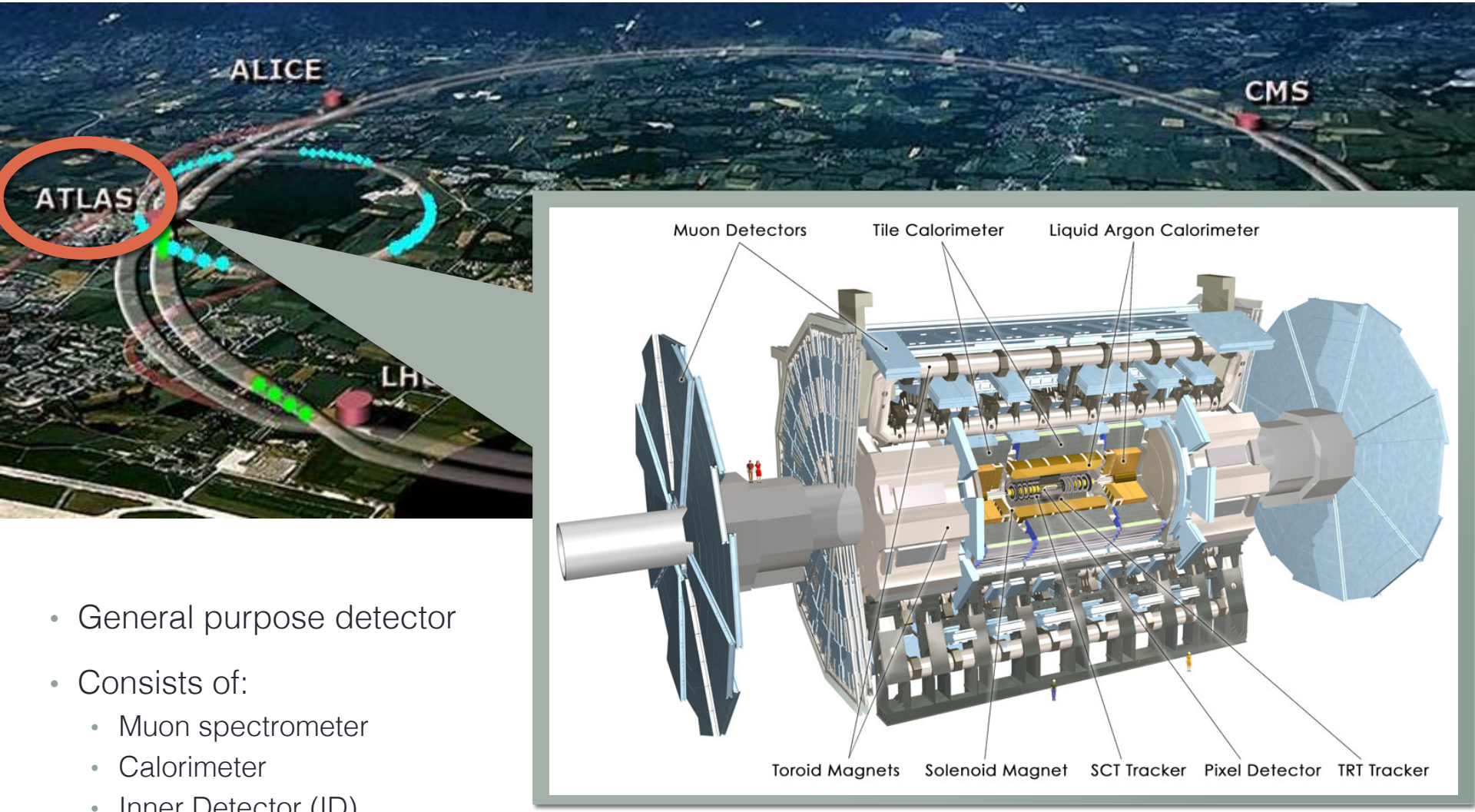
The design and performance of the ATLAS Inner Detector trigger for Run-II

Yang Qin (Quake)

On behalf of the ATLAS Collaboration

ATLAS detector @ LHC



- General purpose detector
- Consists of:
  - Muon spectrometer
  - Calorimeter
  - Inner Detector (ID)
    - ID Provides vital information for charged particle tracking and identification

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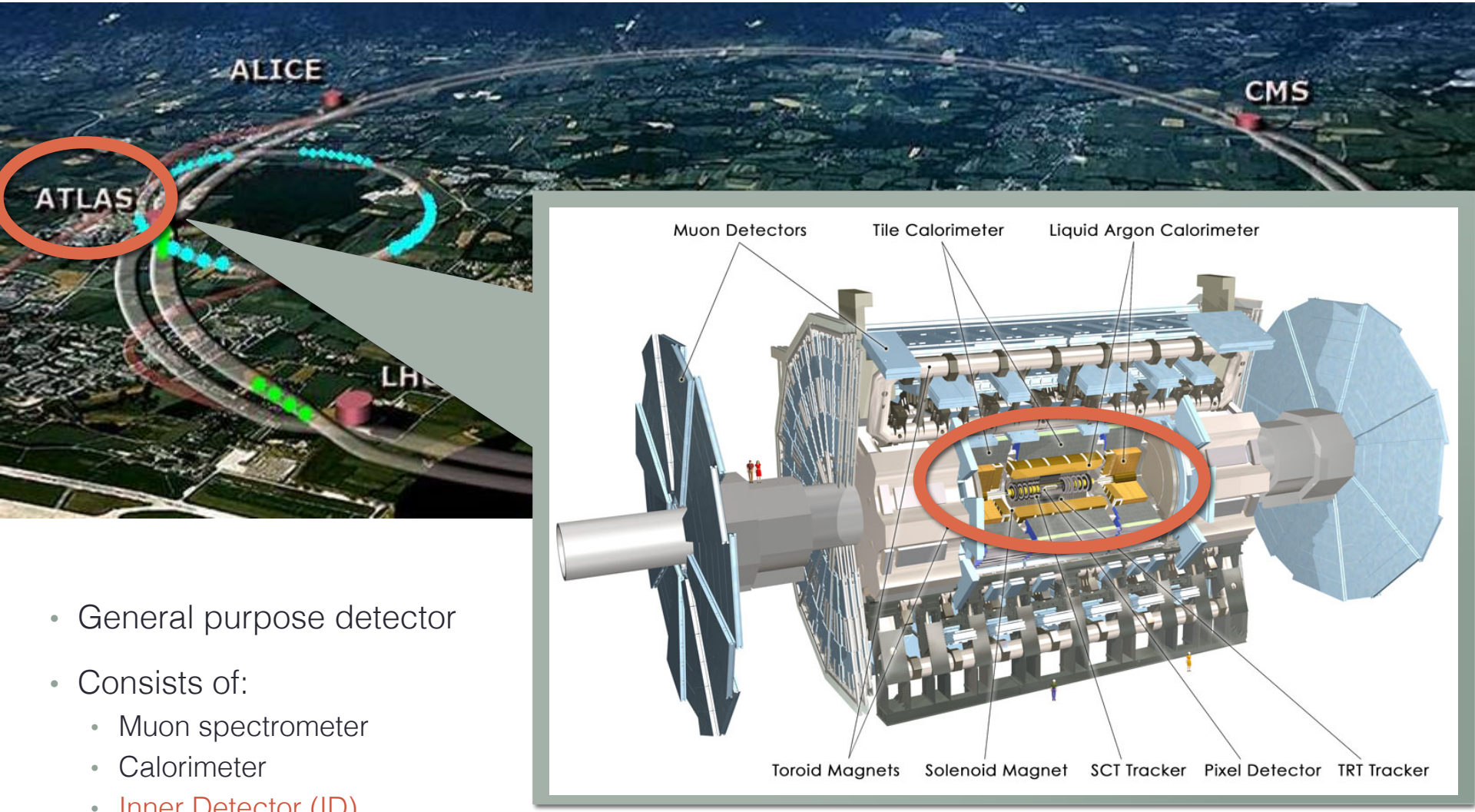

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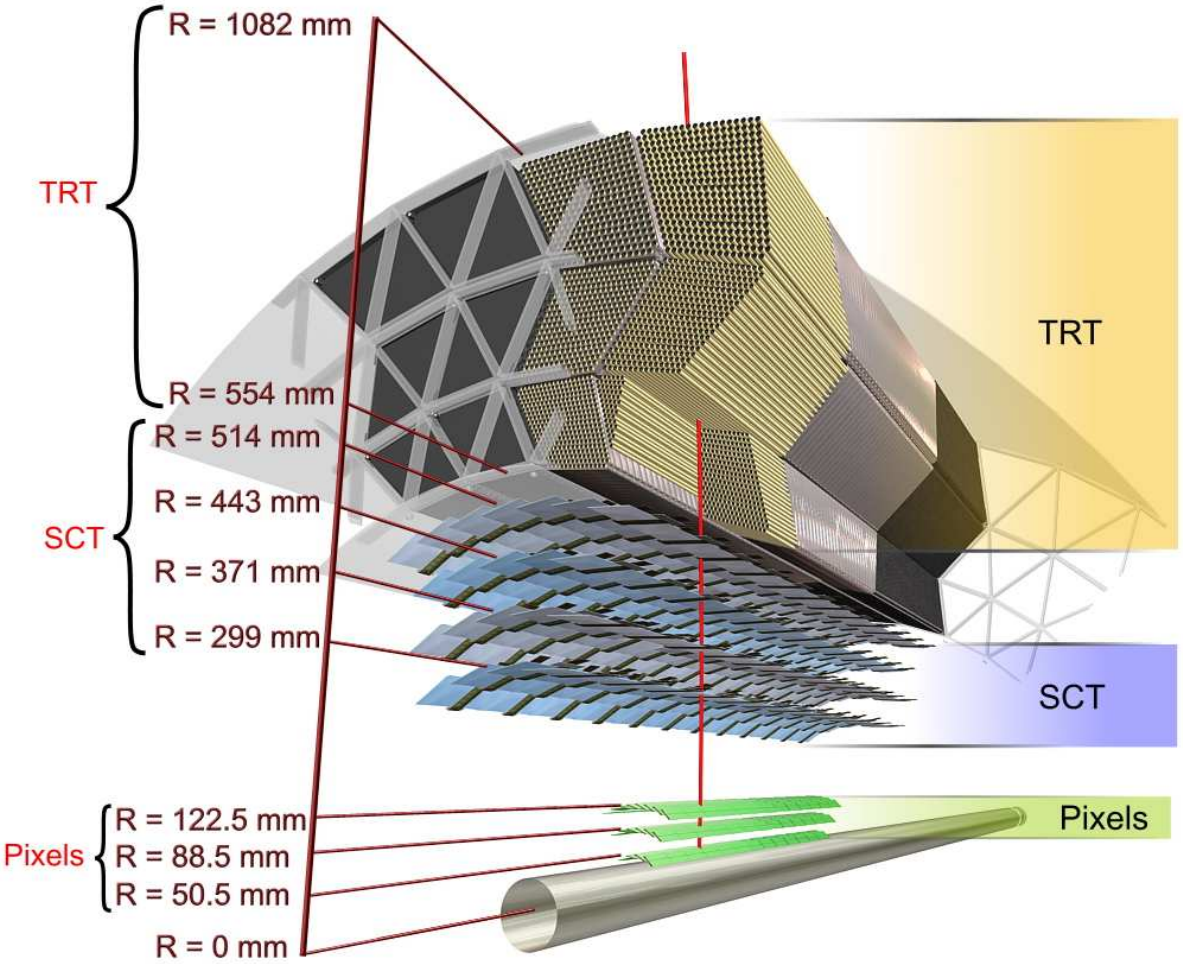
Inner Detector (ID) of ATLAS



