SFU

Improved Track Reconstruction Performance for Long-lived Particles in ATLAS

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on behalf of the ATLAS collaboration

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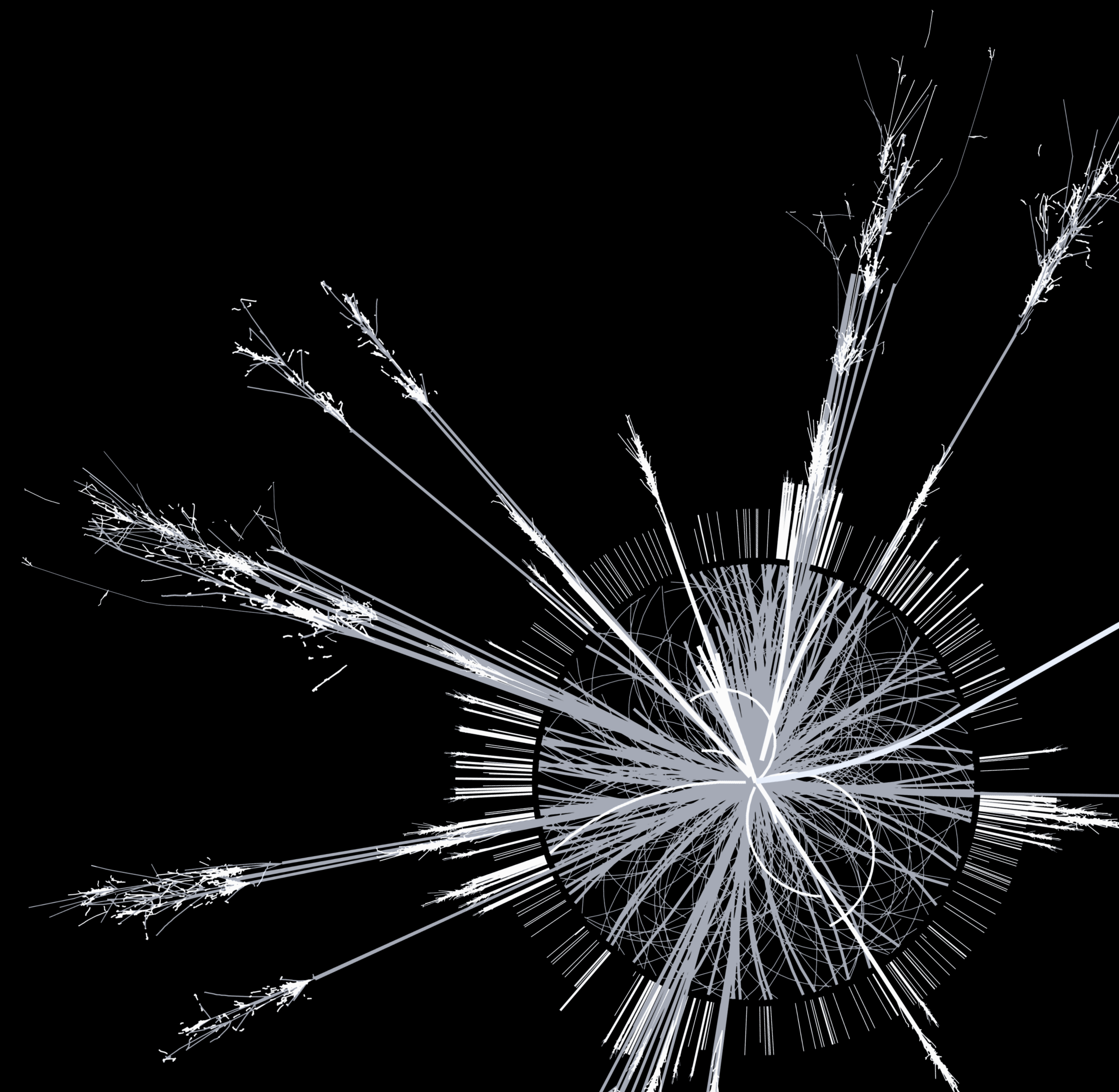
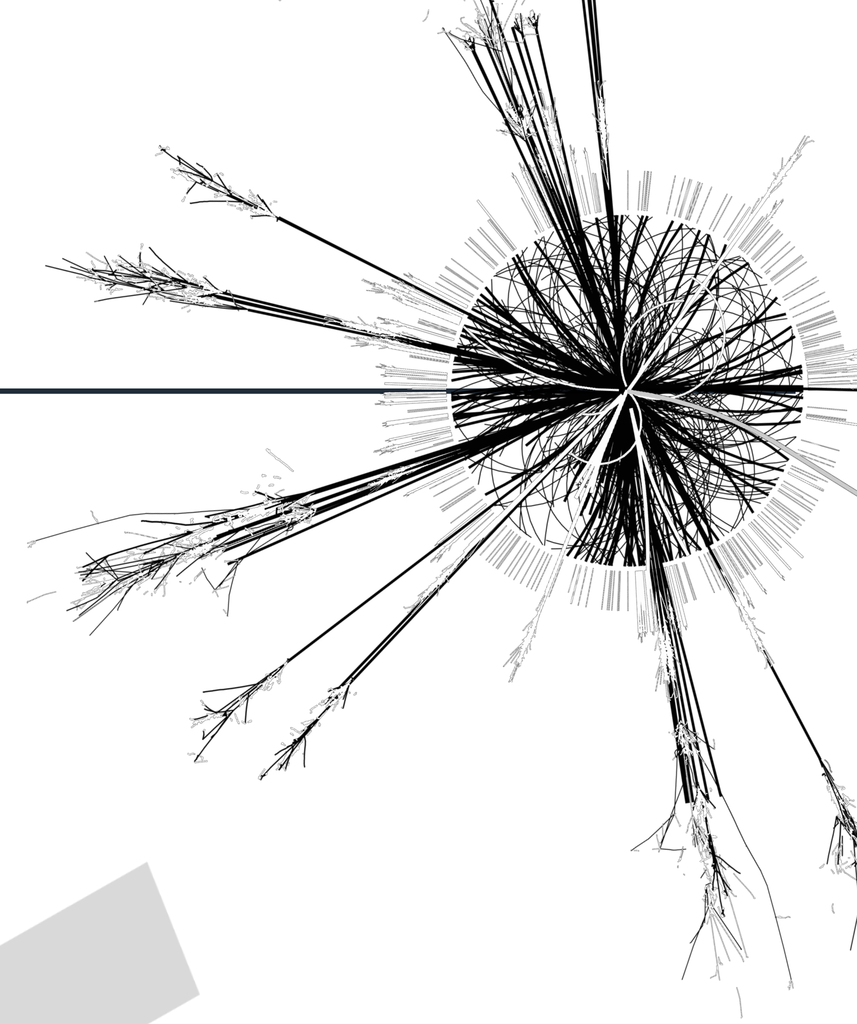


Long-lived particle (LLP) searches in ATLAS



Many BSM models predict particles with macroscopic proper decay lengths ($c\tau \gtrsim 100\,\mu\text{m}$)

- Neutral naturalness/hidden sectors → exotic Higgs decays to long-lived bosons/dark showers
- Seesaw models → long-lived heavy neutral leptons
- R-parity violating SUSY → long-lived neutralinos/sleptons

Gaps in experimental coverage → strong discovery potential!

ATLAS Inner Detector (ID) provides coverage for a wide range of LLP lifetimes

- Highest density of LLP decays expected in ID due to exponential particle decay

Dedicated track reconstruction essential for achieving sensitivity to LLP signatures in the ID

- Displaced vertices, displaced leptons, emerging jets, etc…

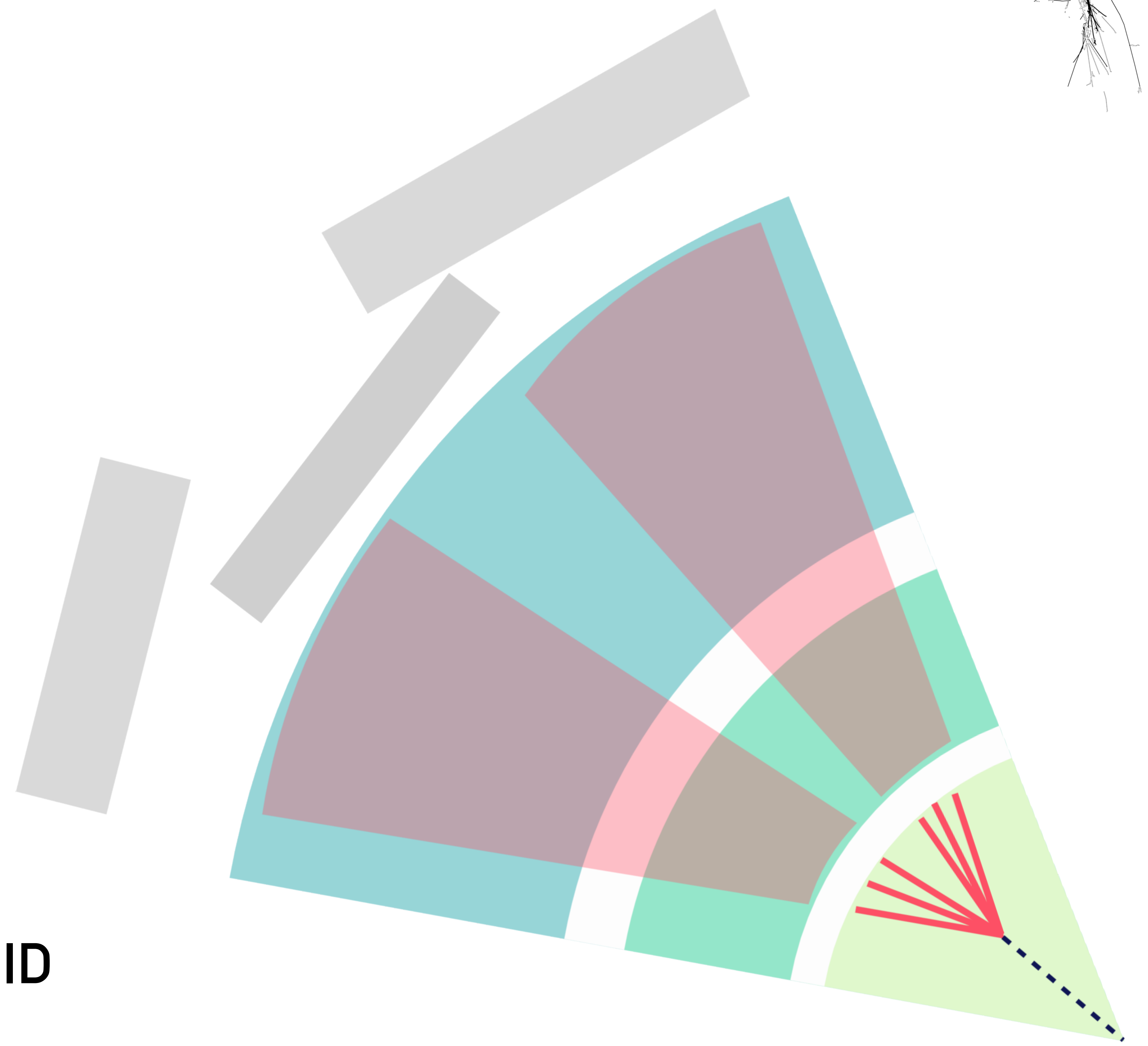
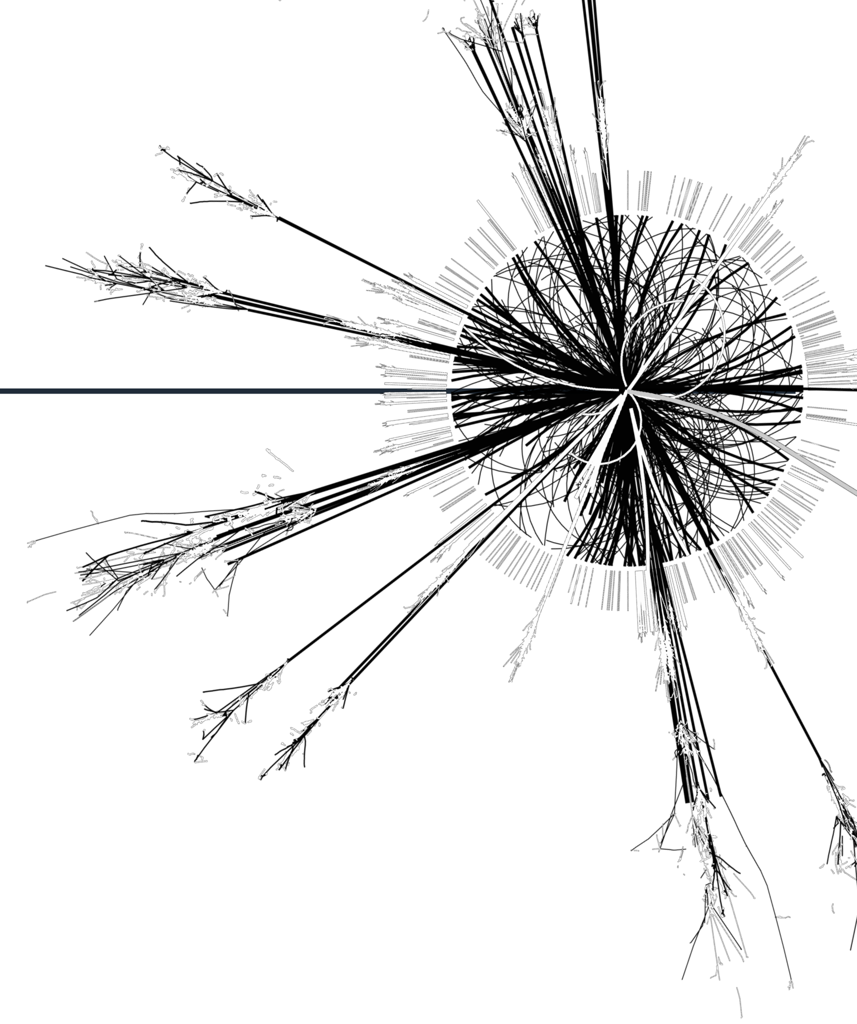


diagram by H. Russell

Large Radius Tracking



Large Radius Tracking (LRT) is an additional ID tracking pass that is run after standard tracking

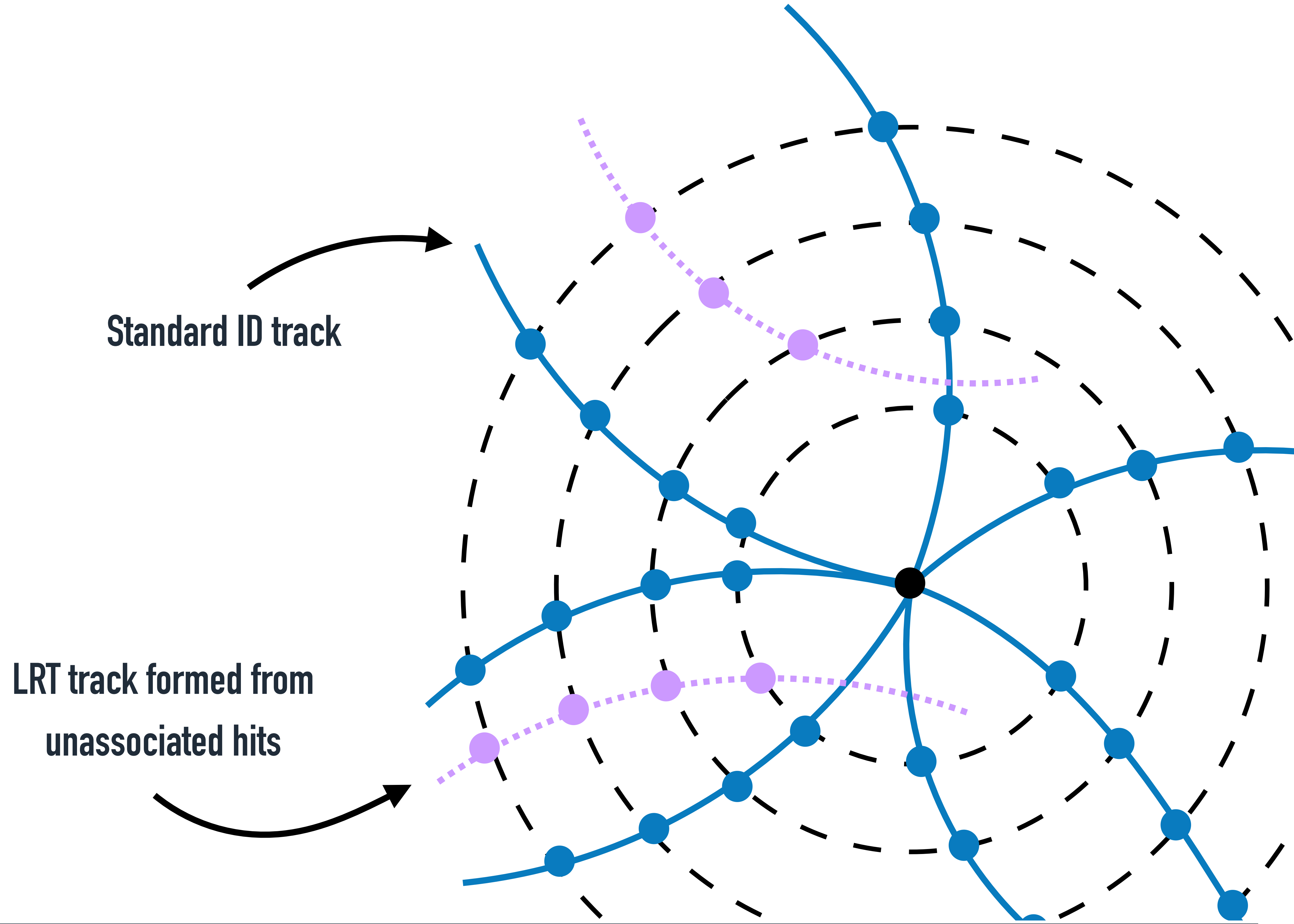
- Run on unused hits with LLP-focused tracking cuts
- Optimized to reconstruct the charged particles originating from LLP decays

