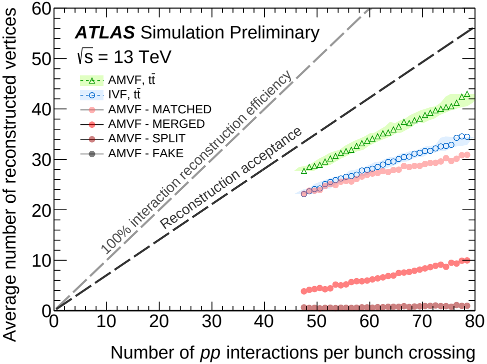
ATLAS. Eur. Phys. J. C 83, 1081 (2023).



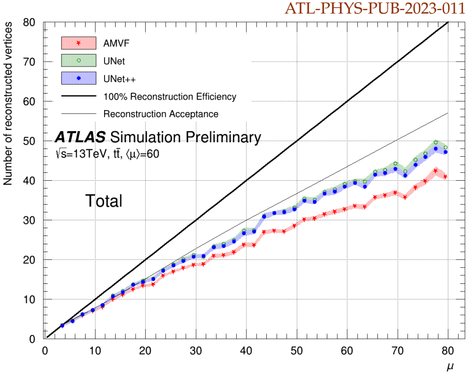
Primary vertex finding

- Original vertex finder ($\leq$ Run 2), was intended for small number of interactions per bunch-crossing.
- For Run 3 changed to “adaptive multi vertex finder” (Acts):
  - Gaussian Track Density seed finder,
  - weighted adaptive Kalman fitter with deterministic annealing, beam spot (transverse plane), and seed based (beam-line) constraints.

IDTR-2022-08



Improve vertex finding with ML?



- ATLAS adaptation of pv_finder (LHCb) based on UNet NN.
- Deep convolutional NN with input features (histograms in z-direction, with $\sim 40\mu m$ resolution):
  - sum and sum of squares of track probability distribution in impact parameter space
  - position of maximum of summed probability distribution in x and y.
- output primary vertex probability distribution as a function of z.

$\rightarrow$ Seems promising, but has not been tested on data.

Summary

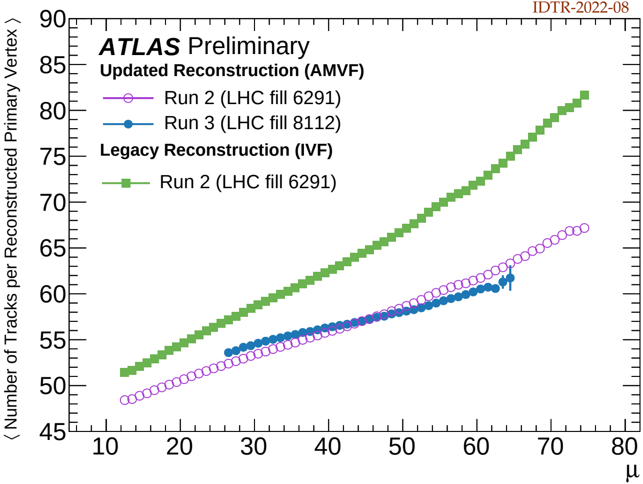
- Track&vertex reconstruction re-optimised for higher pileup conditions of Run 3, significantly reduced processing time at high μ (more than factor 2 at $\mu \simeq 60$), efficiency within 1% of Run 2 reconstruction in most of the phase space.
- Added extra tracking pass to find "large radius tracks", possible because of reduced processing time, and memory consumption.
- Likely can maintain stable tracking performance till the end of Run 3.

(*Strategies for Run 4 have been discussed by H. Hayward, Jul 18*)

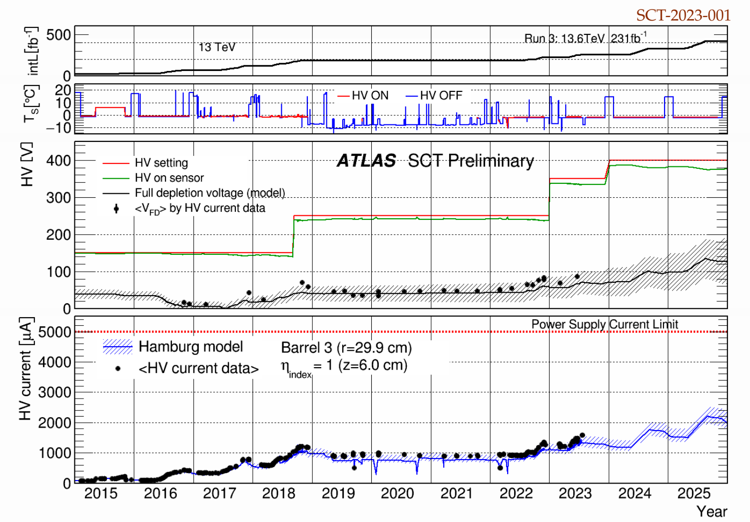
Appendix

Primary vertices in data

IDTR-2022-08



SCT projections



Impact of hypothetical inefficiency

Relaxed Si-hit requirement