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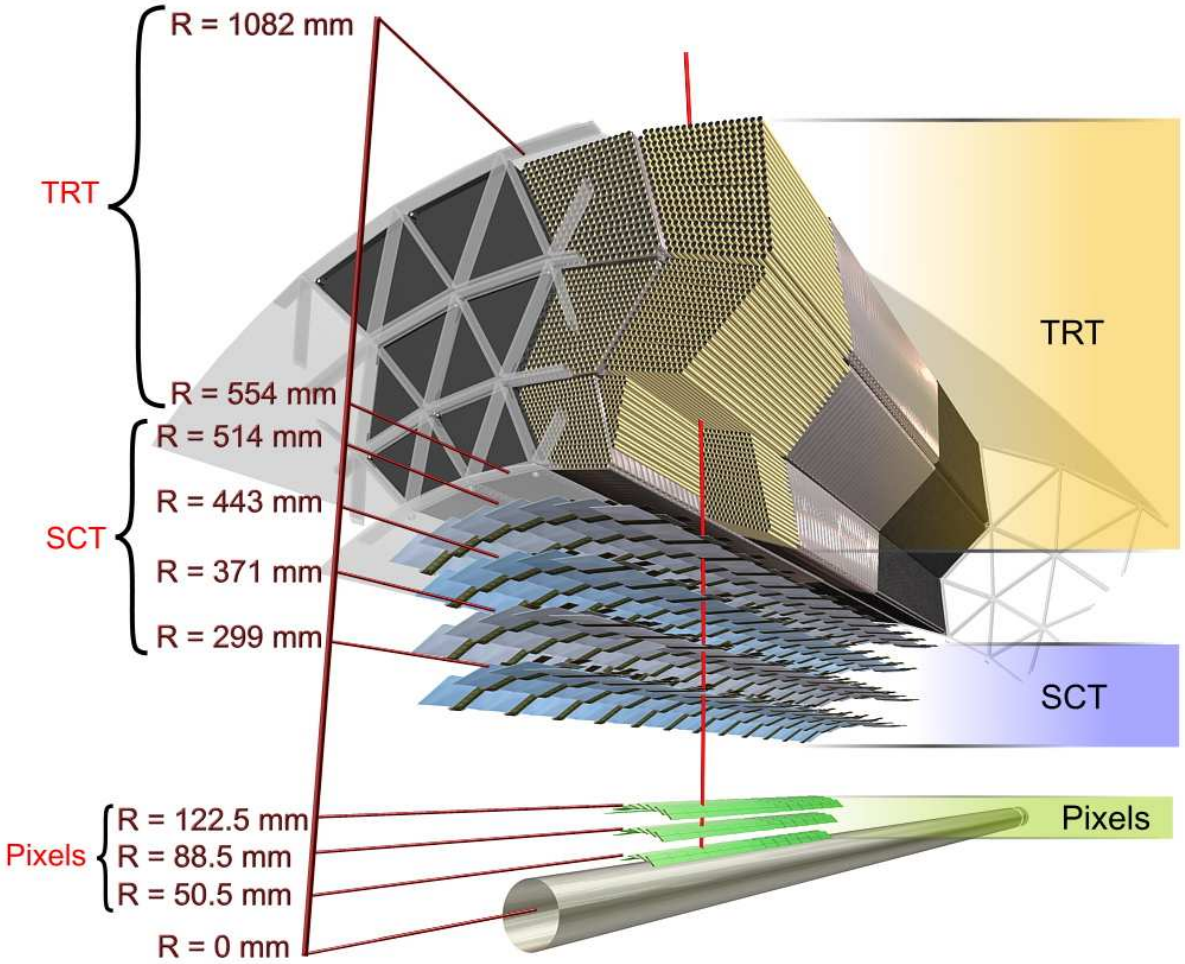

- Pixel detector
  – 3 layers

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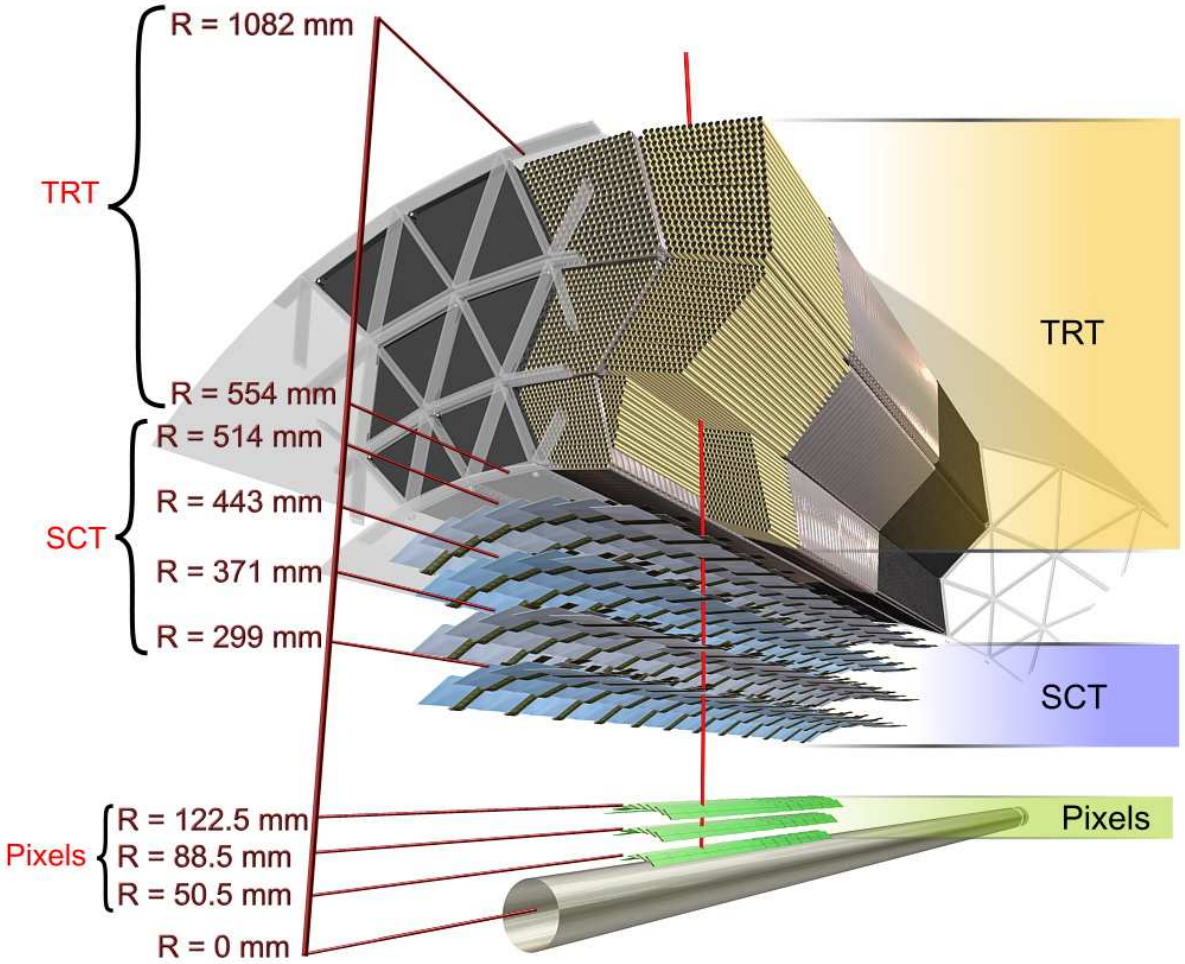

- SCT (Semiconductor Tracker)
  - strip detector
  - 4 barrel layers + 9 forward layers
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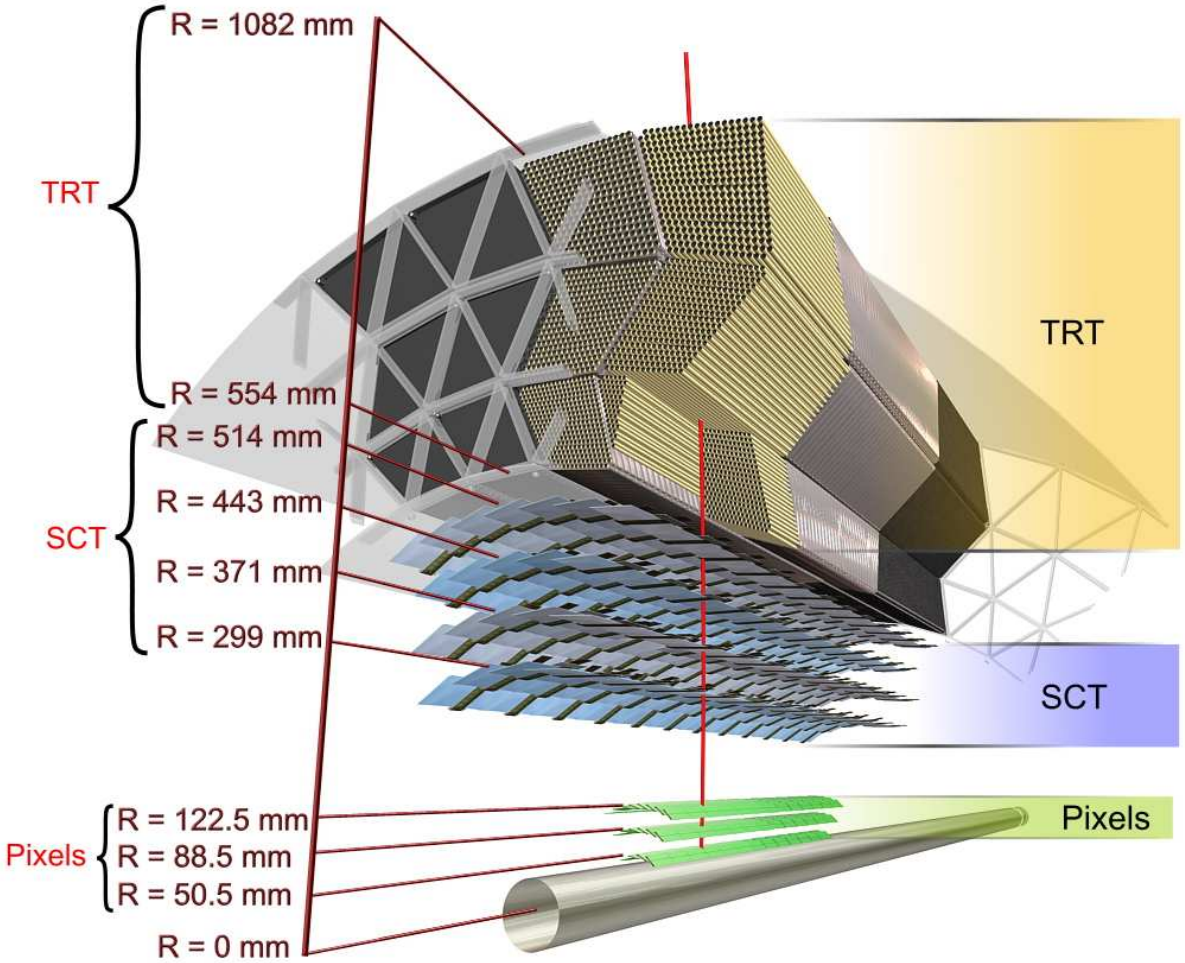
Inner Detector (ID) of ATLAS