Crucial component of many LLP searches

- Increasingly important aspect of ATLAS search program

LRT is based off of the standard ATLAS track reconstruction with several modifications, ex:

- $|d_{0,\max}|$: 5mm → 300mm
- $|z_{0,\max}|$: 200mm → 500mm

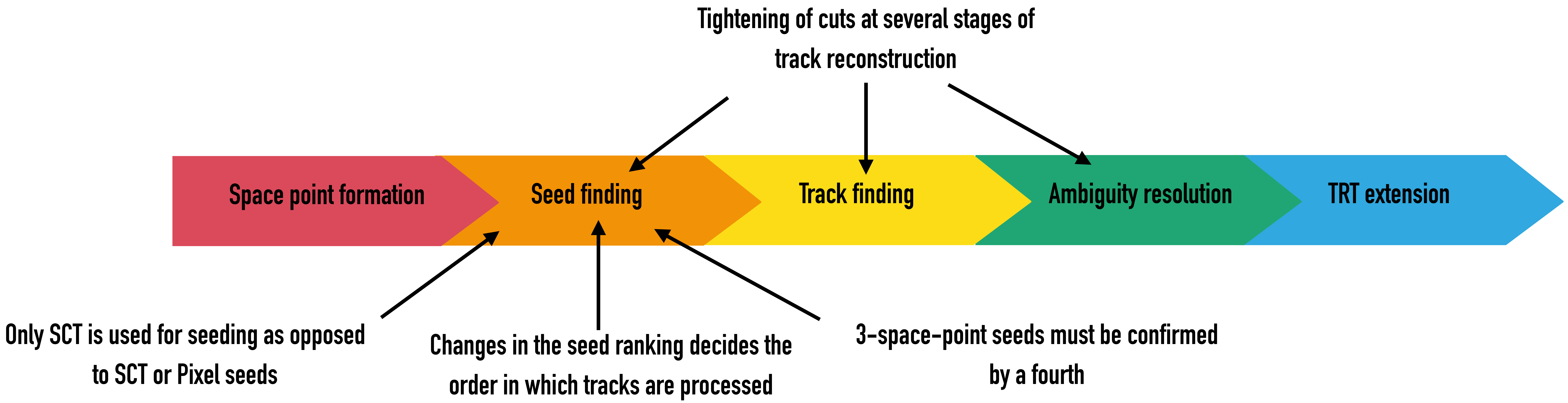


Changes in LRT for Run 3

Run II LRT implementation optimized for high reconstruction efficiency

- Very high rate prohibited LRT being run in standard reconstruction
- Special data stream needed

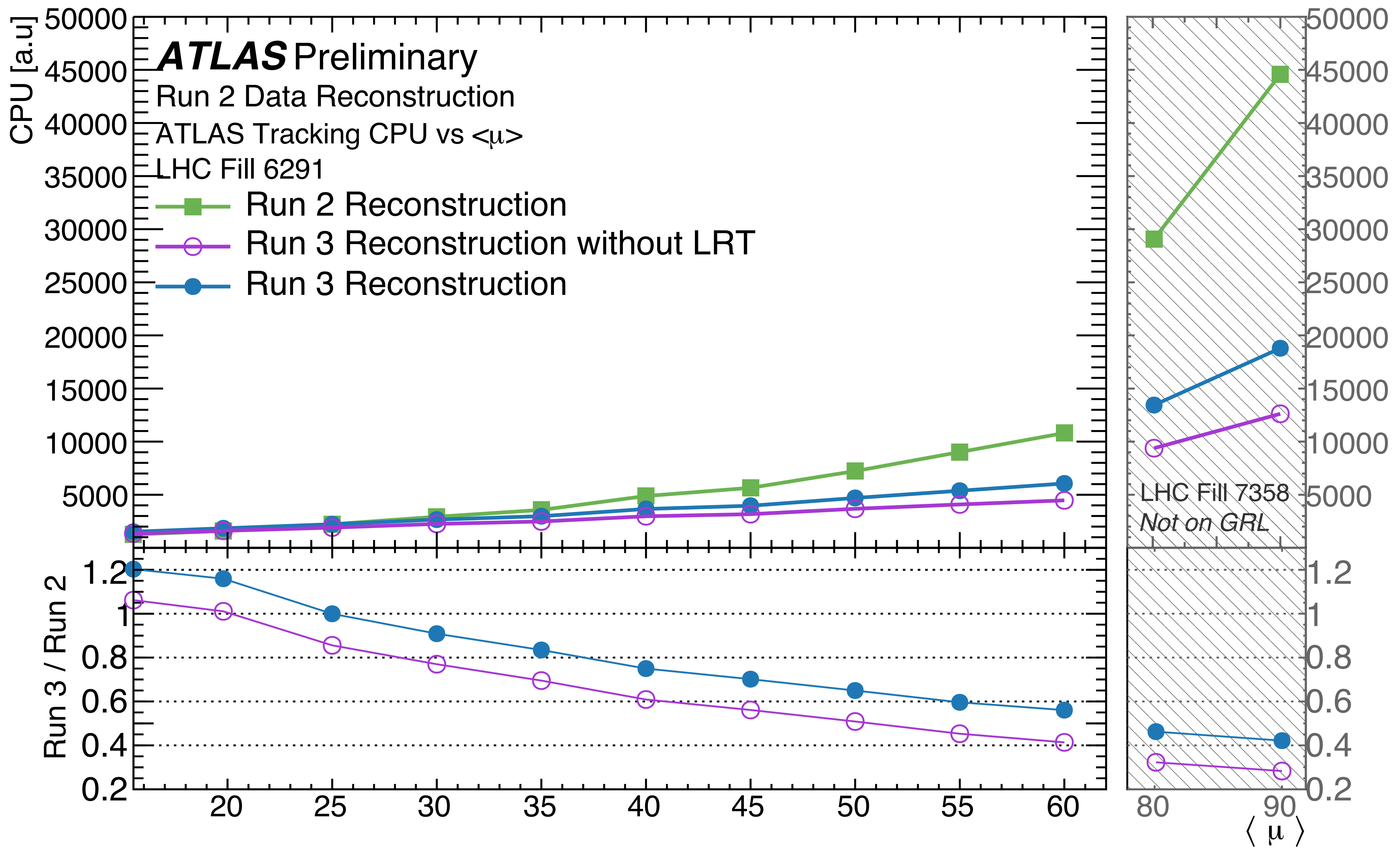
Run III implementation re-optimized for fake reduction and CPU time



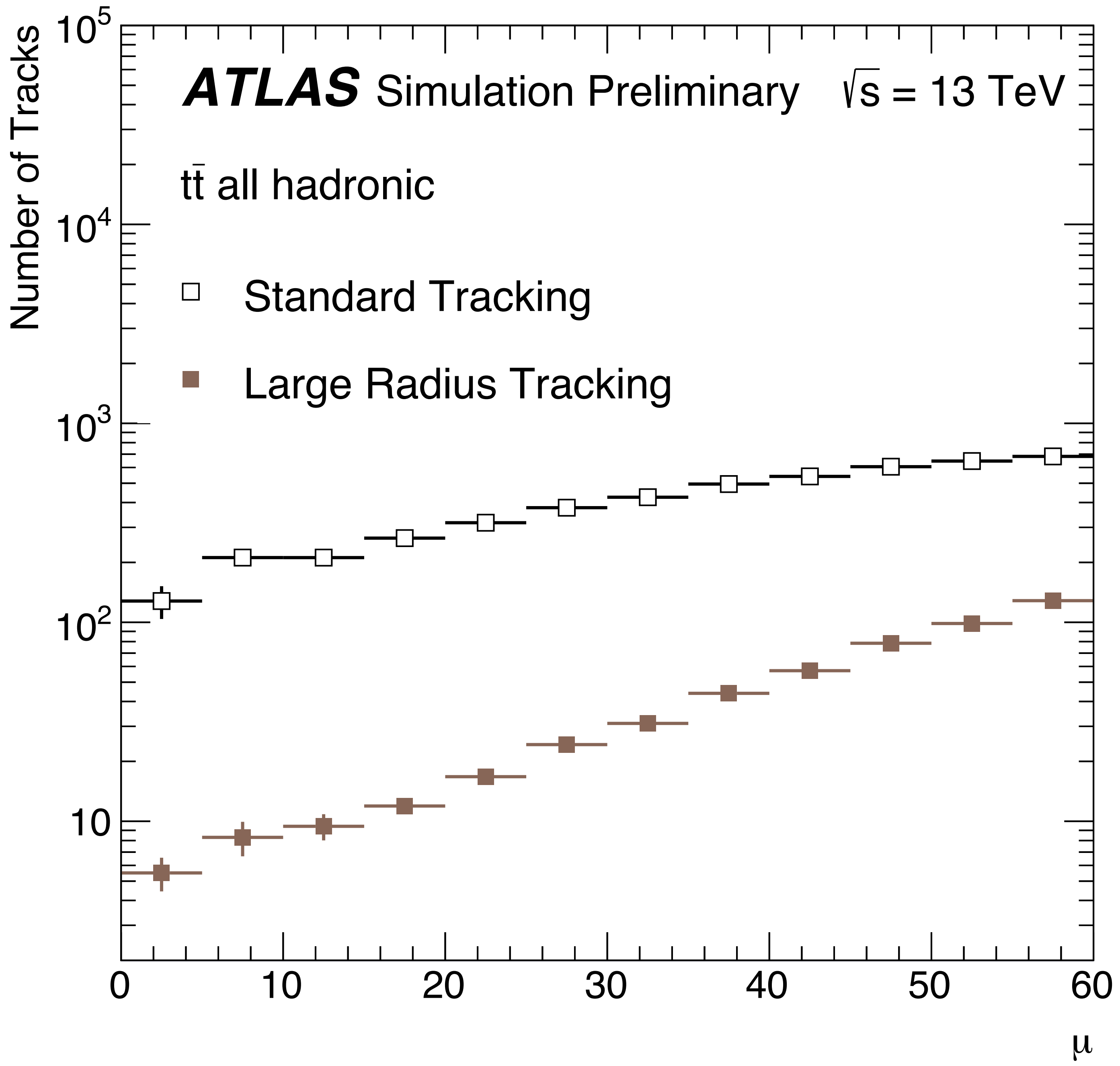
Computing Performance

End result of optimization: 95% reduction in fakes with only 10-15% reduction in signal efficiency

- Run 3 standard tracking + LRT is now faster than Run 2 standard tracking alone
- Allows for LRT to be run in standard Run 3 reconstruction



Standard tracking CPU performance also greatly improved! See poster by M. Vessella

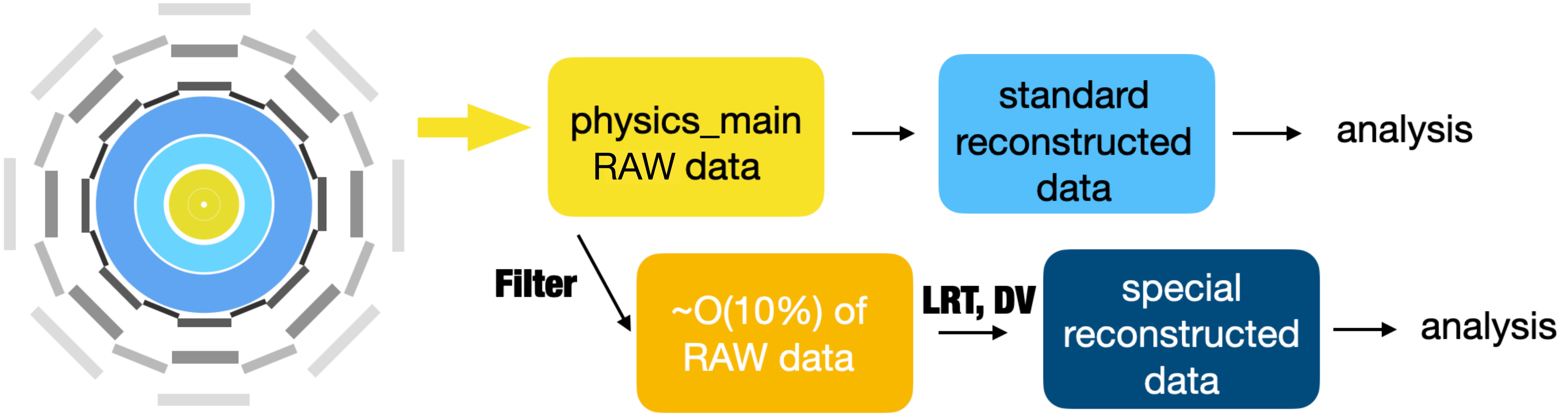


LRT accounts for < 10% of total tracks on average

Implications for analysis

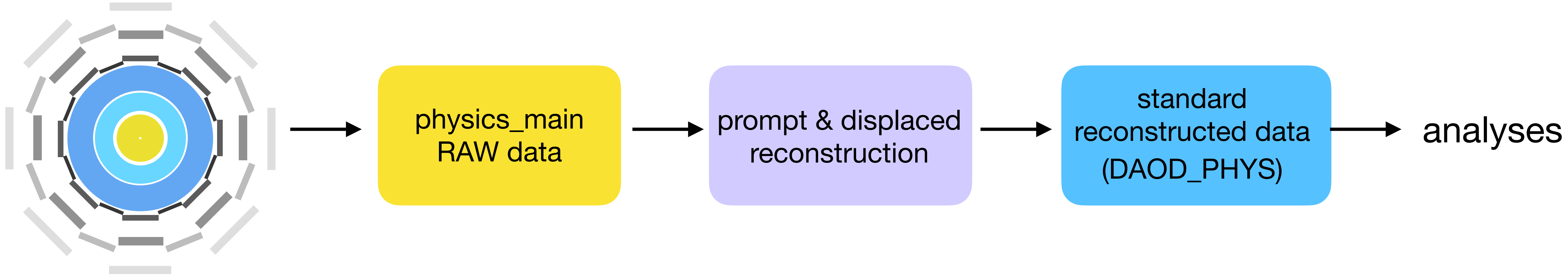
Run II LRT workflow relied on "filters" to preselect events for LRT

- Significant amount of effort needed to develop/validate
- Requires dedicated reprocessing of large amounts of data
- LRT unavailable in MC (unless specifically requested)
- <u>Preselection limits analysis sensitivity and flexibility</u>



Run III LRT run by default as part of standard reconstruction

- No longer need to develop analysis-specific filters → much easier to R&D new ideas
- Increased flexibility in analysis strategy
- MC with LRT now available by default
- Allows standard analyses to make use of LRT tracks



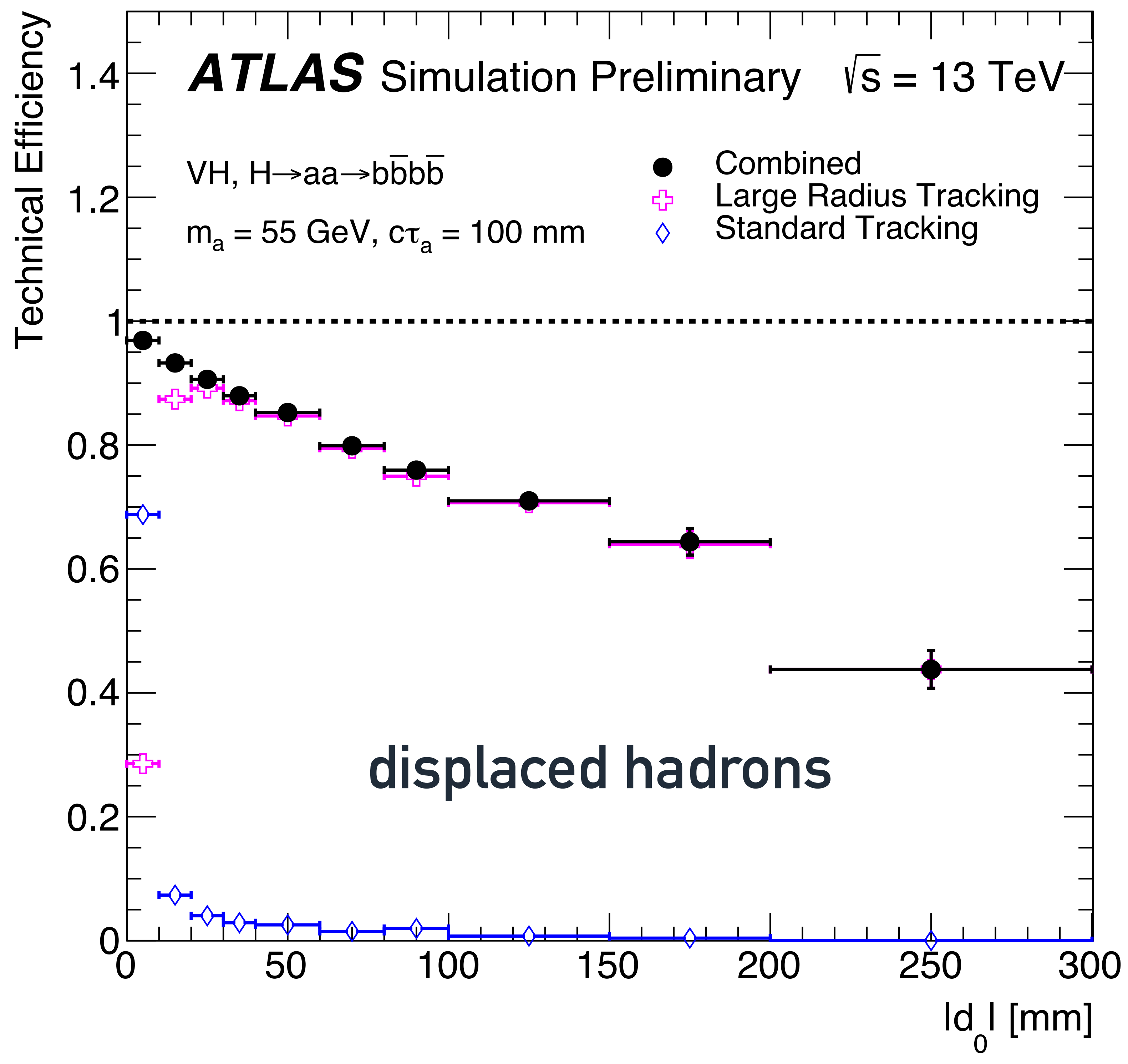
LLP Reconstruction Efficiency

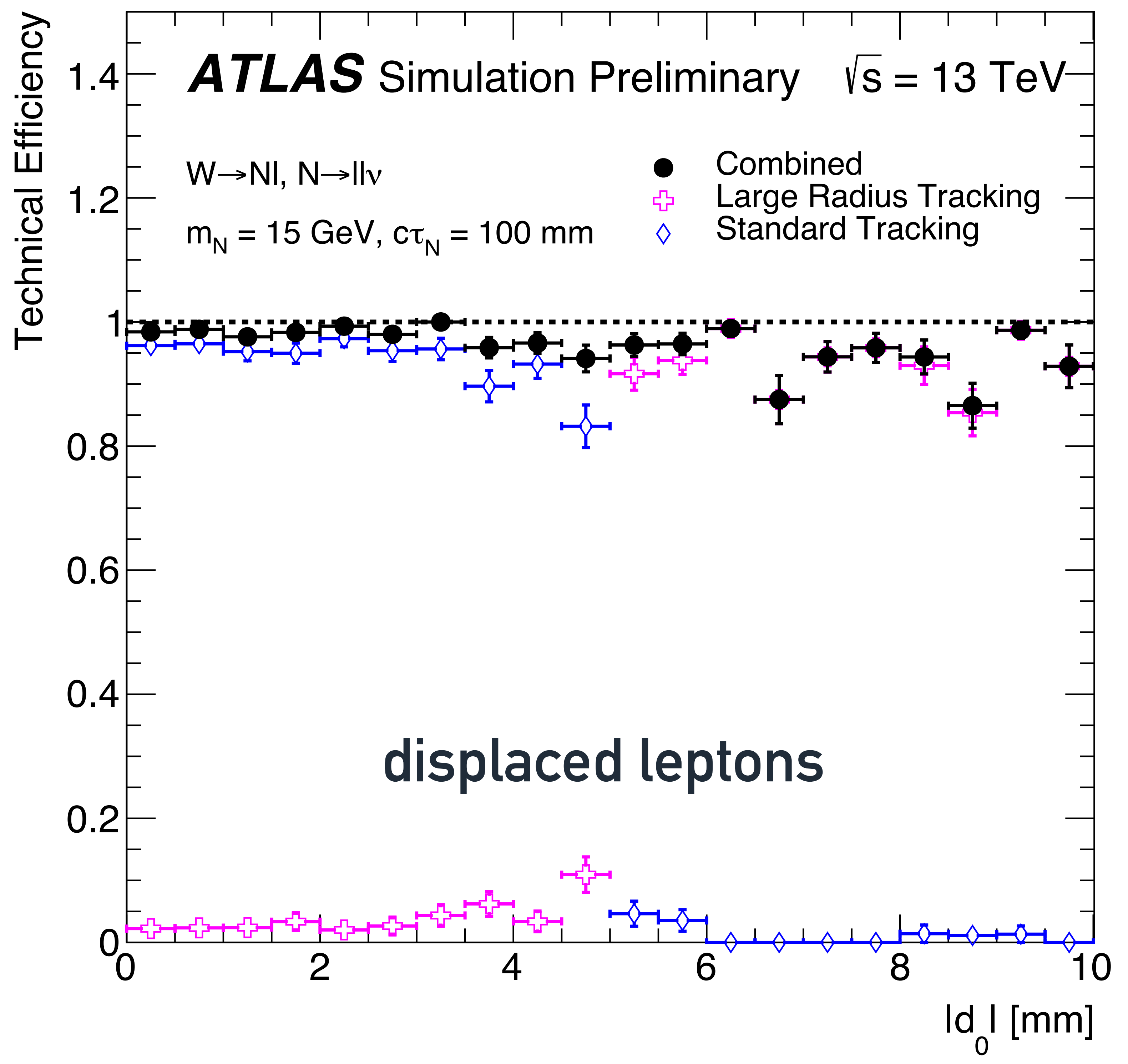
LRT recovers significant loss of standard tracking efficiency for truth particle $|d_0| > 5$ mm

- Technical efficiency: fraction of “reconstructible” truth particles matched to an LRT track
  - Quantifies performance on truth particles that could in principle be reconstructed by LRT

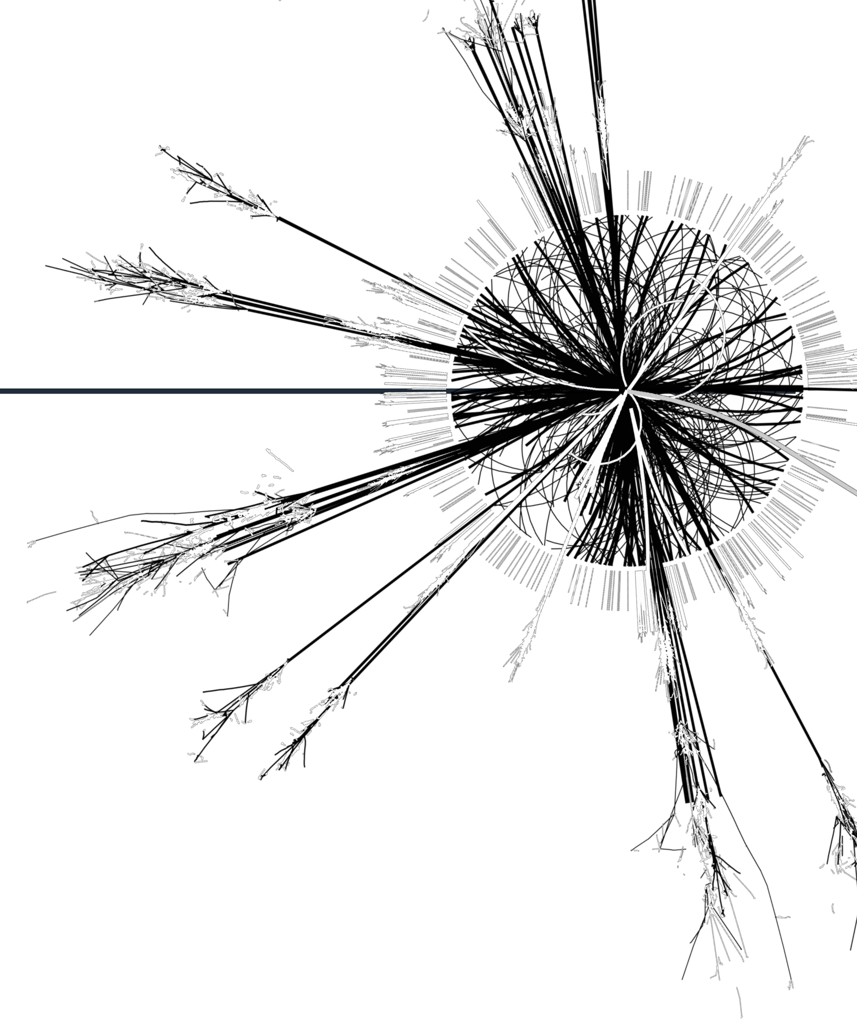
“Reconstructible” truth particle selections

- From LLP decay
- Charge = ± 1
- $r_{\text{prod}} < 440$ mm
- $p_T > 1$ GeV, $|\eta| < 2.5$
- $N_{\text{Si}}^{\text{hits}} \geq 8$





Fake Rate



Many analyses using LRT make use of additional secondary vertex reconstruction algorithms

- Ex: ATL-PHYS-PUB-2019-013

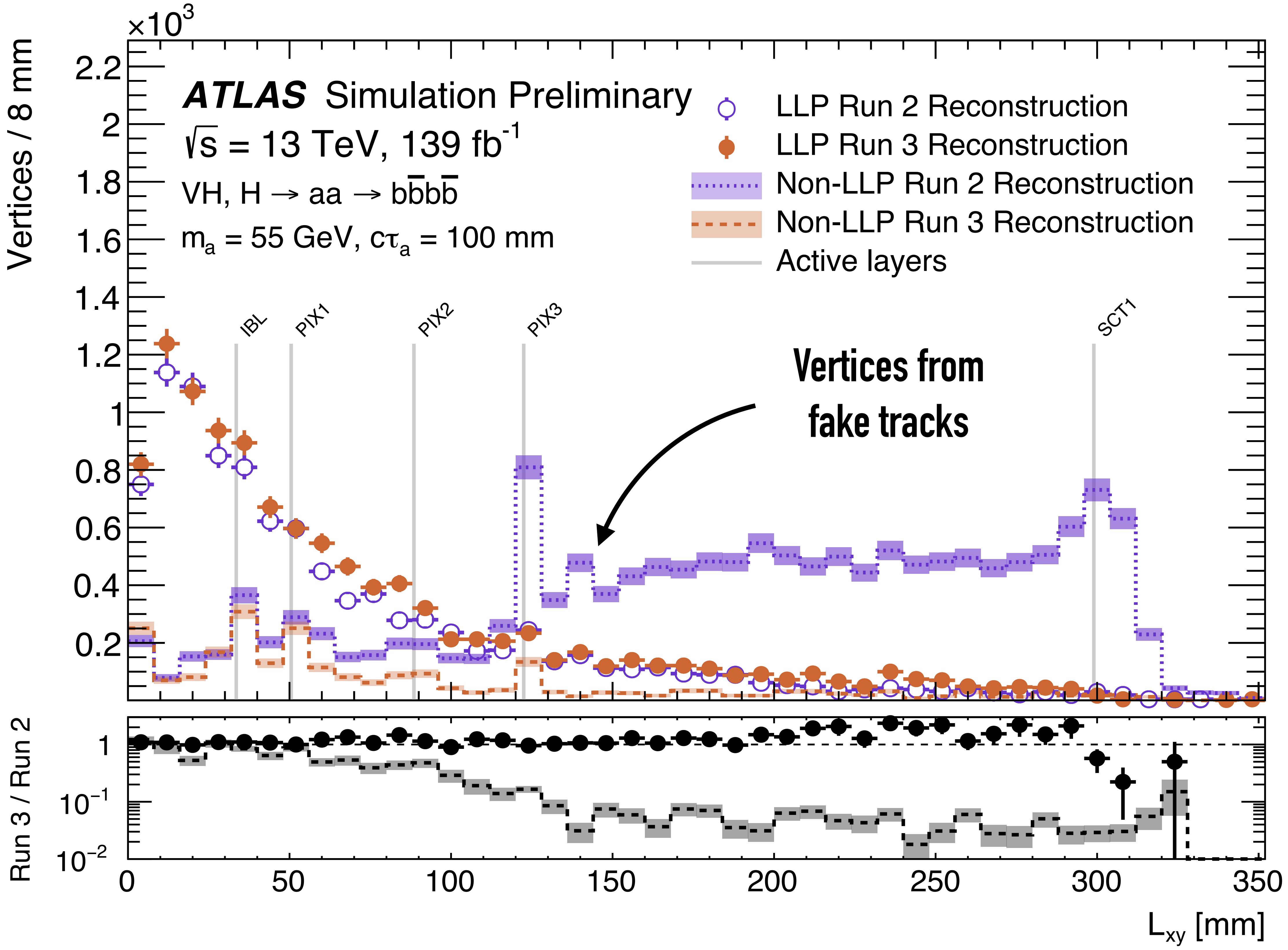
Large number of LRT fakes → large fake vertex backgrounds

- For light LLP signatures, these fake vertices can be challenging to reject

Run 3 LRT configuration gives rise to ~10x fewer fake vertices

- Despite tighter LRT cuts, vertex reconstruction efficiency improves due to cleaner vertexing environment

Large analysis gains expected!