Silicon detectors

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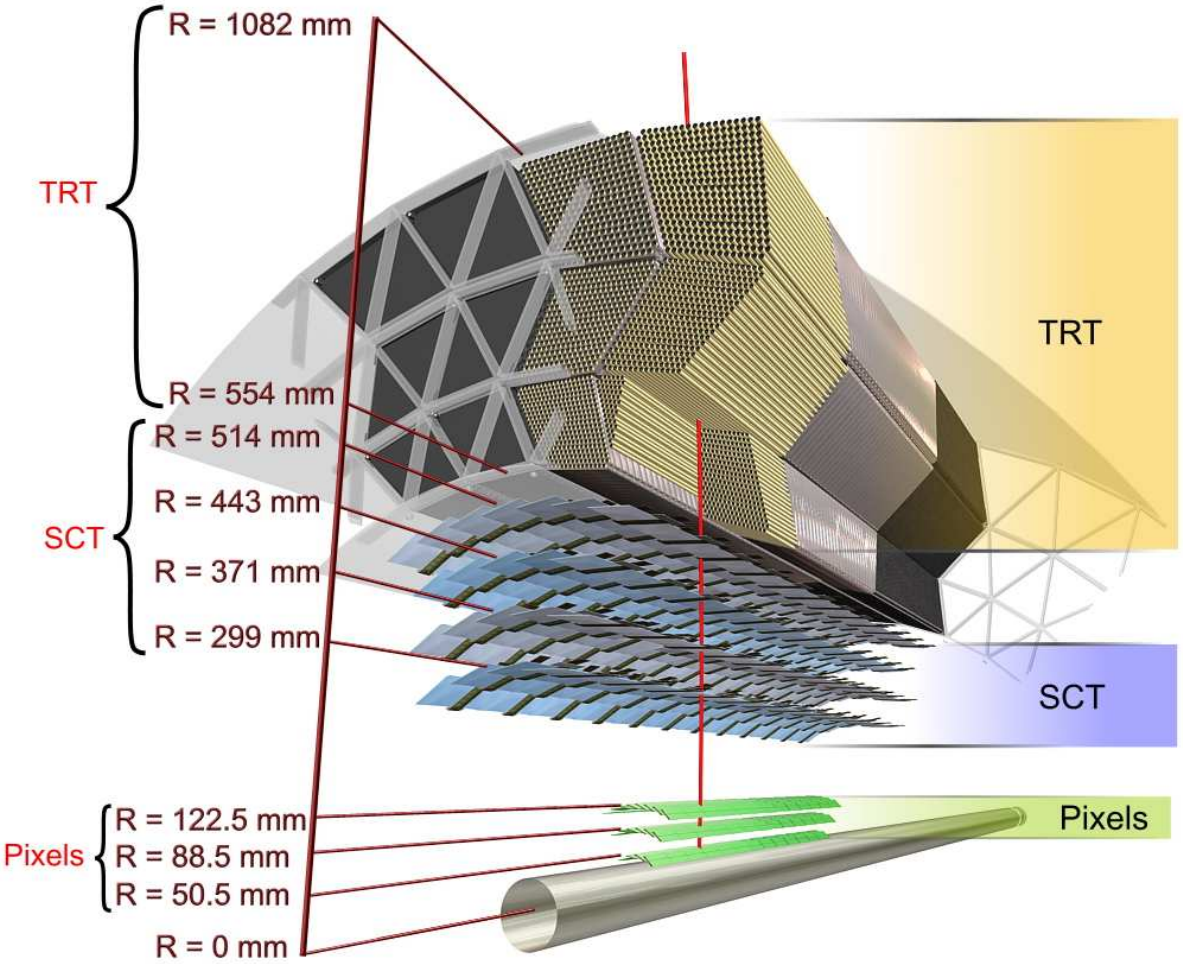

- TRT (Transition Radiation Tracker)
  - optimally 36 hits
- SCT (Semiconductor Tracker)
  - strip detector
  - 4 barrel layers + 9 forward layers
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Upgrade 2015

- Upgrade of LHC:
  - Higher centre of mass energy: 8 TeV → 13 TeV
  - Bunch interval 50ns → 25ns
  - Higher luminosity: 8 x 10^{33} $cm^{-2}s^{-1}$ → 2 x 10^{34} $cm^{-2}s^{-1}$
  - Higher pile-up, from 8 TeV → 13 TeV: $\langle\mu\rangle$ ~ 20.7 → ~50

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- For ID
  - IBL (Insertable B-Layer), 33.25mm from the beamline
    – improve resolution
  - Upgraded trigger hardware/firmware
  - Redesign of the trigger software
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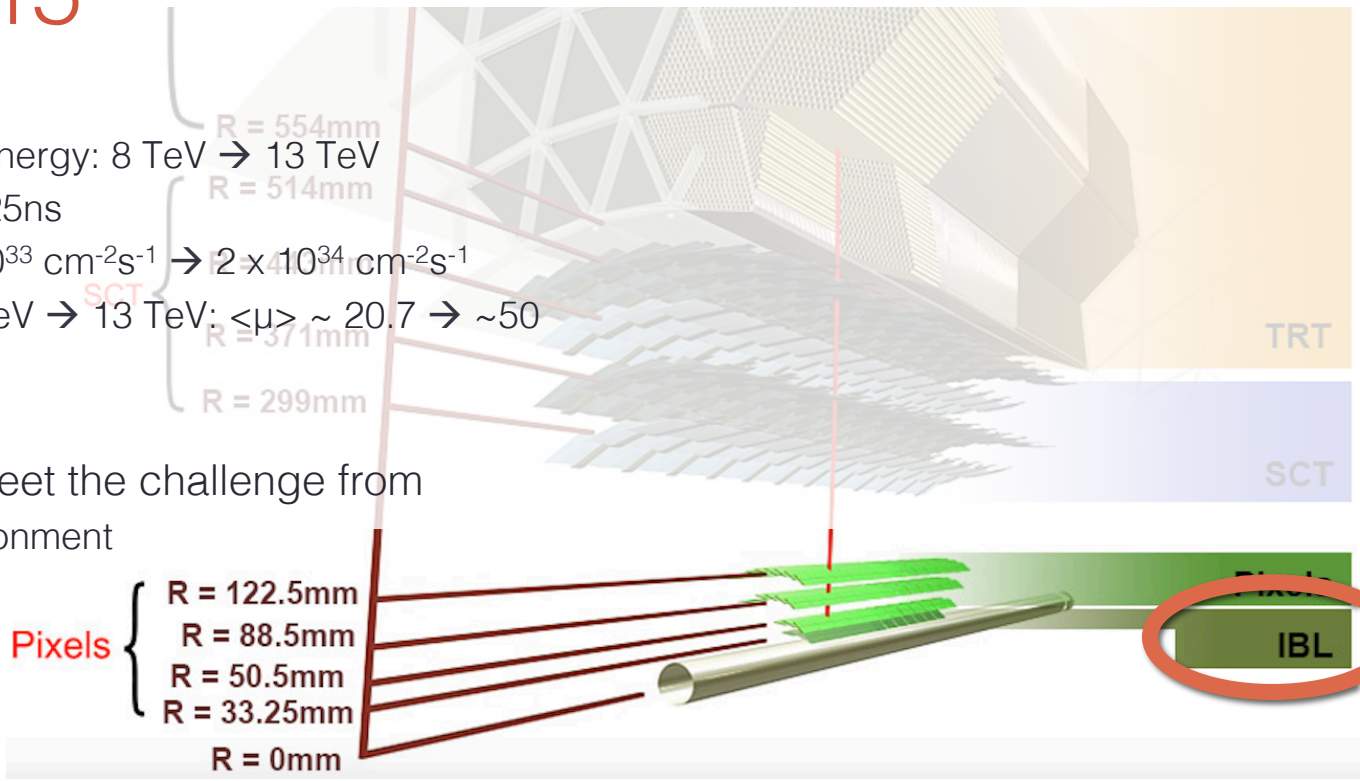