Data vs MC agreement

Comparisons performed between "zero-bias" data and simulated samples of inelastic pp scattering events

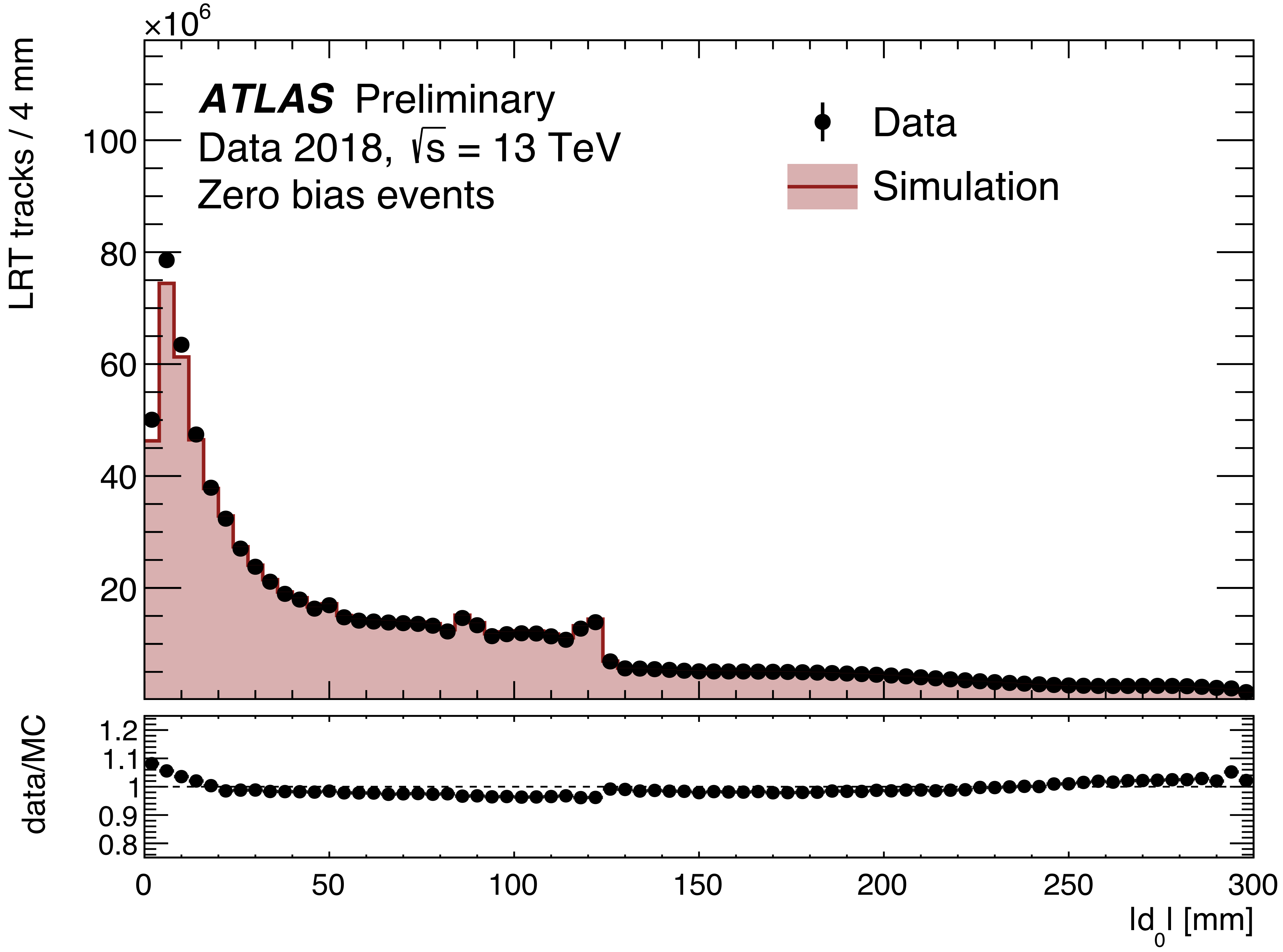
- Inclusive, unbiased sample to probe LRT performance

Simulation is normalized to data by the total number of reconstructed LRT tracks

LRT $|d_0|$ distribution well modelled in simulation

- Features coinciding with active material layers observed in both samples

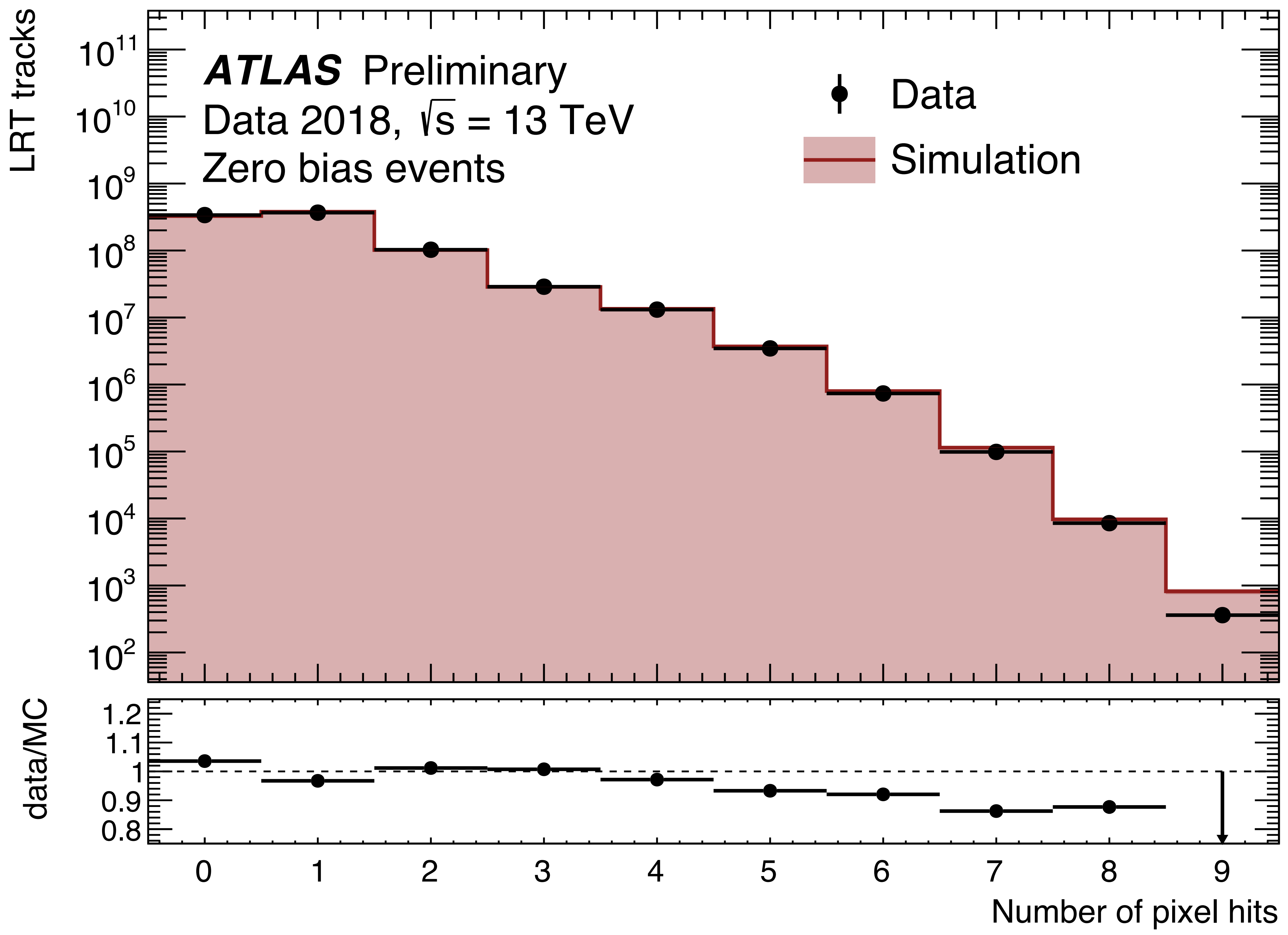
  → Corresponds with low-p_T particles produced in secondary material interactions

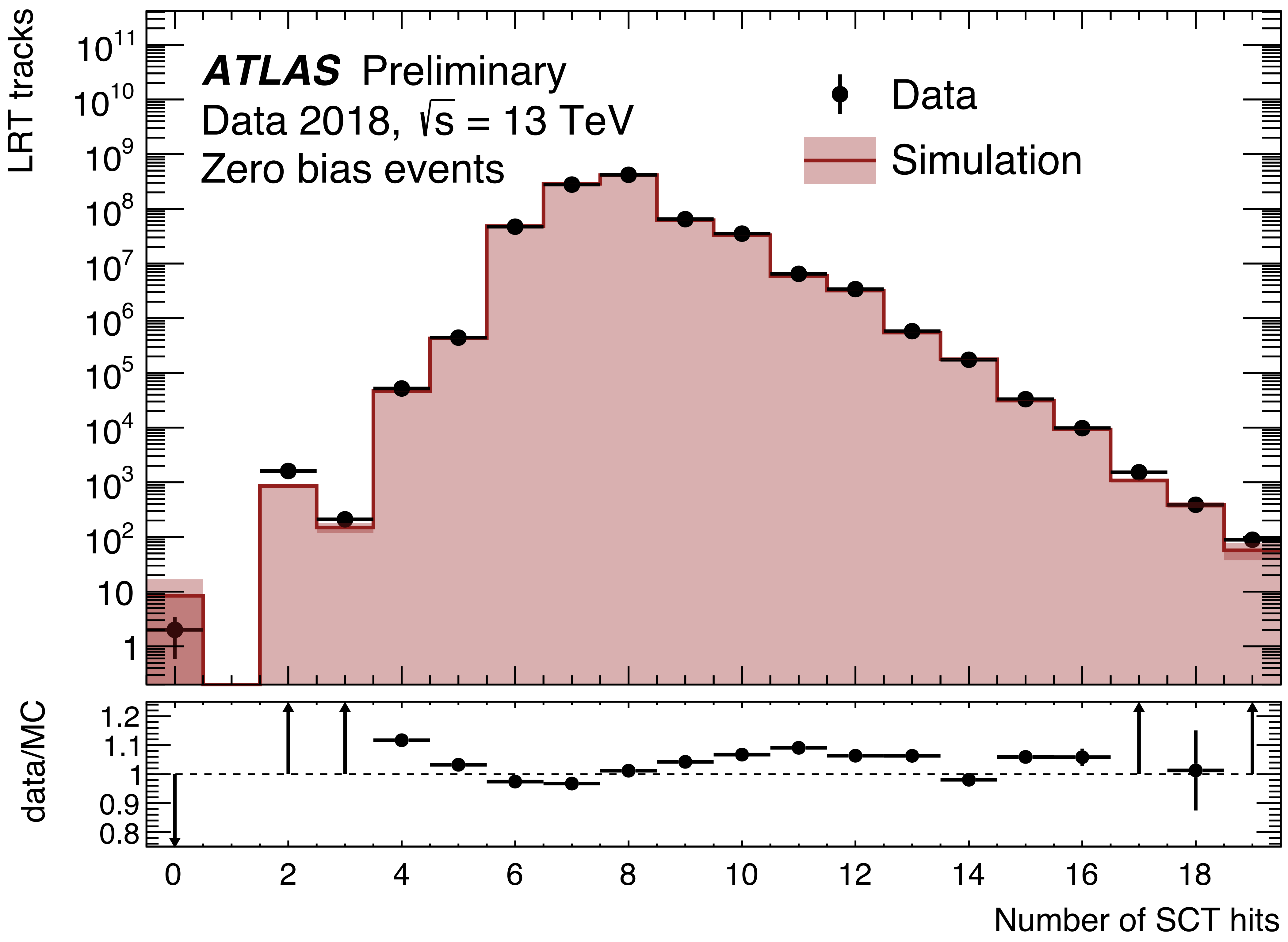


Data vs MC agreement

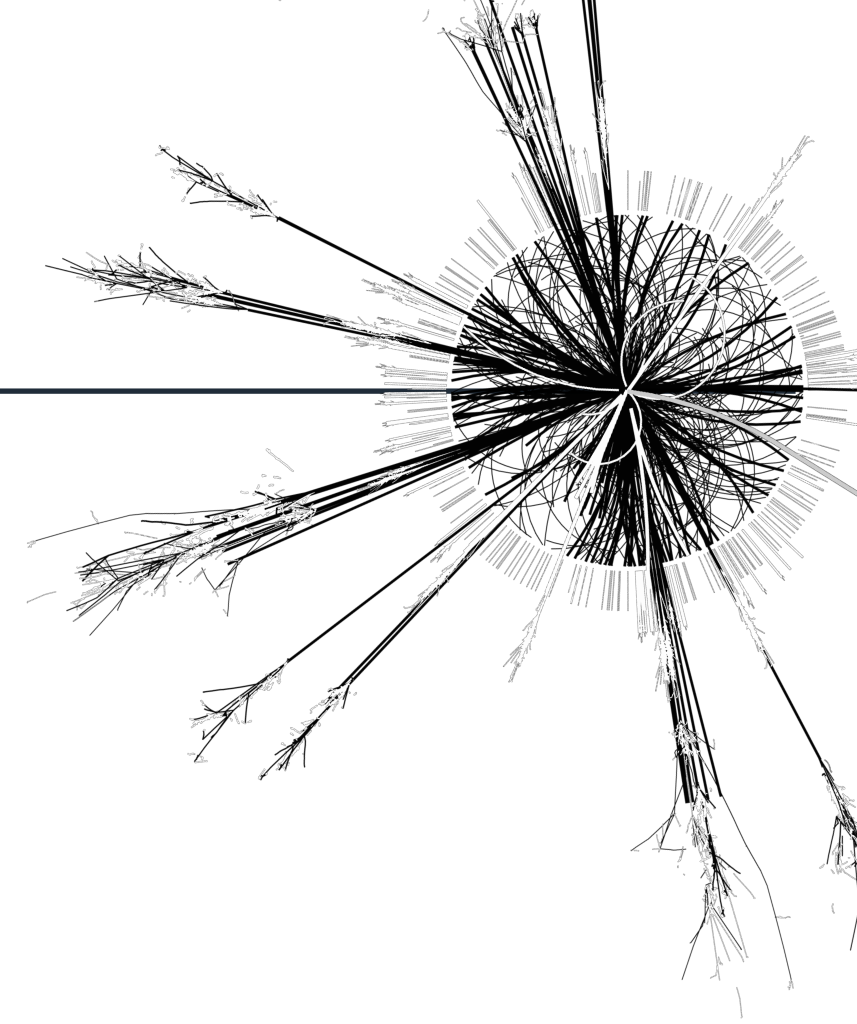
LRT pixel and SCT hit distributions well modelled in simulation

- Promising as prospective input for low-level LLP taggers





Data vs MC agreement



To probe LRT efficiency in data, need a “standard candle”

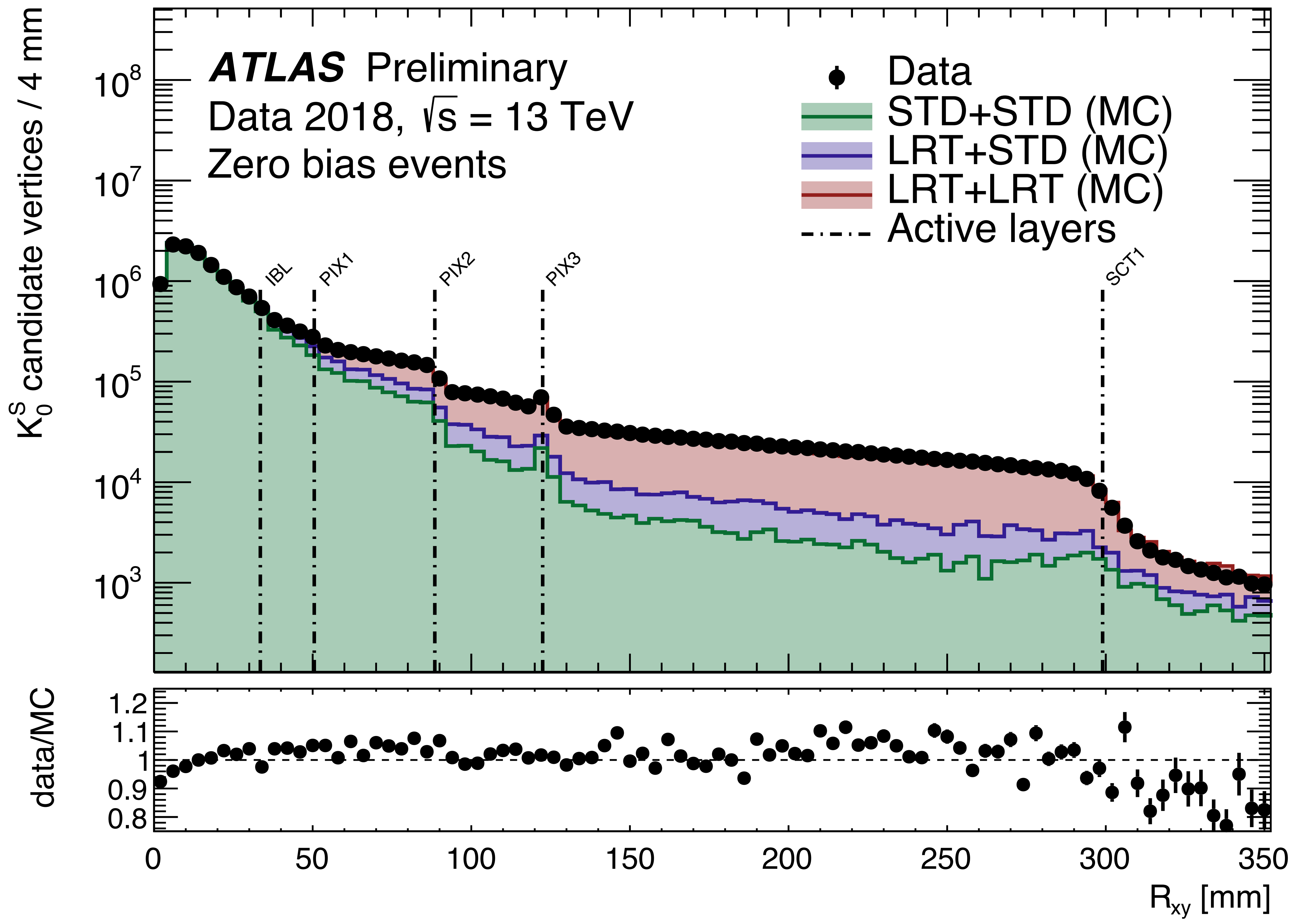
- K_0^S decays are an ideal candidate: $c\tau = 27 \text{ mm}$

Identify K_0^S decays by reconstructing 2-track vertices using combined collection of standard + LRT tracks

- K_0^S candidates selected by requiring $472 \text{ MeV} < m_{\text{vtx}} < 522 \text{ MeV}$
- No additional background rejection or subtraction performed

After normalizing MC to data, distributions show excellent agreement

- Indicates that LRT efficiency in data closely matches MC performance



Data vs MC agreement

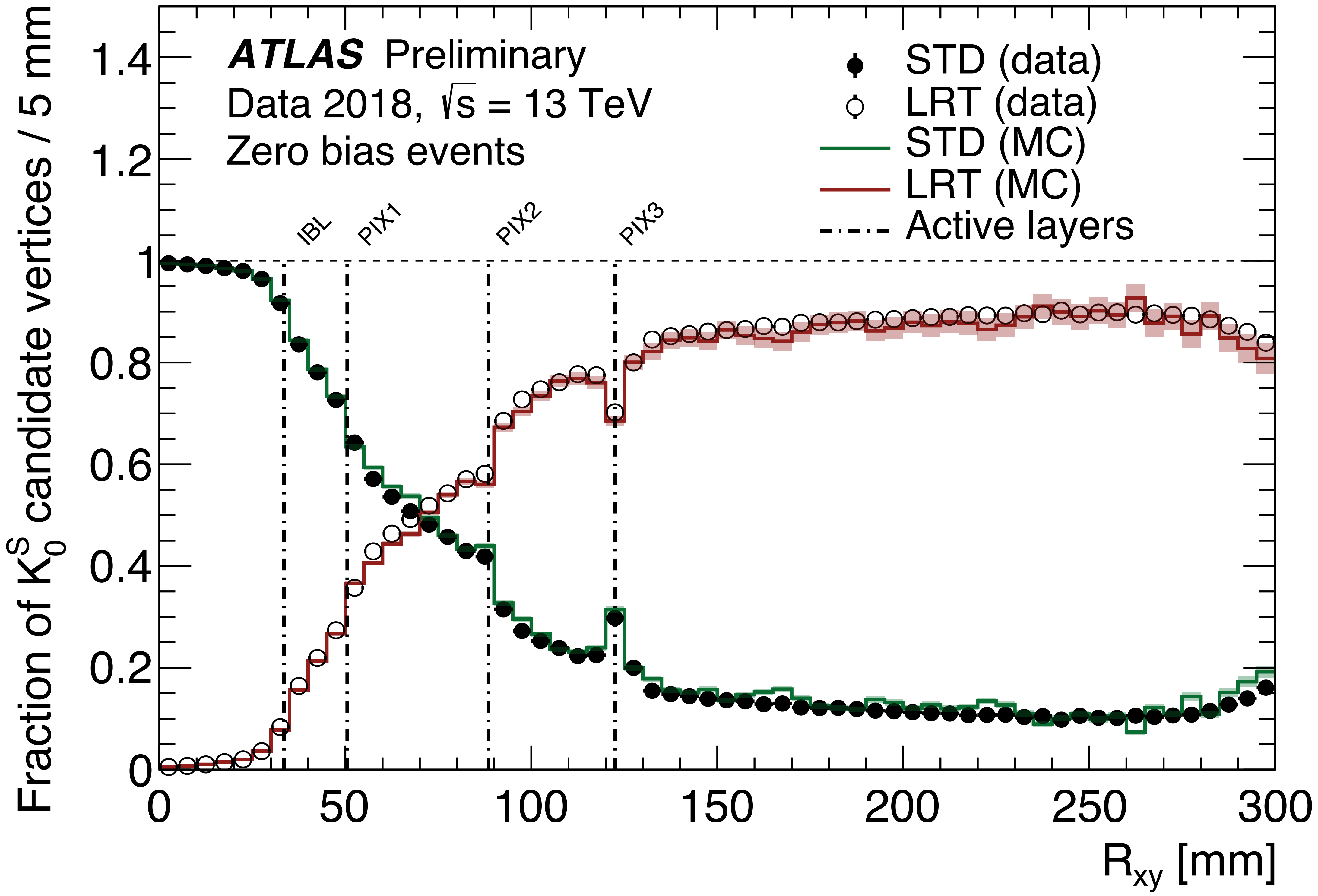
Compare fractions of K_0^S vertices with 0 or 1+ LRT tracks

- LRT brings clear benefits for displaced decays in data with $R_{xy} \gtrsim 30$ mm
- Outside the 3rd Pixel later, LRT accounts for ~90% of K_0^S vertices

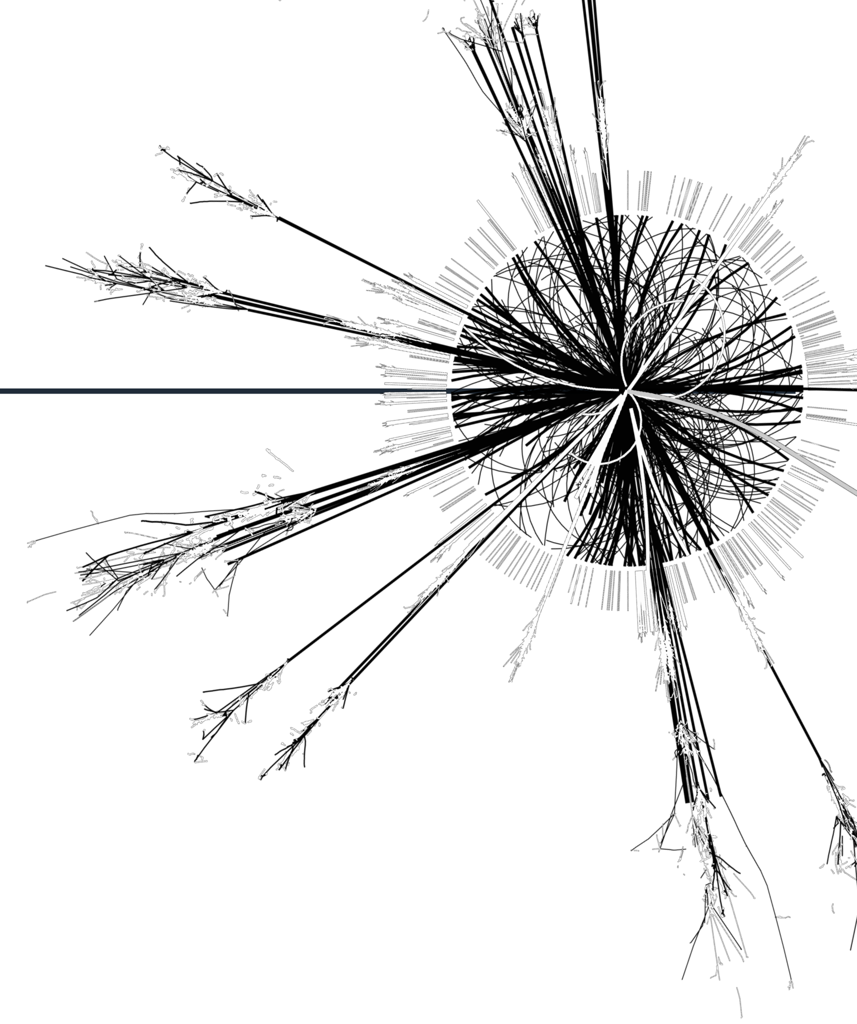
Good agreement once again points to excellent LRT modelling!

- No indication of systematic differences between data and MC

Work to derive systematic uncertainties on LRT efficiency ongoing



Conclusion



Large radius tracking has been completely overhauled in preparation for Run III

- 95% reduction in fakes with only 10-15% reduction in efficiency

Speedup allows for LRT to be included in the standard ATLAS reconstruction chain

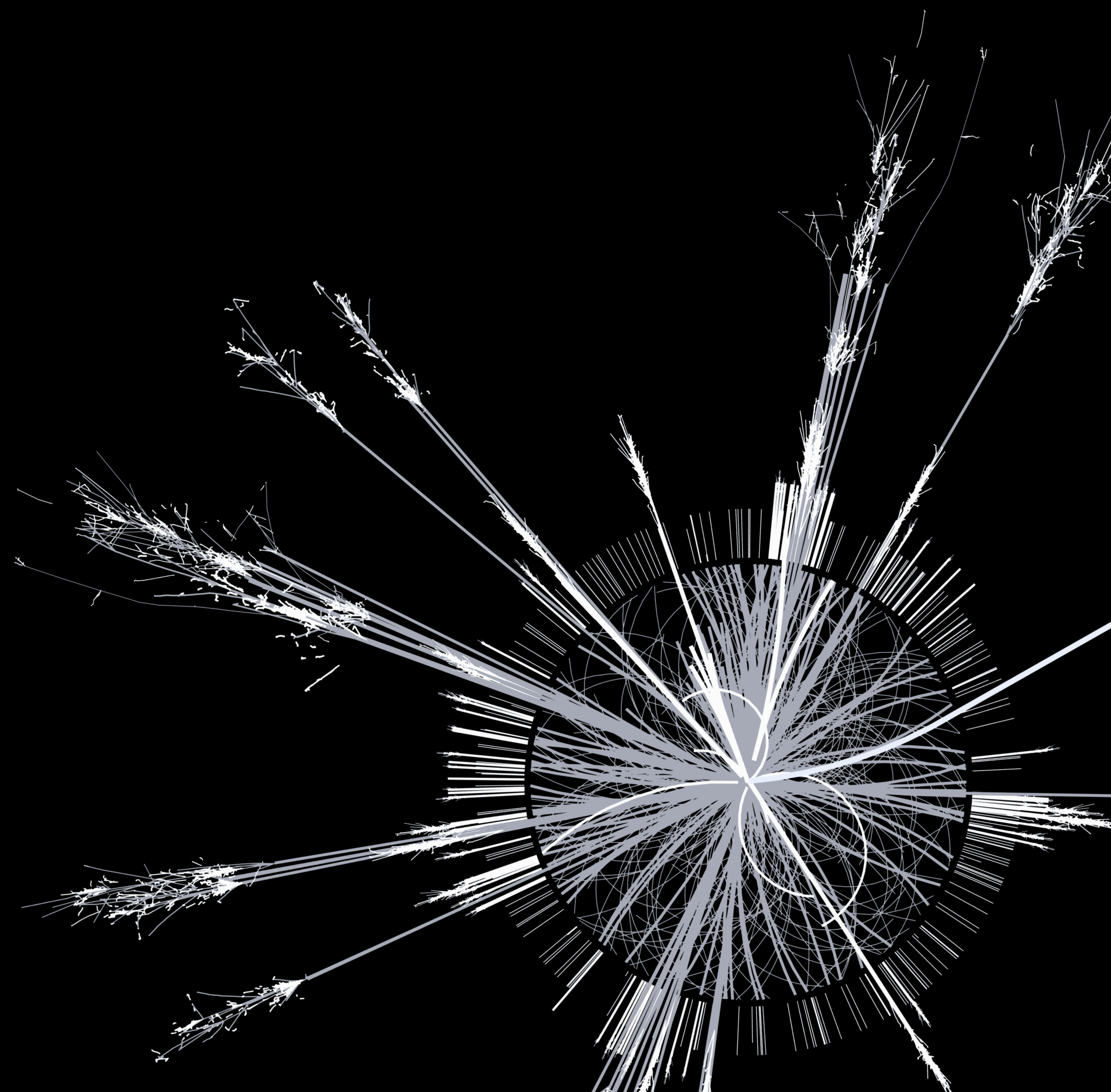
- Significantly simplifies workflow for LLP analyses
- Allows non-LLP analyses to also benefit from LRT

Data/MC comparisons show good modelling of low-level track quantities

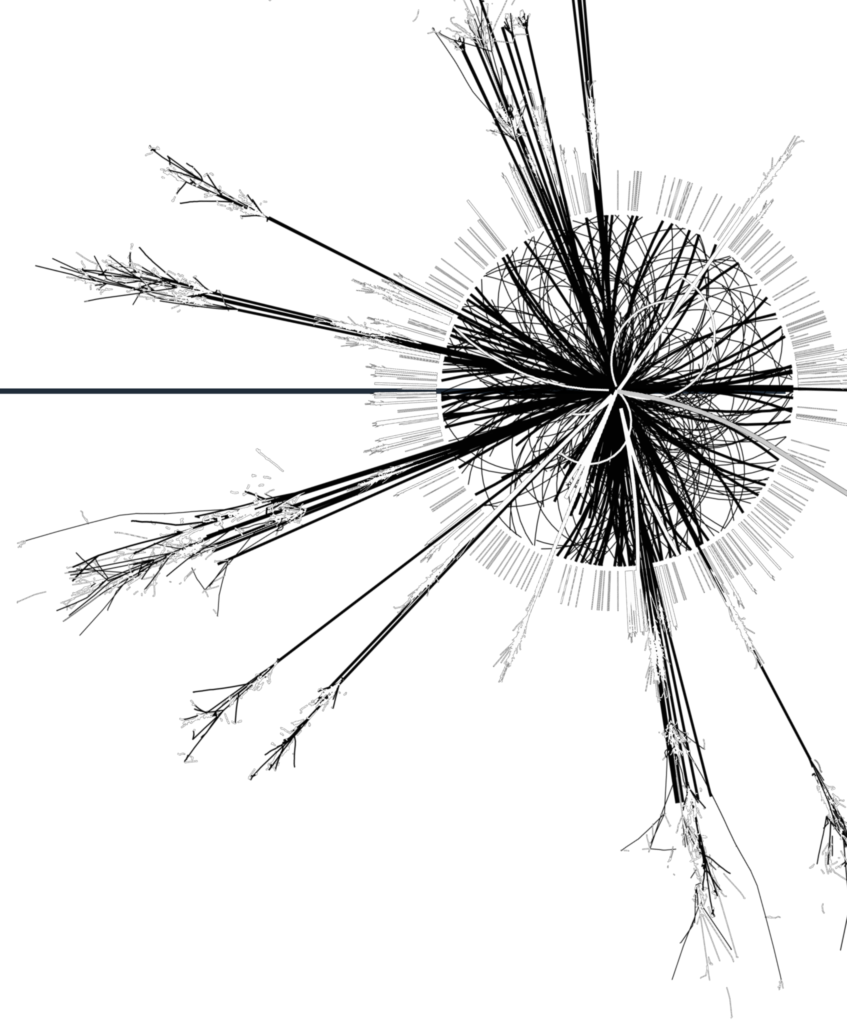
Updates will revolutionize the ATLAS LLP search program

- Improved performance, increased flexibility, more physics!