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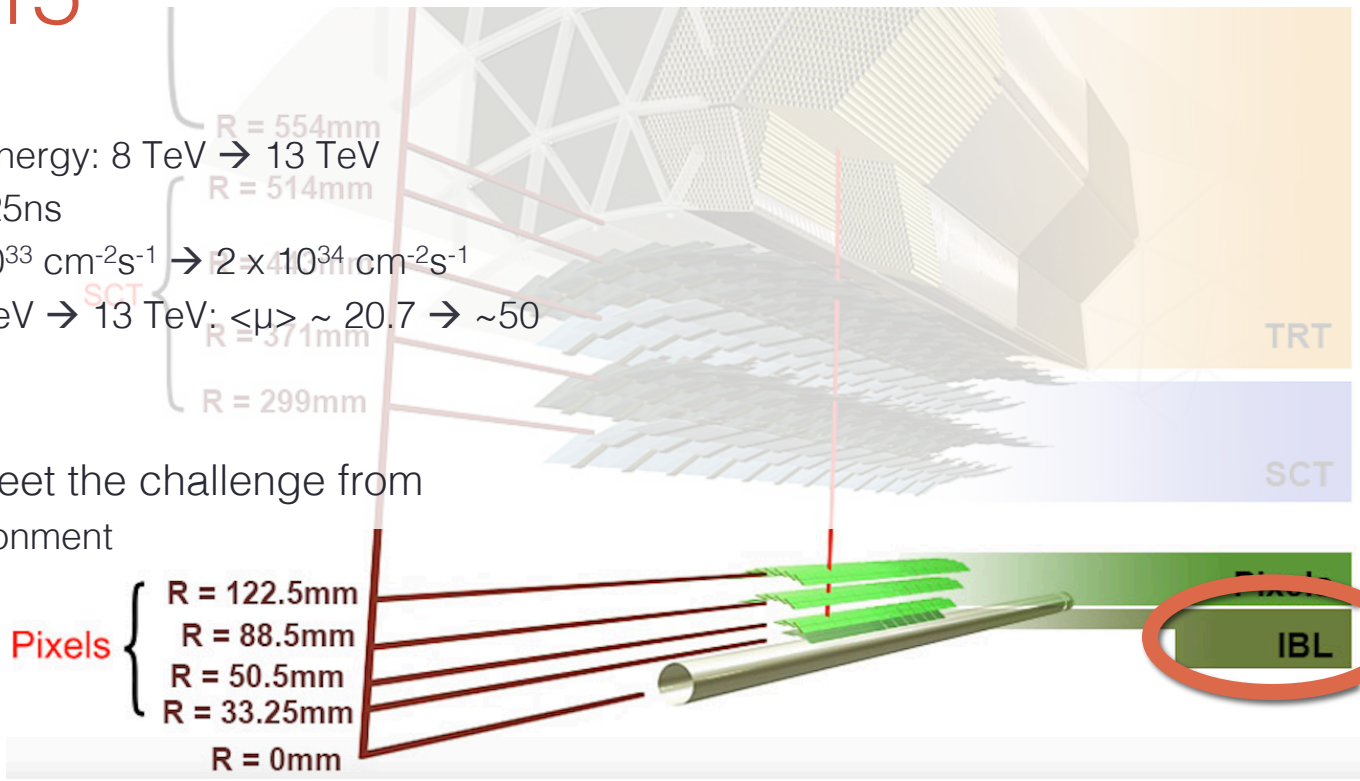

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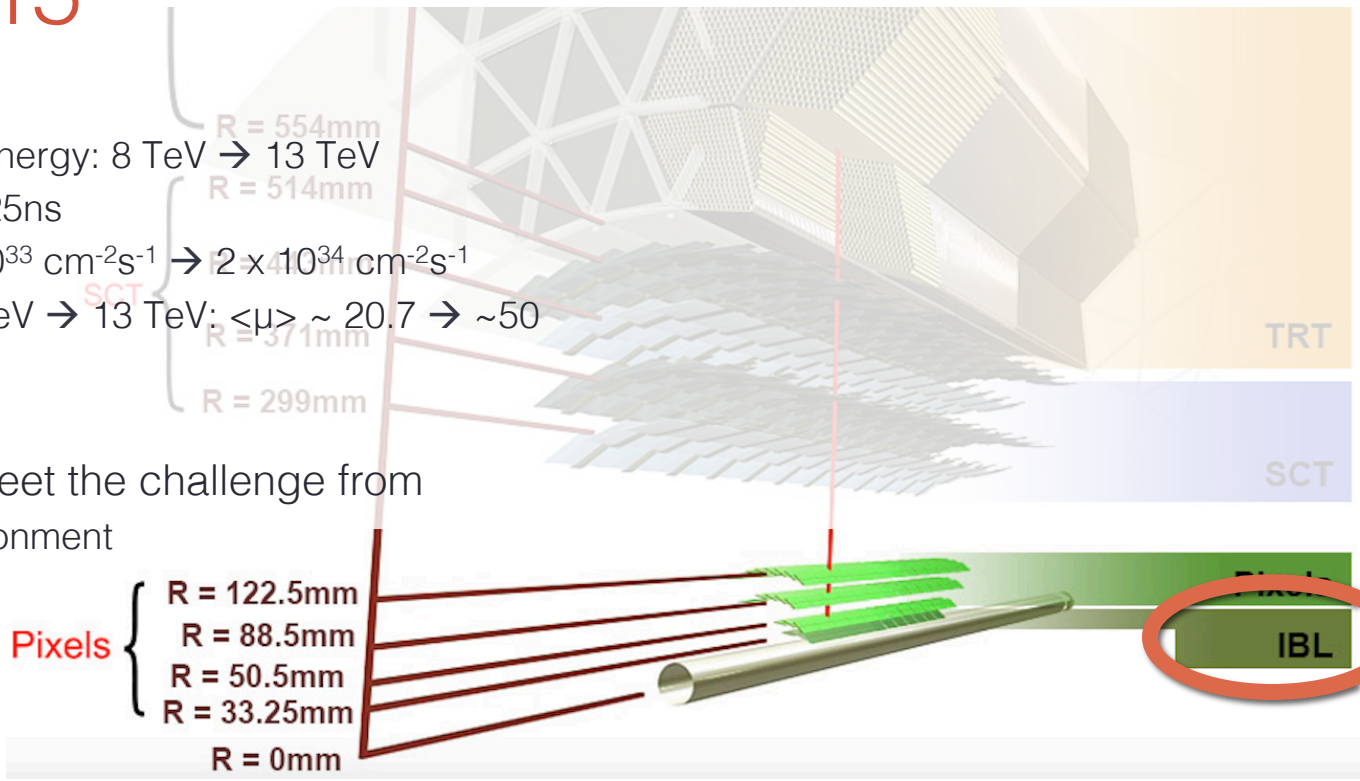

ID trigger system

- In Run-I, 3-level system

L1 (Level 1)

- Hardware/firmware
- 20 MHz input rate
- < 2.5 μs decision
- 70 kHz peak output
- No ID

L2 (Level 2)

- Software
- ~75 ms decision
- 5-6 kHz output

EF (Event Filter)

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- In Run-II, 2-level system

L1 (Level 1)
- 40 MHz input rate
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HLT (High Level Trigger)
- Target decision time: 200ms
- 1 kHz output
- Single PC farm

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Late 2015: New ID track processor Fast TracKer (FTK) Talk by N. Asbah

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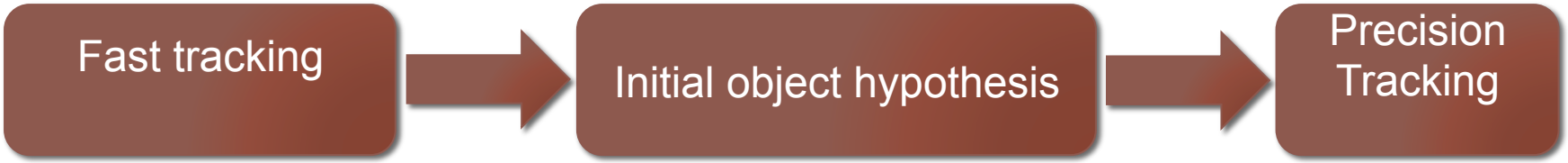
HLT algorithm



- Two-stage tracking:
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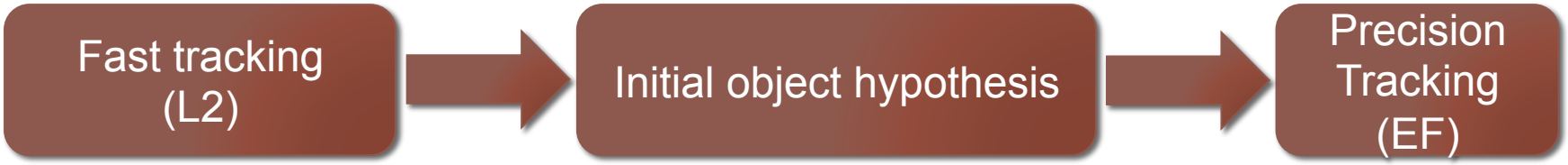

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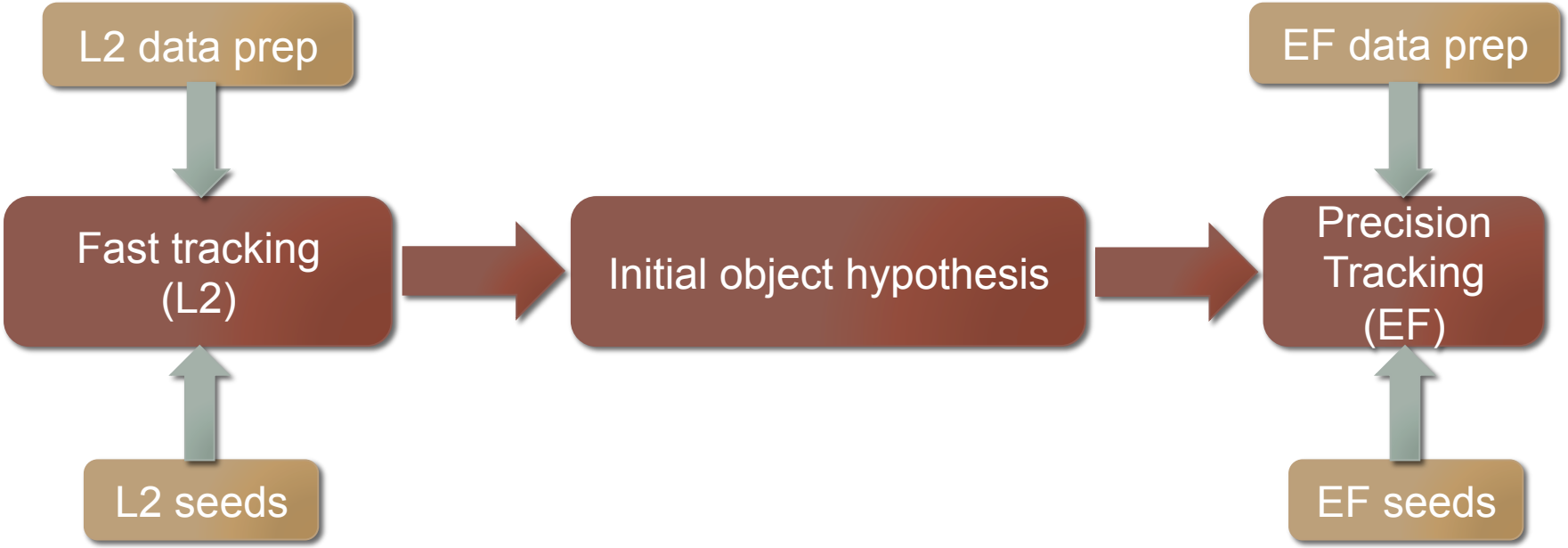

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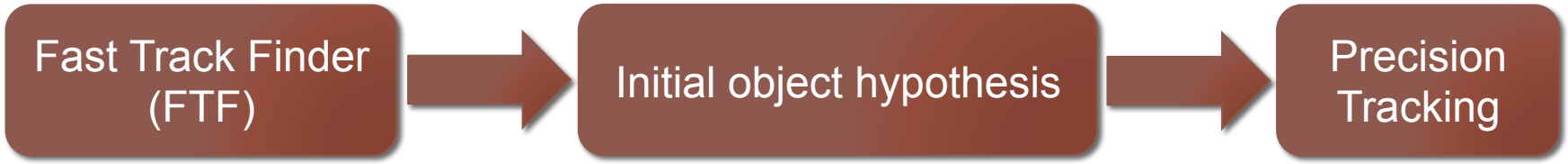