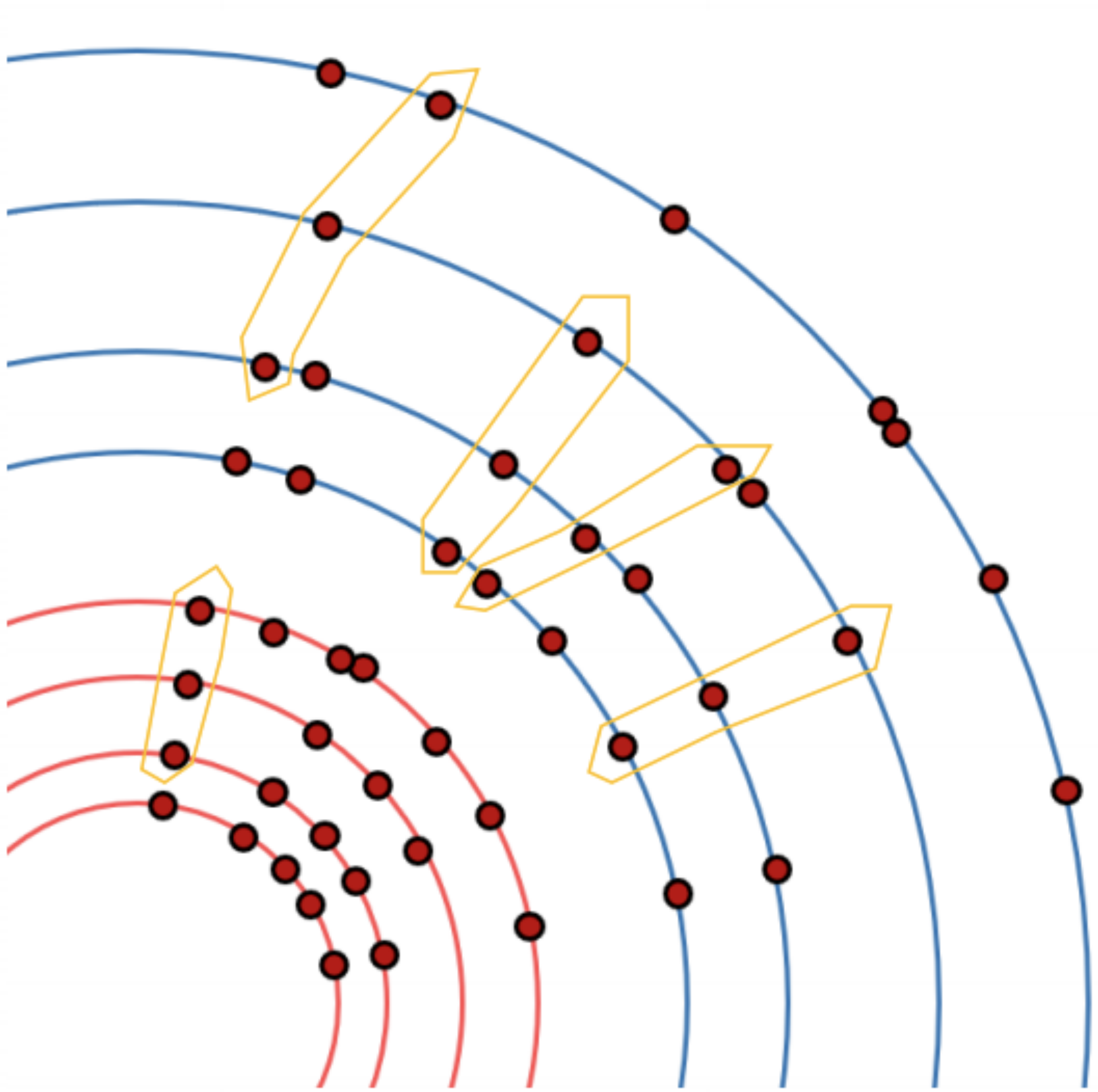
Backup



ATLAS Tracking Overview



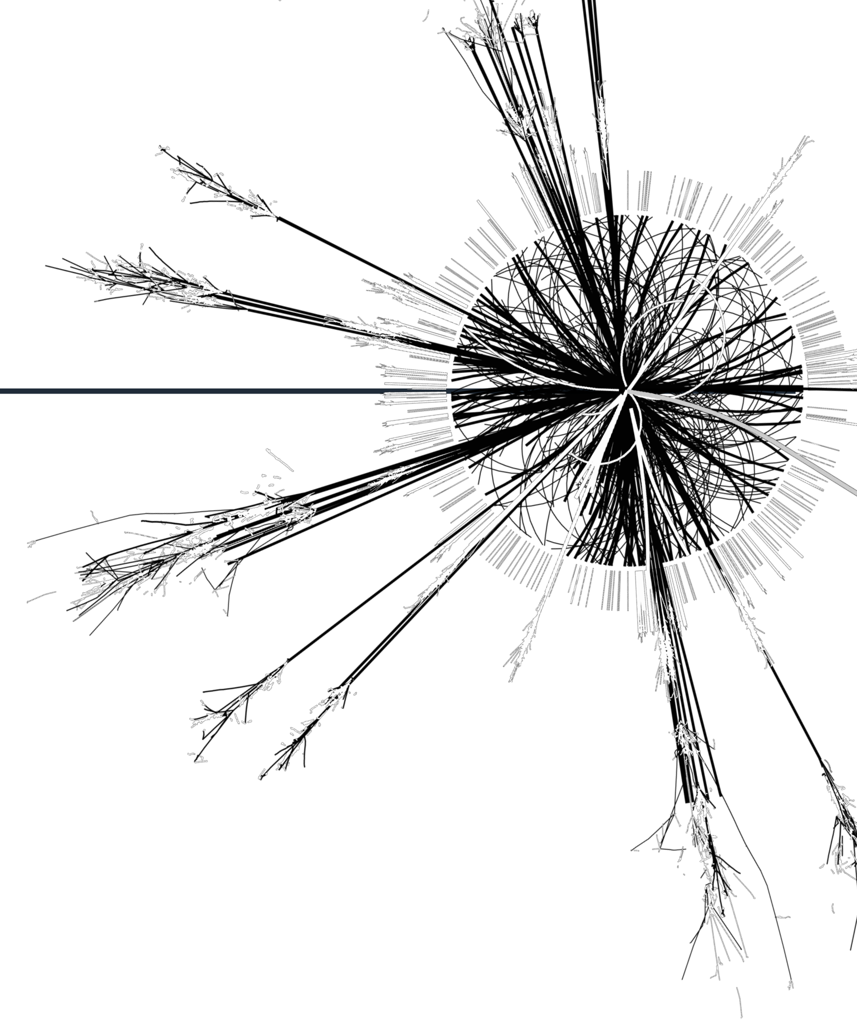
1. Form track seeds consisting of triplets of space-points (SP) in the either the Pixel or SCT subdetectors which are compatible with originating from a charged particle track
    - Loose selection criteria applied to improve computational time (e.g. $|d_0|$ cuts)

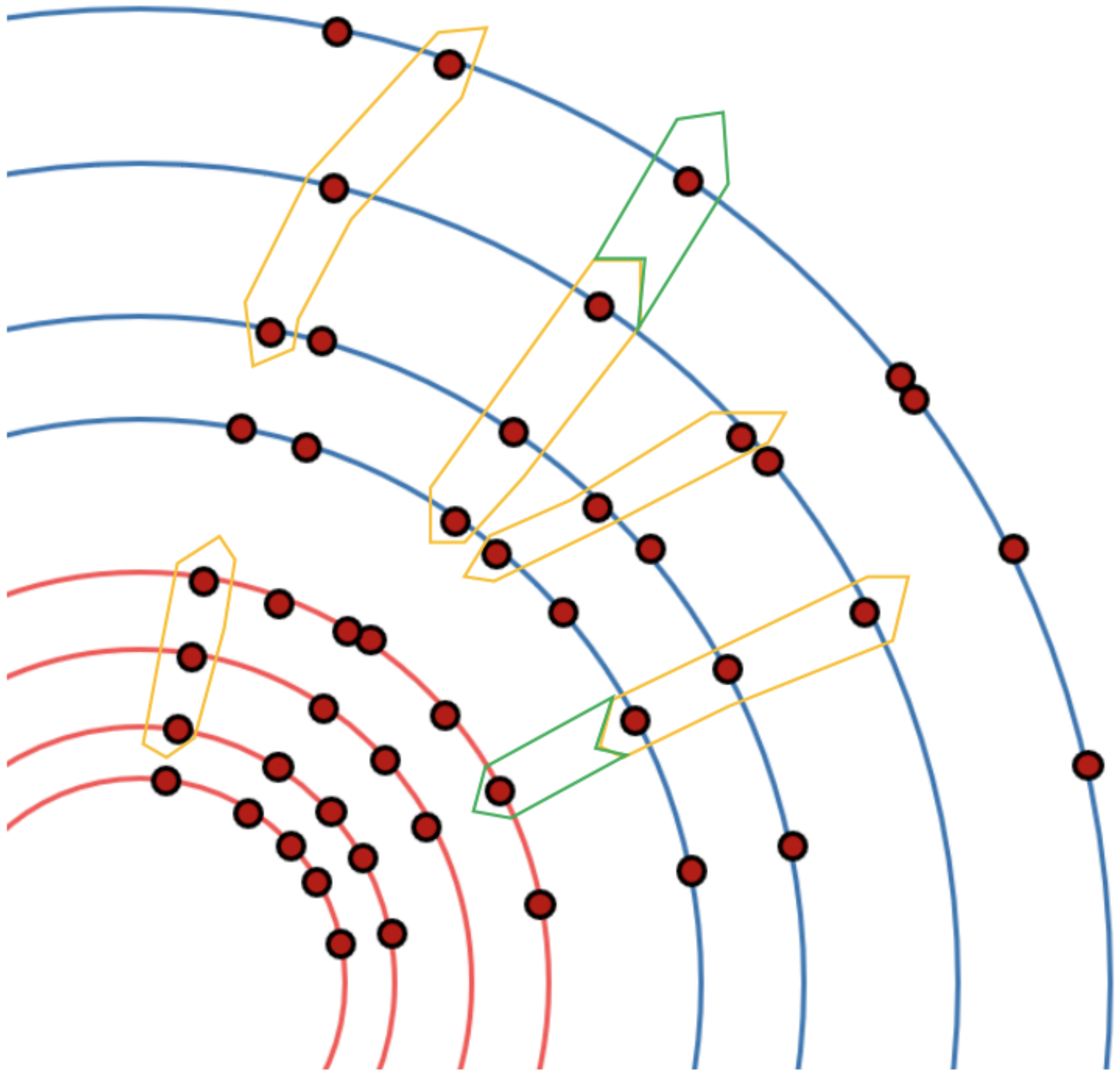


Seed finding

ATLAS Tracking Overview

2. Look for confirmation seeds (i.e. fourth space-point from a different layer)
   - Helps determine order in which seeds are processed downstream





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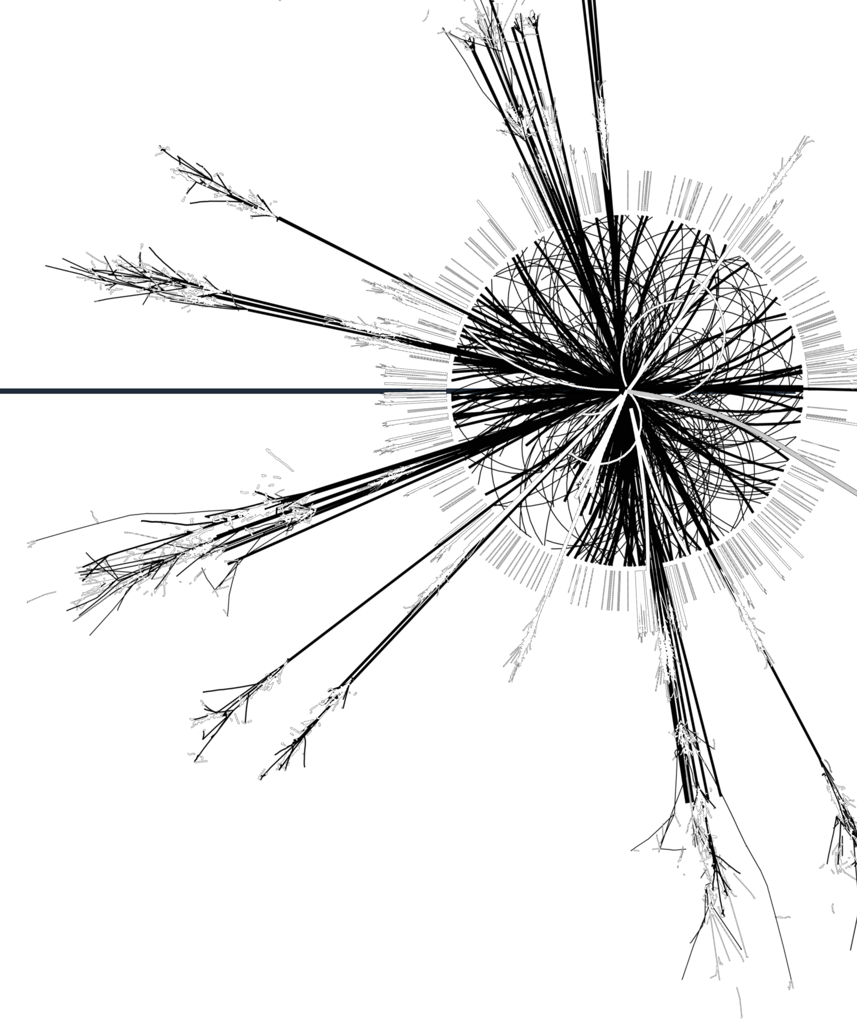
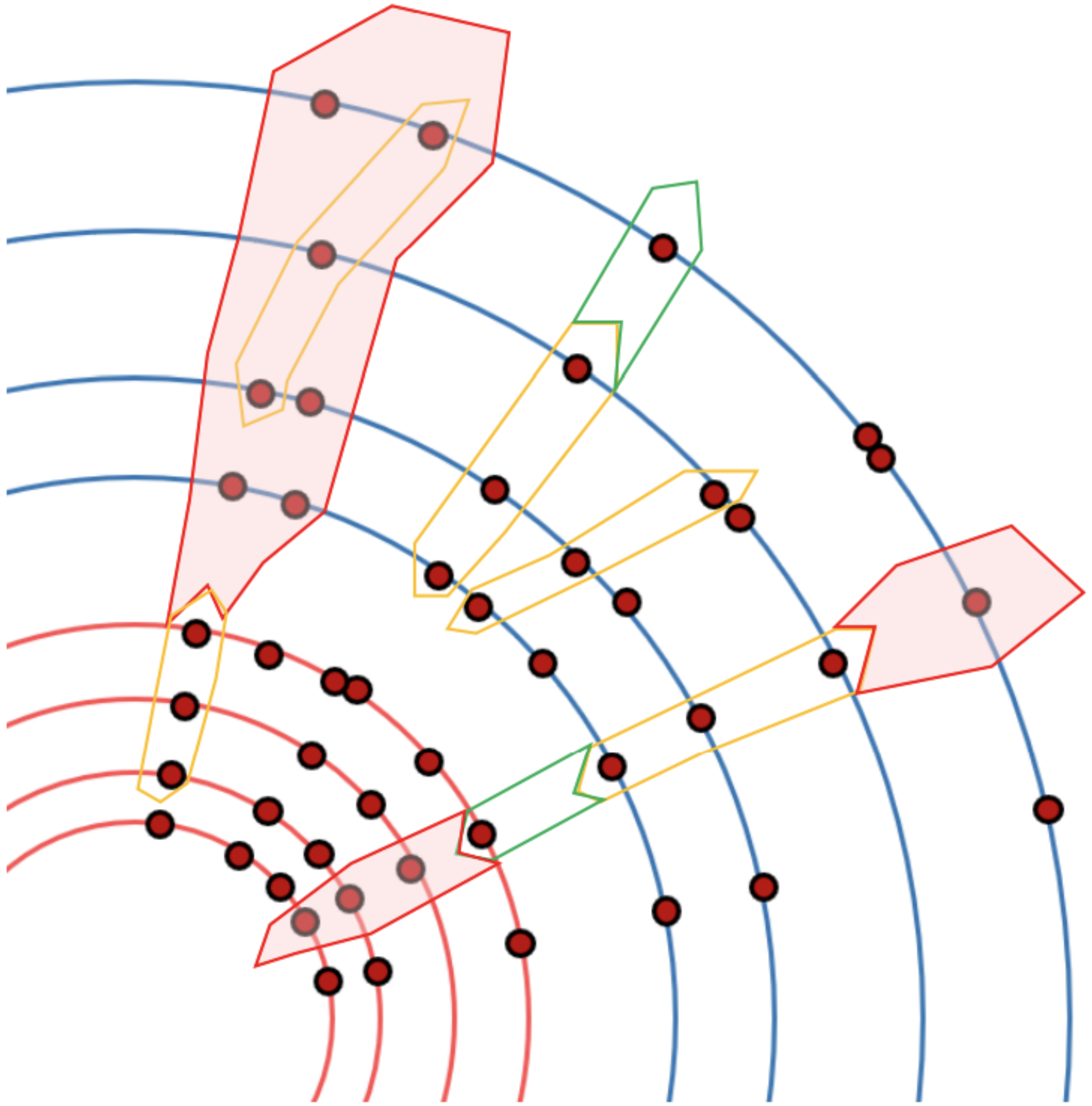
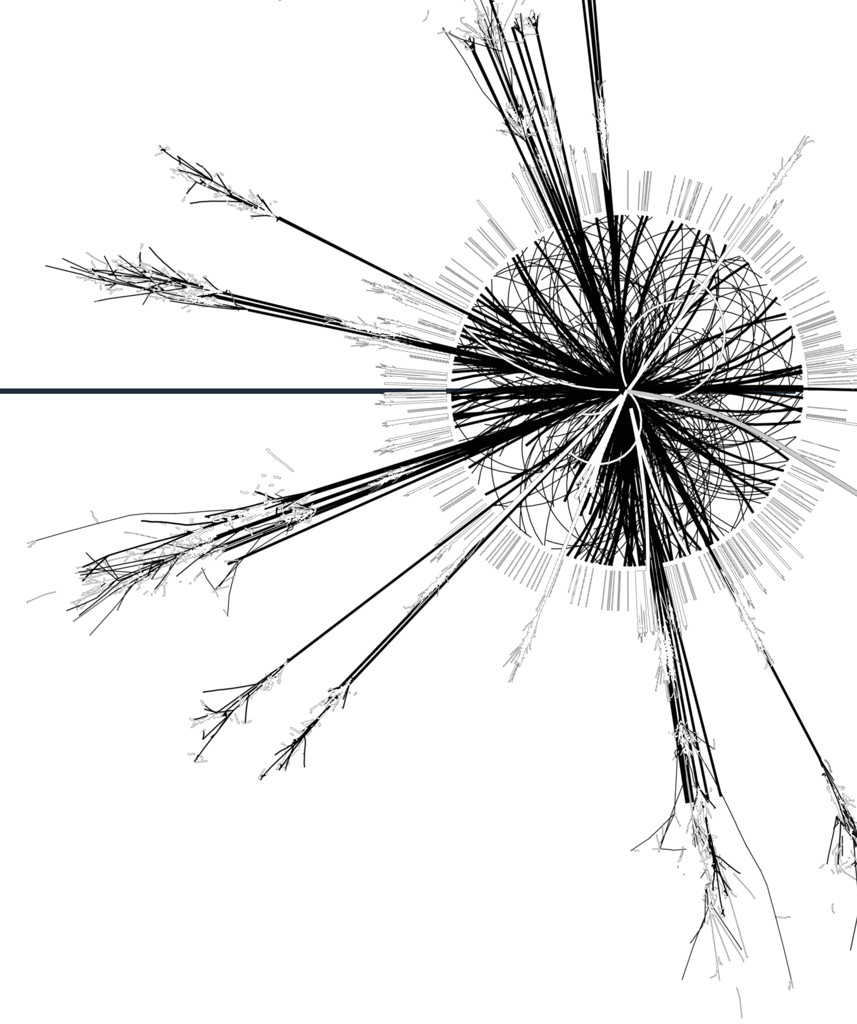


3. Search roads are built through the remaining detector based on the estimated seed trajectory
    - Reduces combinatorics (and thus computational time) as it only considers clusters on a subset of modules in the path of the seed.

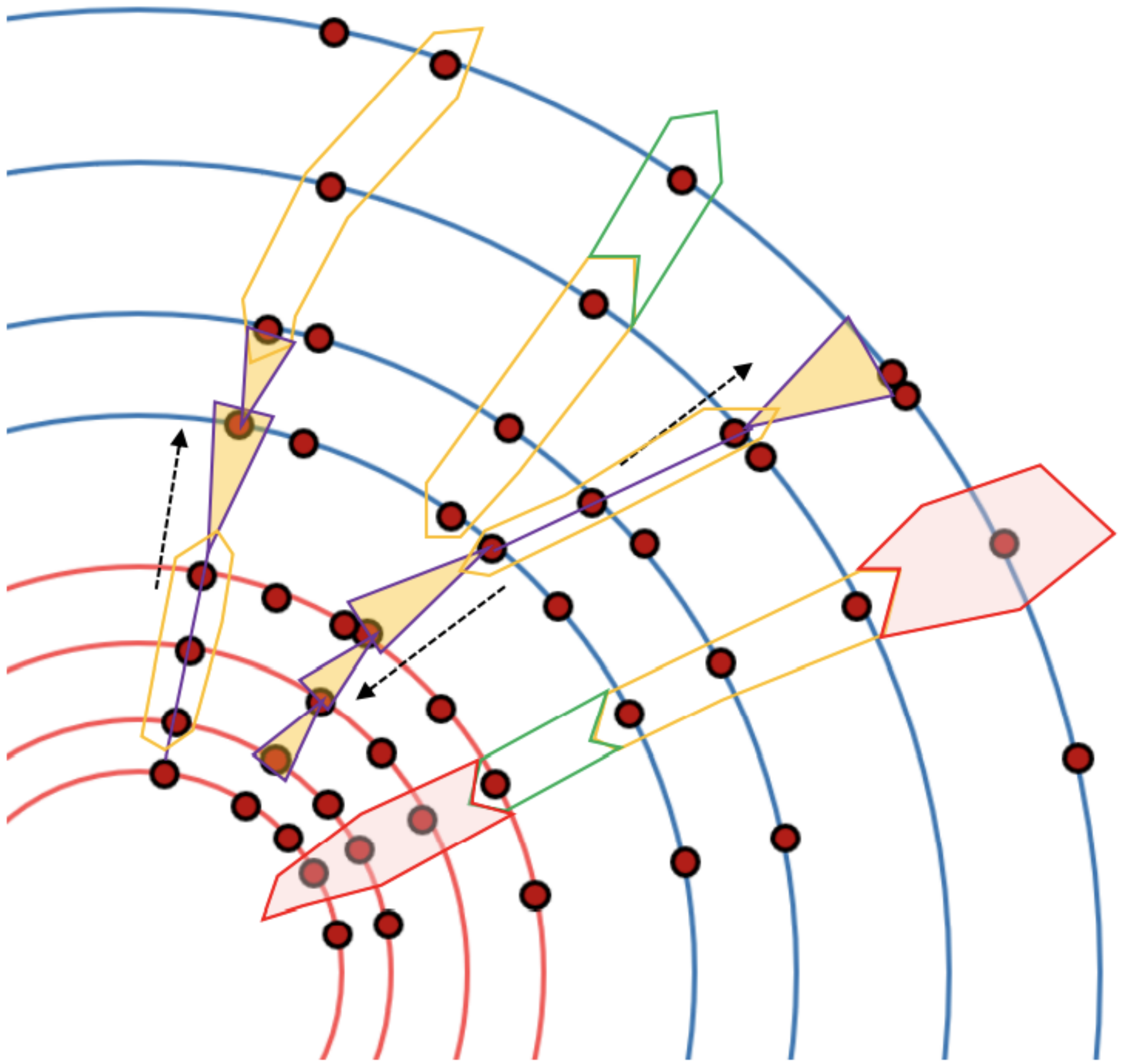


Track finding

ATLAS Tracking Overview



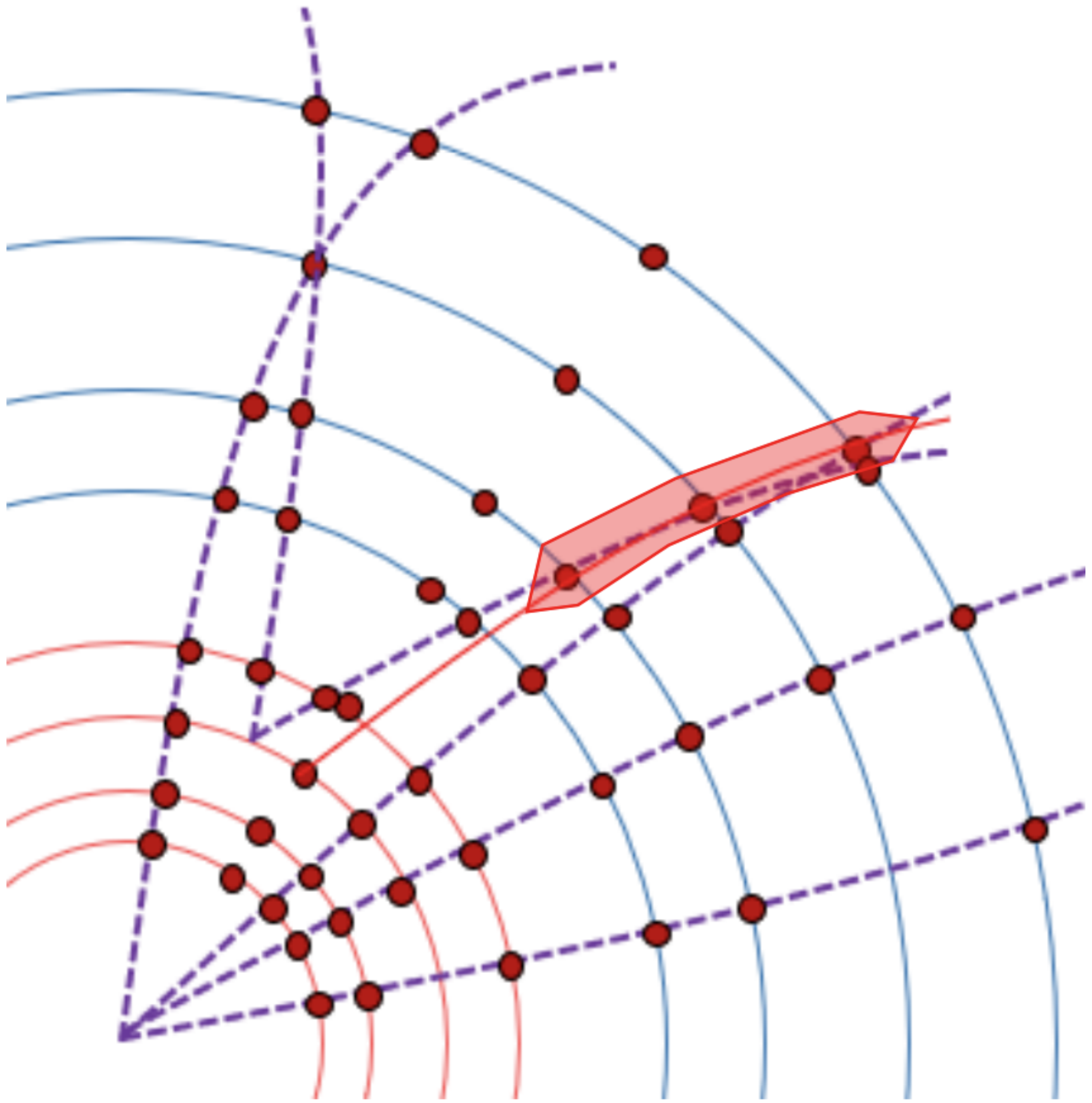
4. Seeds are extended along the search roads through a combinatorial Kalman filter, which searches for adjacent clusters both outwards and inwards in R while attempting to smooth the trajectory



Track finding

ATLAS Tracking Overview

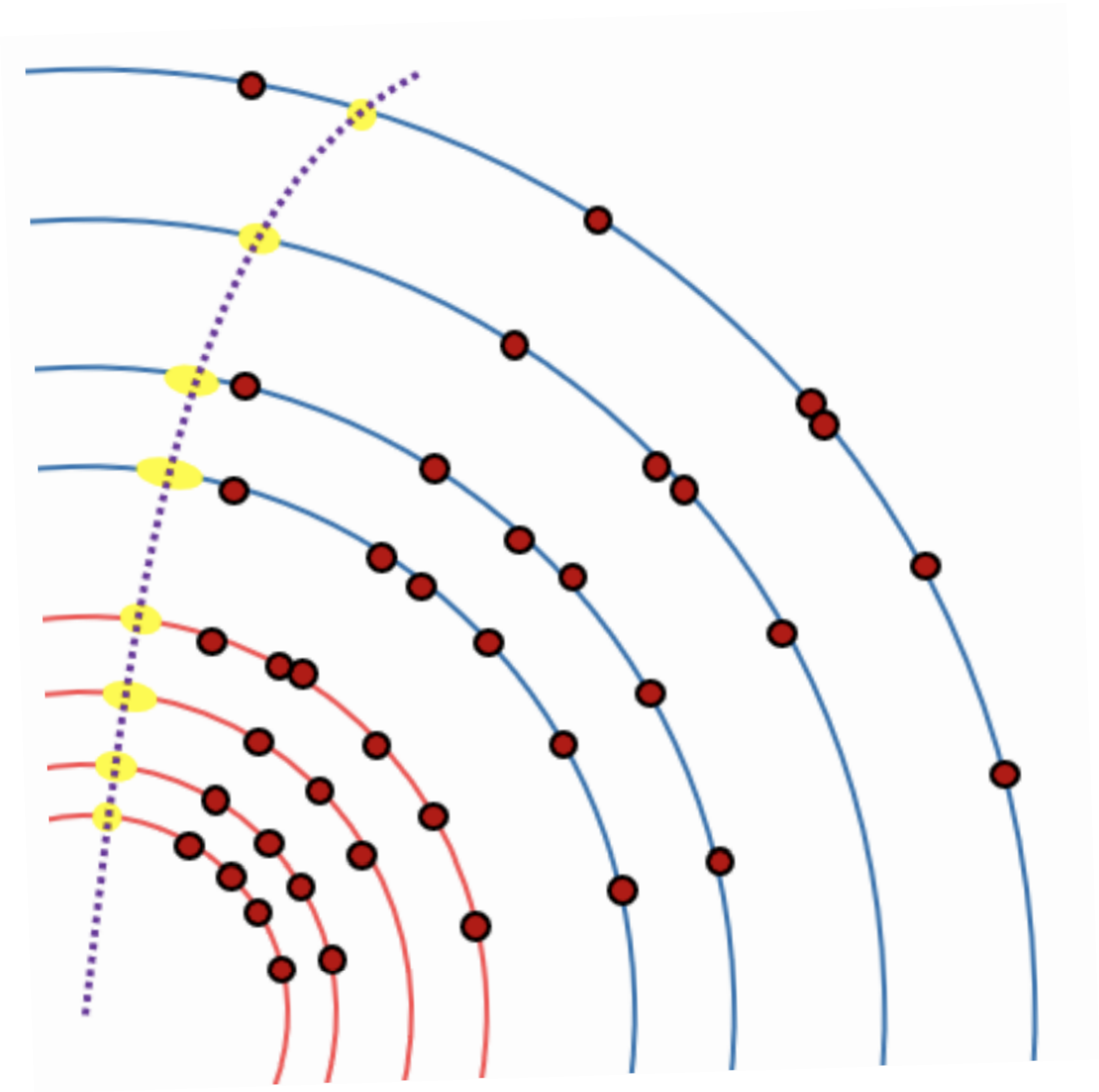
5. End result is a set of potential track candidates that then undergoes further refinement.
    - The the Kalman filter approach is fast, but is relatively imprecise and doesn't resolve ambiguities.



Track finding

ATLAS Tracking Overview

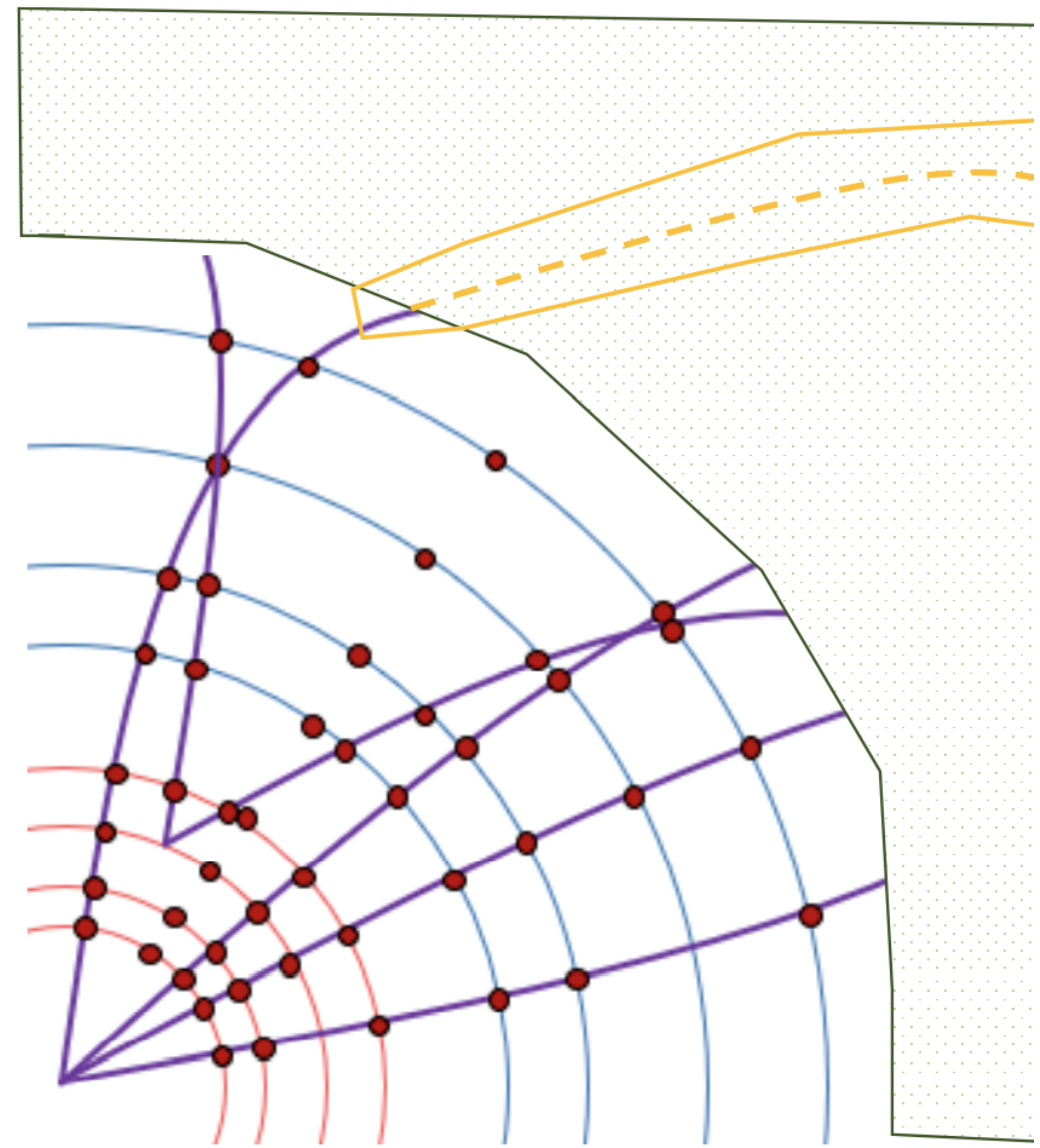
6. Track candidates are scored, and lower-quality candidates sharing a large number of associated hits with higher-quality ones are rejected
   - The refined track candidates are then re-fit using a global χ^2 method to obtain the final track parameter estimate