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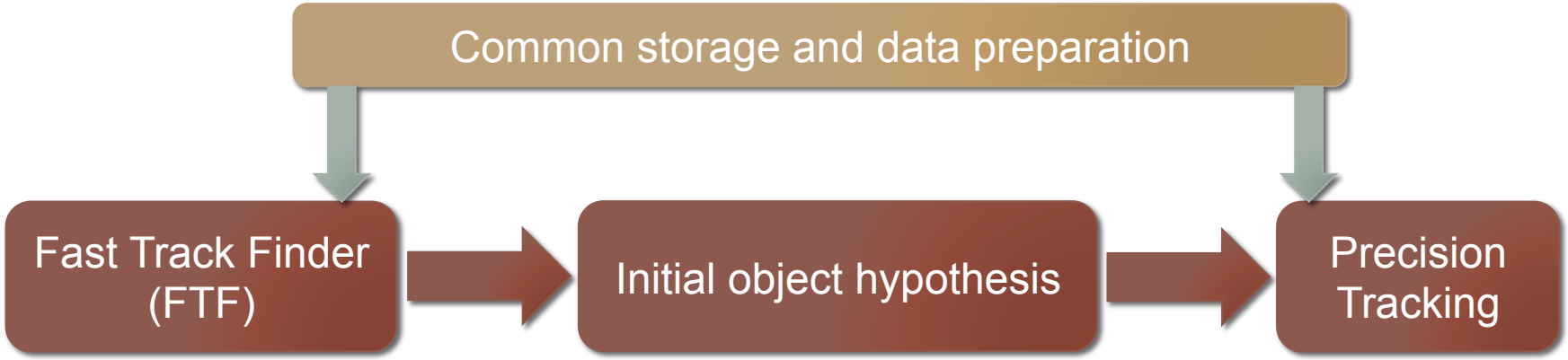

- Two-stage tracking:
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- Time saved using:
  - Common data preparation

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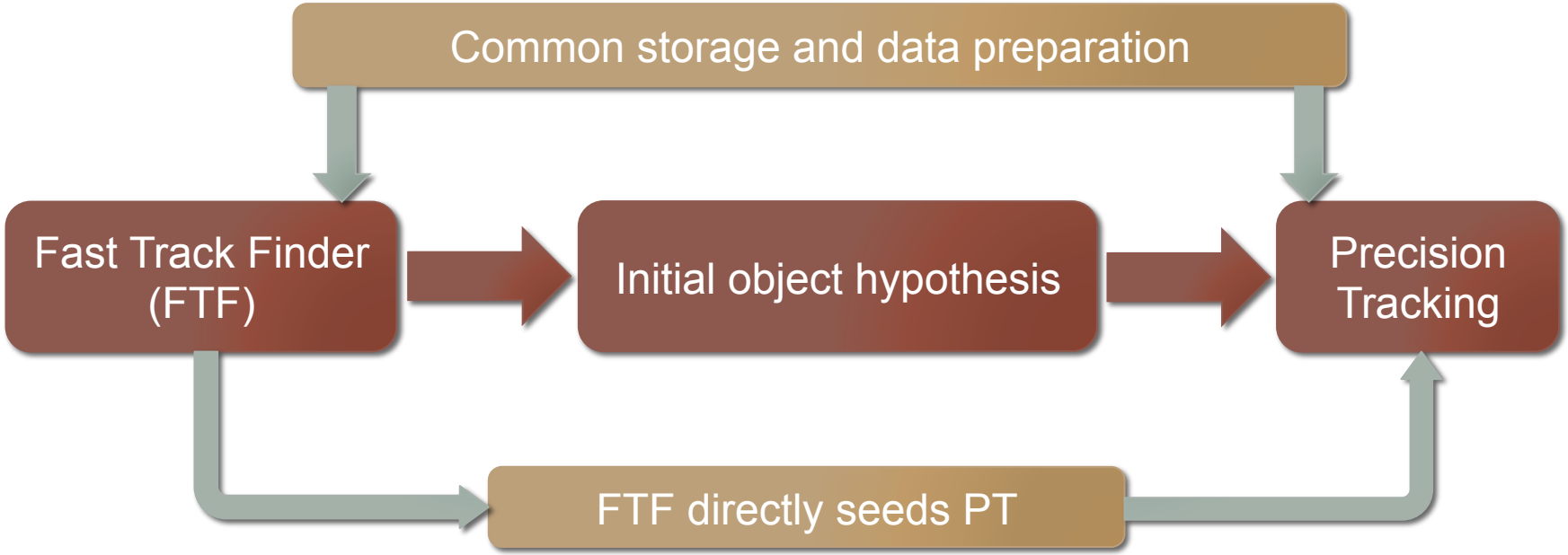

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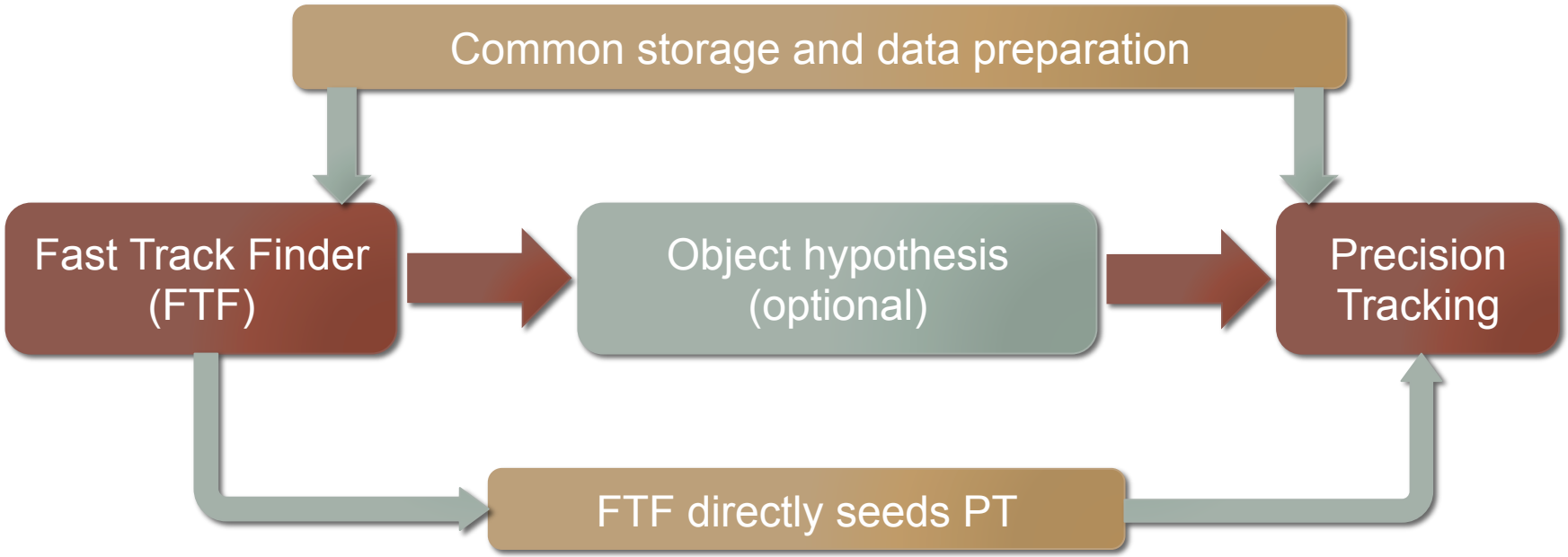

- Two-stage tracking:
  - Fast tracking
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- Time saved using:
  - Common data preparation
  - FTF seeds PT, prevent duplicated pattern recognition stage
- Extra flexibility from optional hypothesis stage

Profiling and optimisation

- Run-II algorithm built from Run-I blocks
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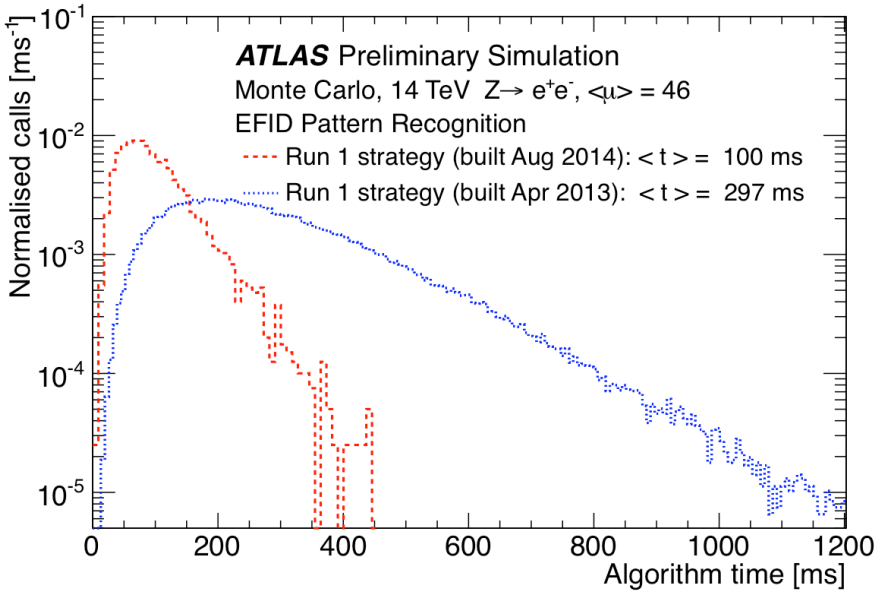
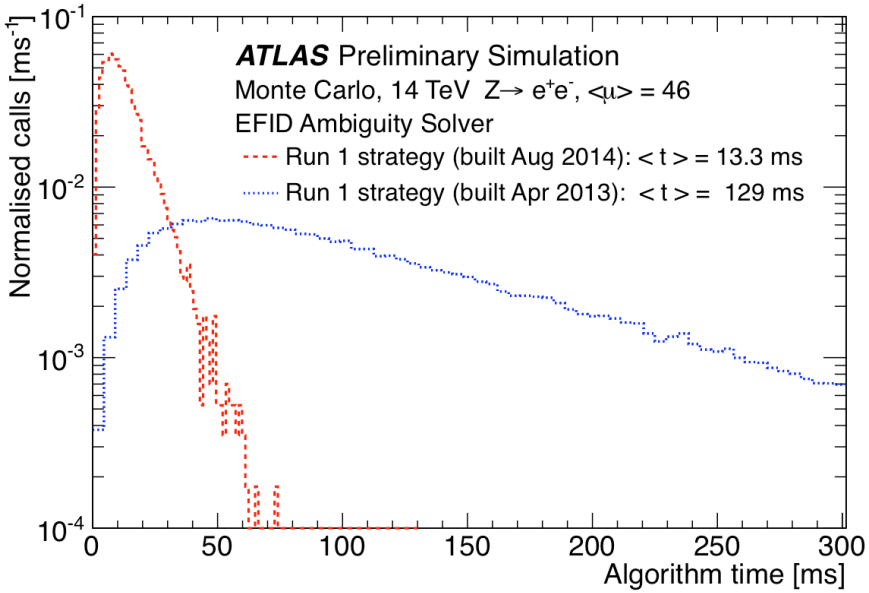