Ambiguity resolution

ATLAS Tracking Overview

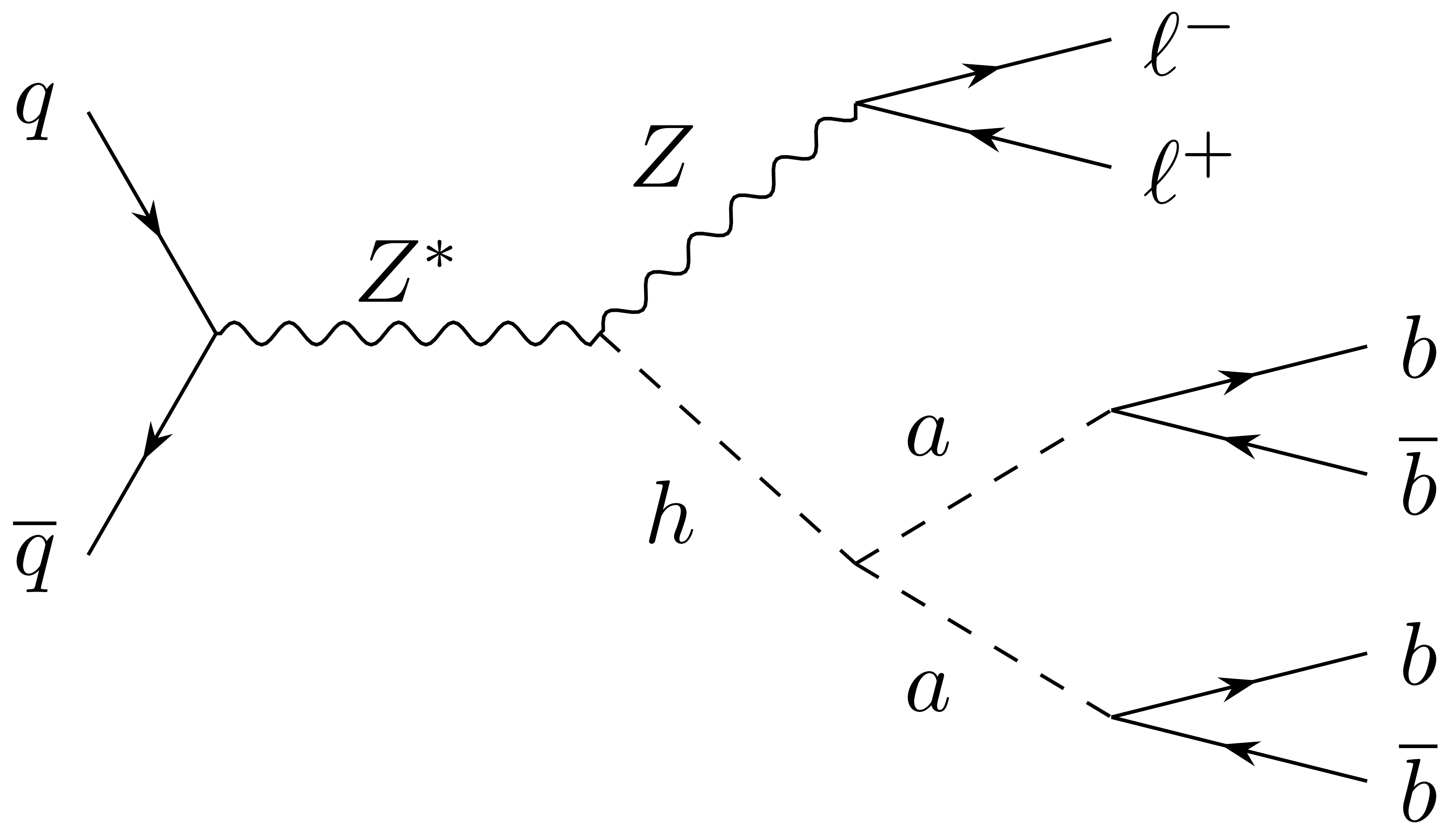
7. TRT hits are added to tracks and the whole tracks are refit if the extension is successful.



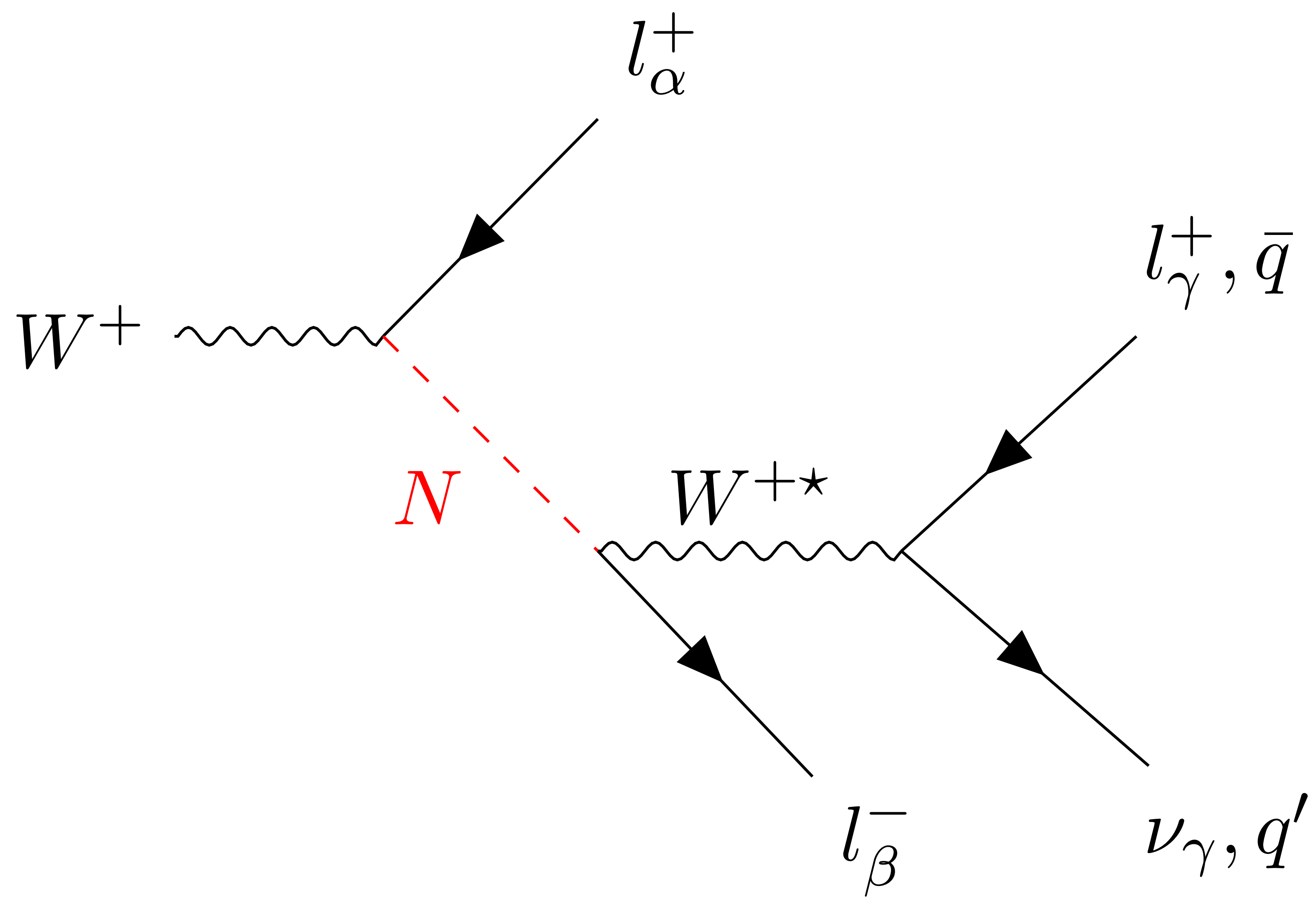
TRT extension

Signal models considered

Displaced hadrons



Displaced leptons



LLP Reconstruction Efficiency

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"Selected" truth particle selections

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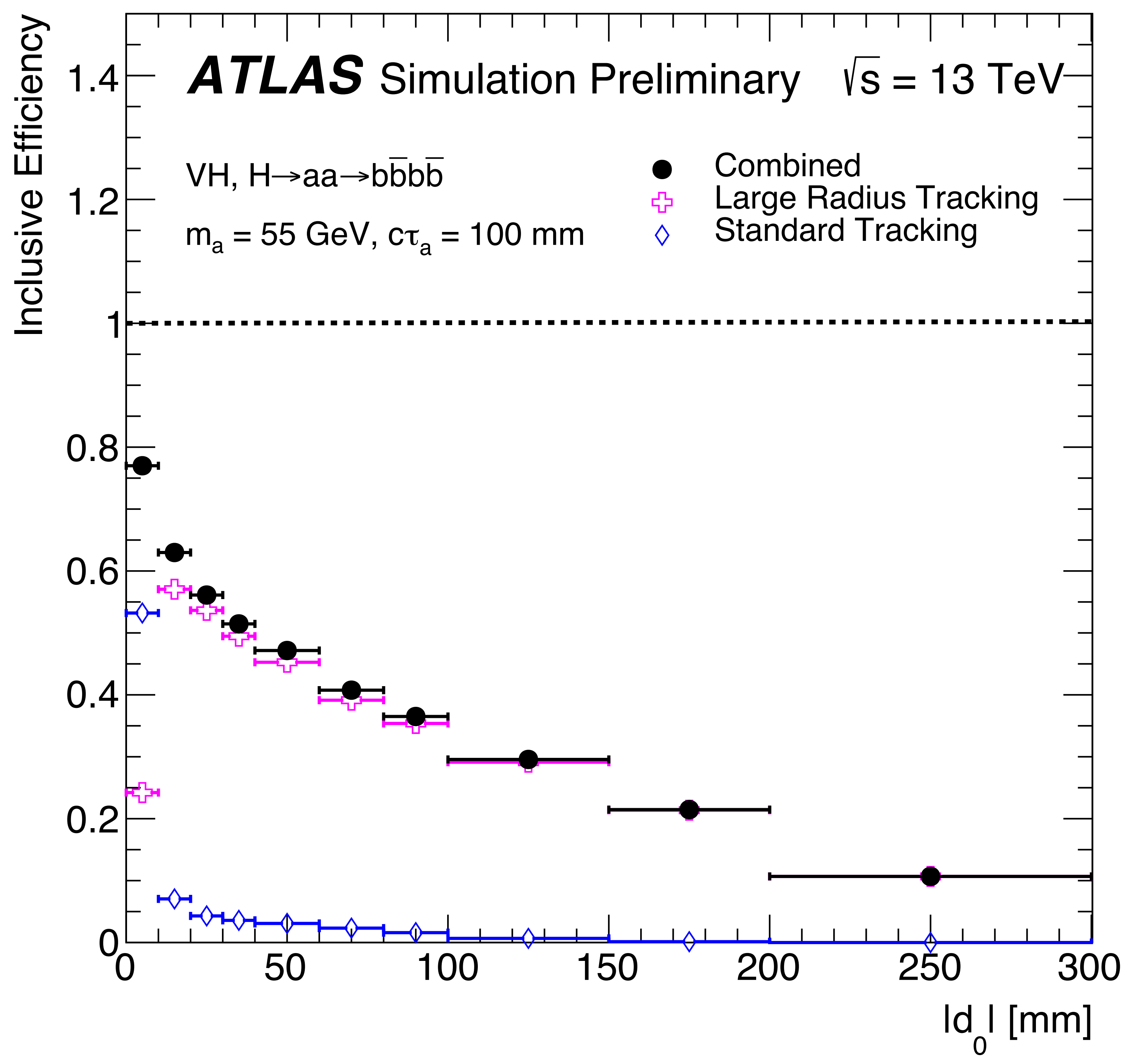
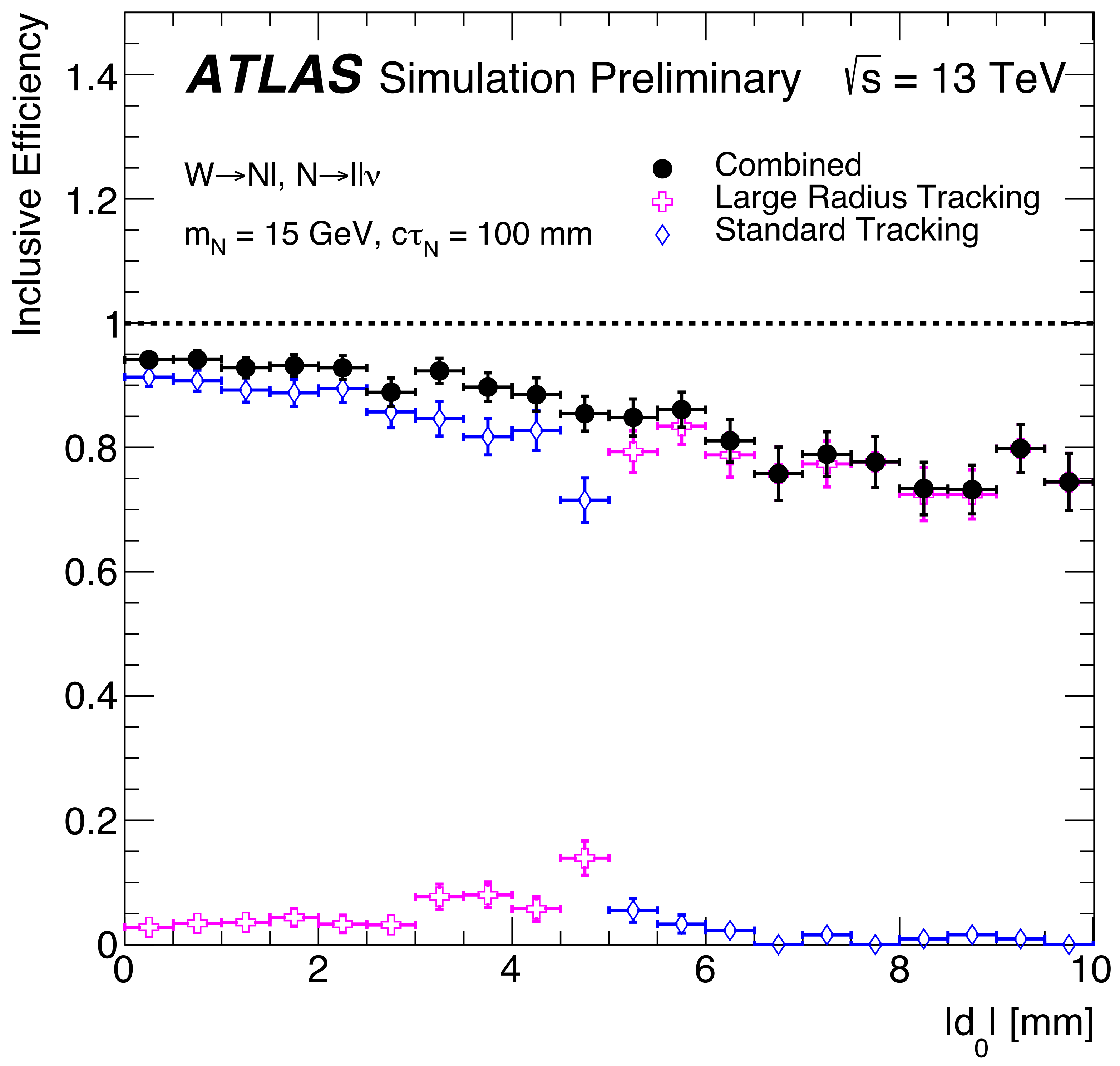
displaced hadrons



displaced leptons



Data vs MC agreement

LRT TRT hit distributions well modelled in simulation