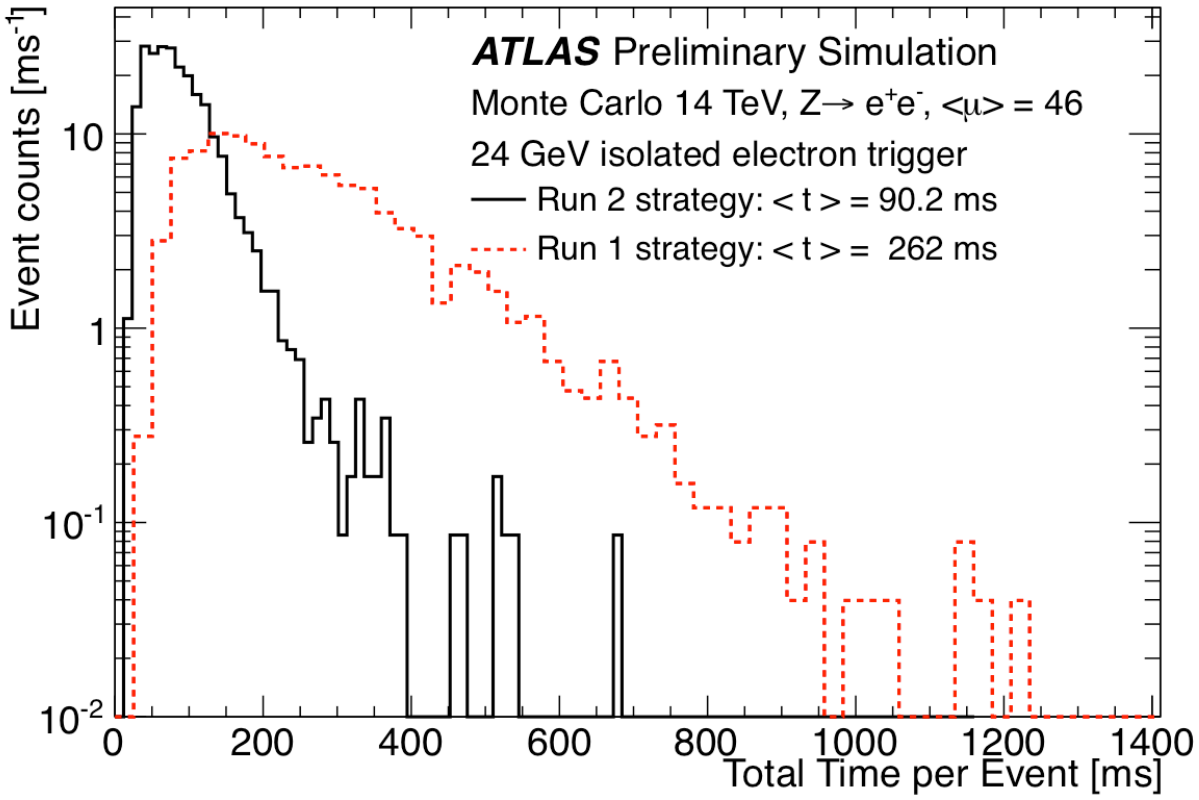
- ~3 times faster
- Pure technical improvement



- ~10 times faster
- Combination of tech & redesign

Improvement in Run-II strategy

- Time saved from
  - merged data preparation
  - single pattern recognition stage



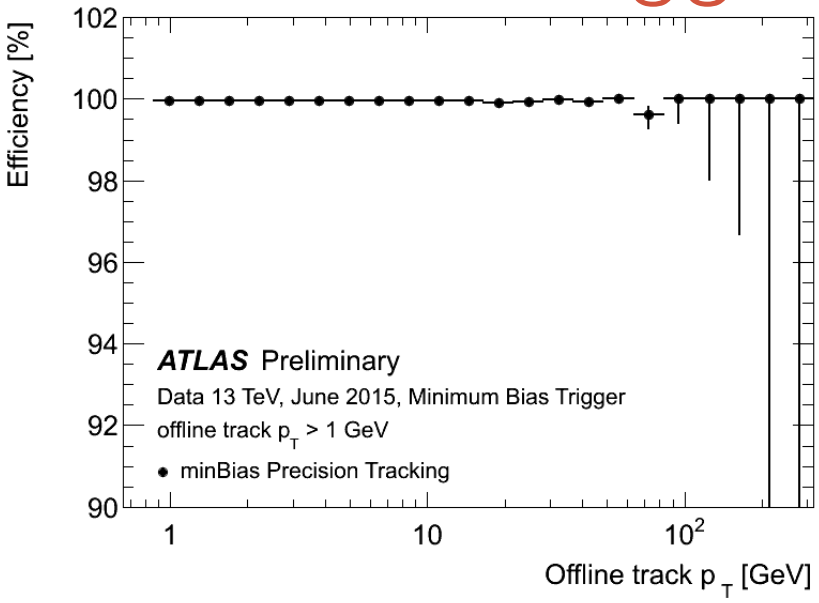
Run-II HLT tracking performance

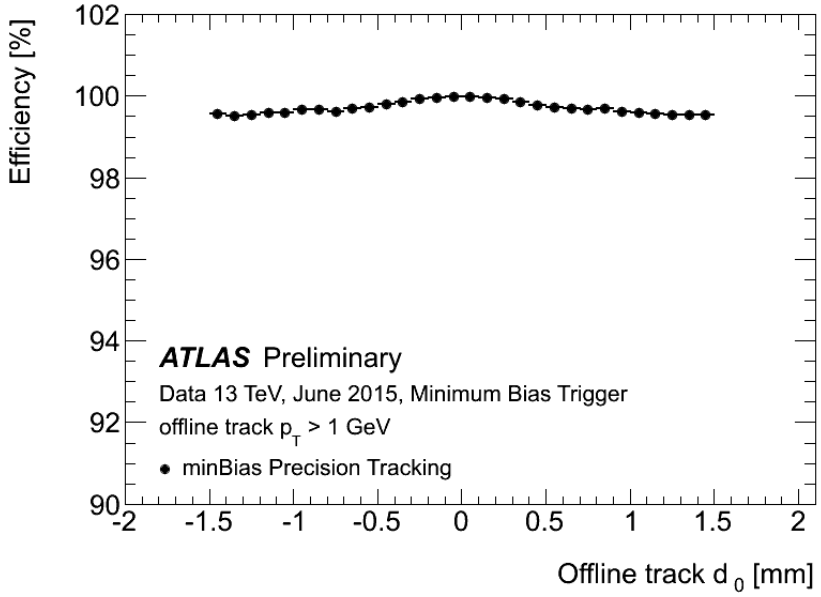
- Plots produced from 13 TeV data collected in June and July 2015

- Dedicated performance triggers are used
- Select unbiased sample of events without ID track requirement

- Efficiencies, residuals, and resolutions are calculated w.r.t. the tracks found by the offline reconstruction software

Minimum bias trigger





- Efficiencies as a function of
  - p_T: transverse momentum
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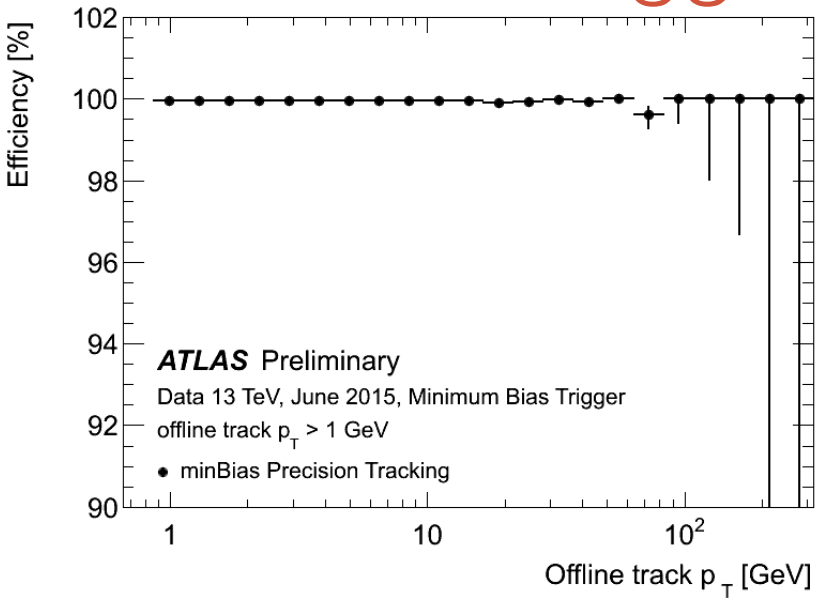

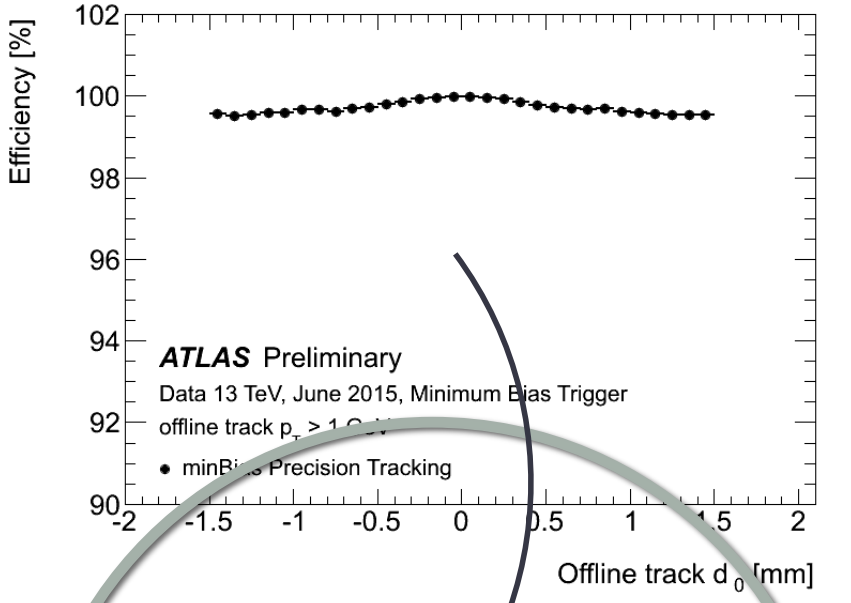

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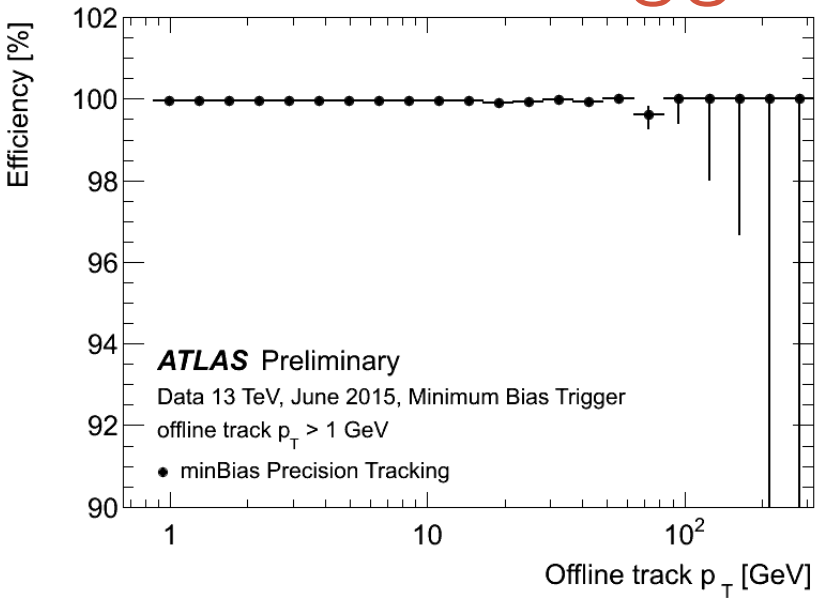

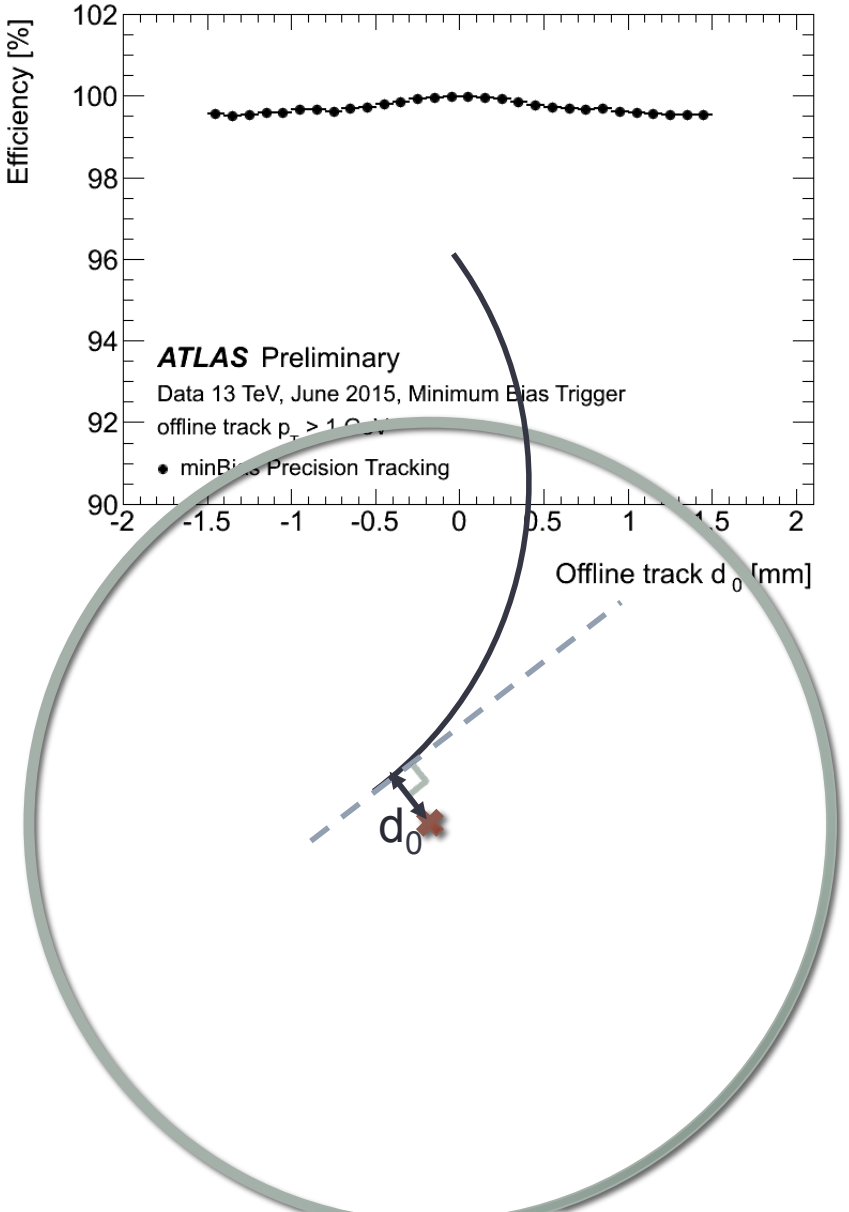

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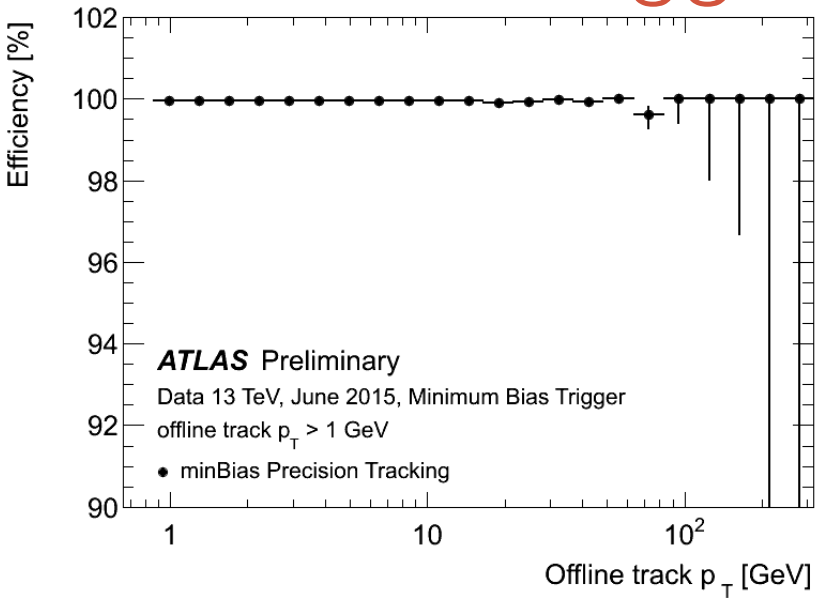

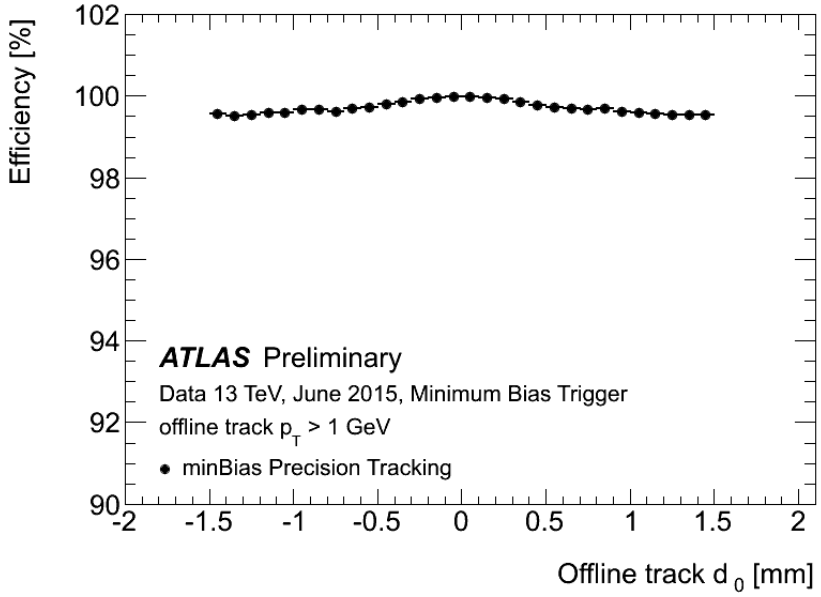

- Efficiencies as a function of
  - p_T: transverse momentum
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- Very high efficiencies achieved

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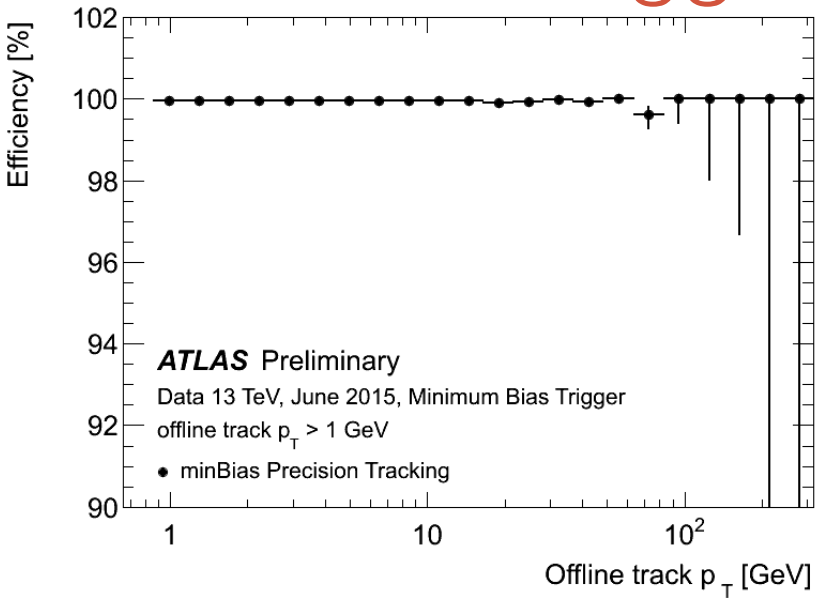
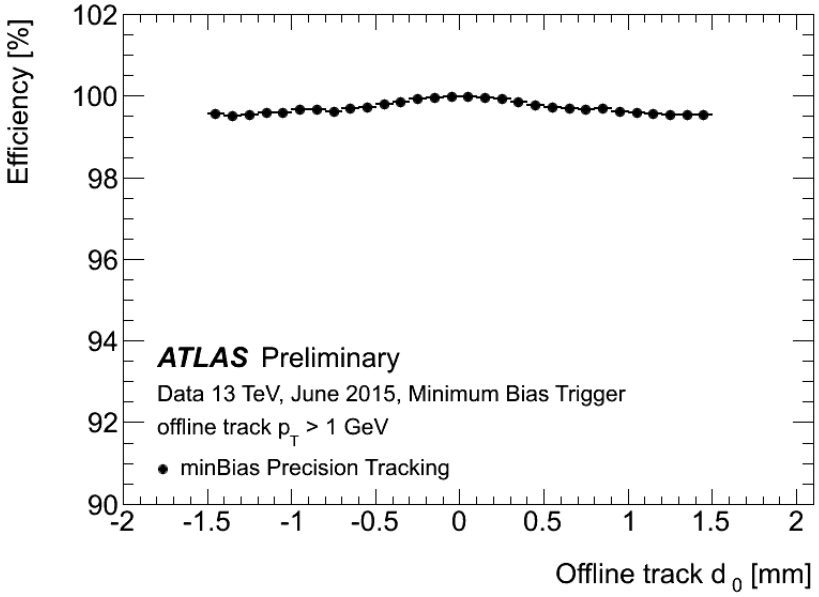
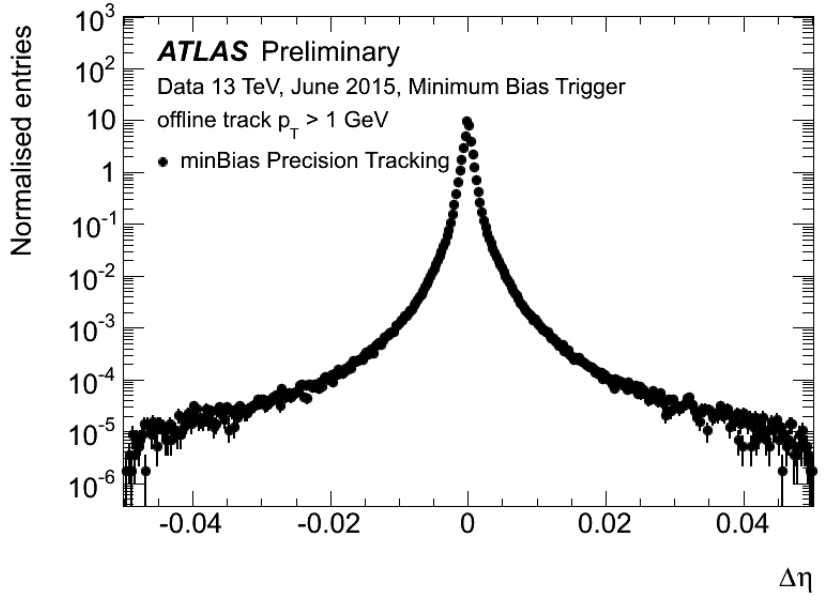




- Efficiencies as a function of
  - p_T: transverse momentum
  - d_0: transverse impact parameter
- Very high efficiencies achieved
- η: pseudorapidity



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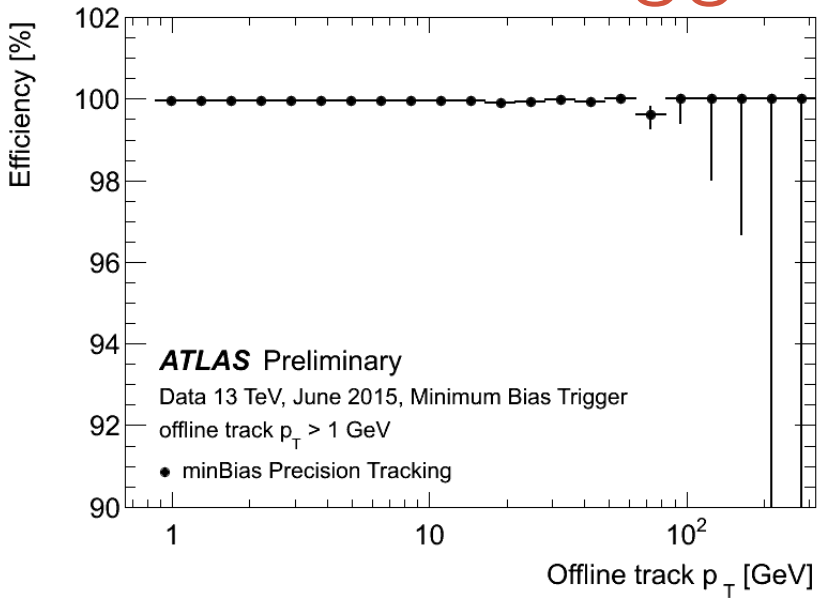

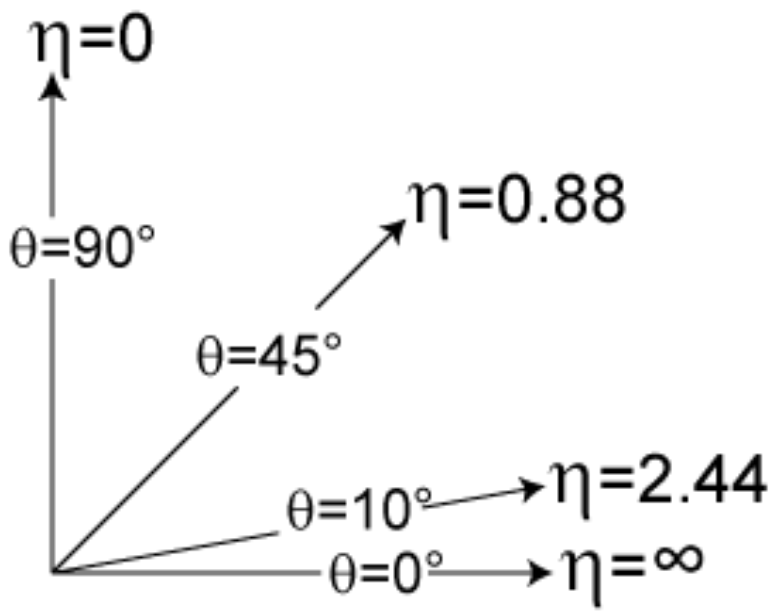

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  - p_T: transverse momentum
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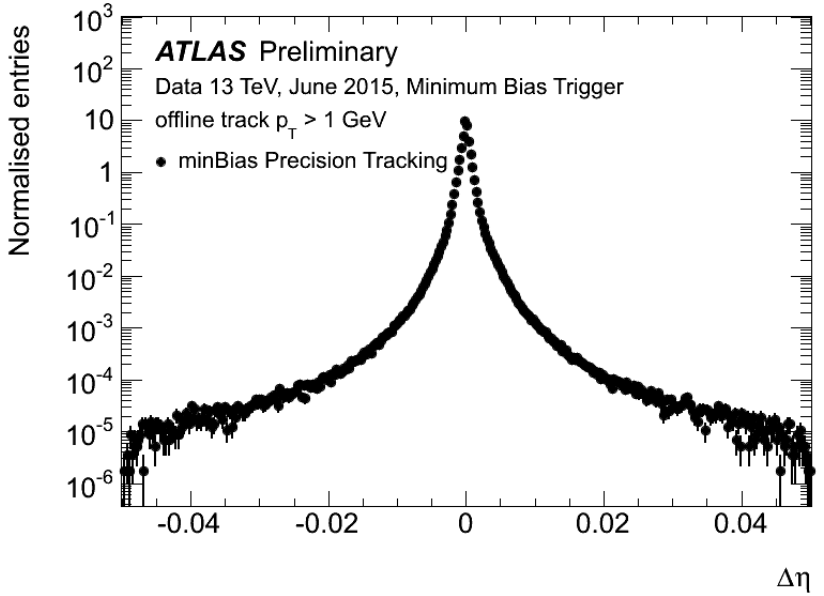
$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



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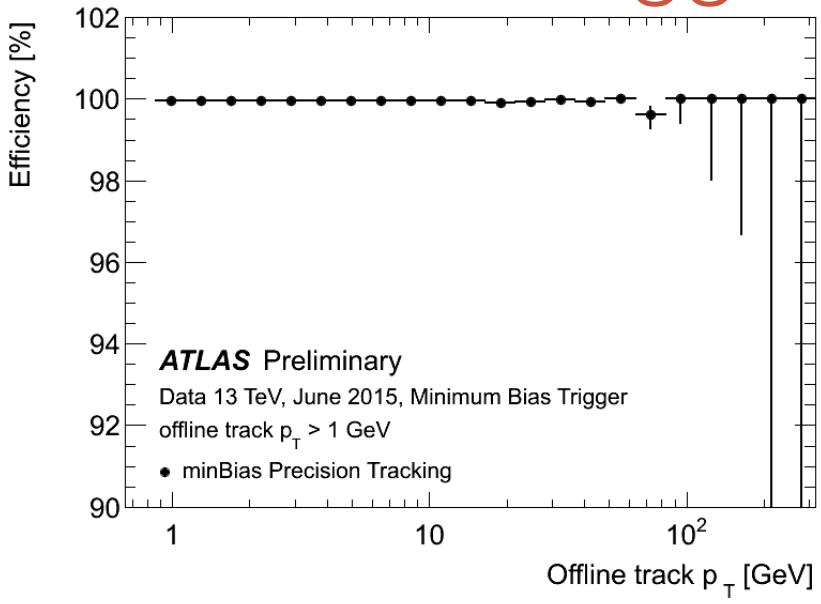

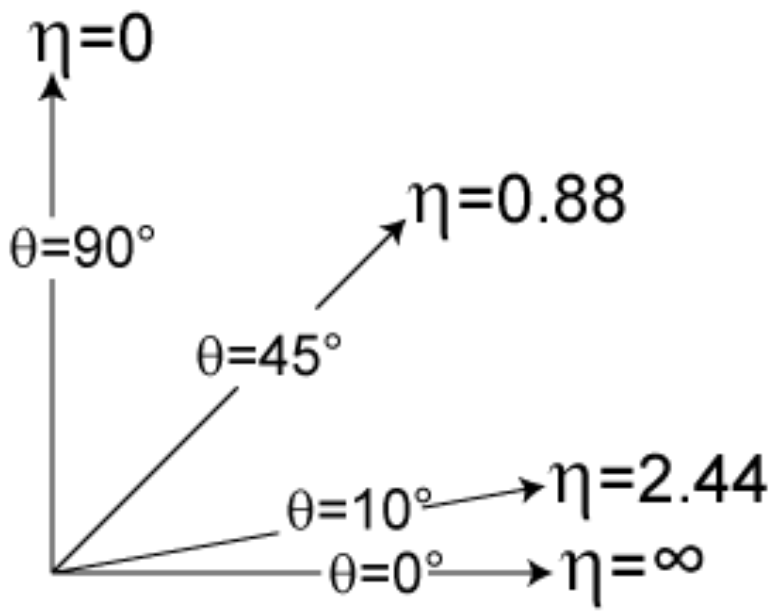

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- Very high efficiencies achieved
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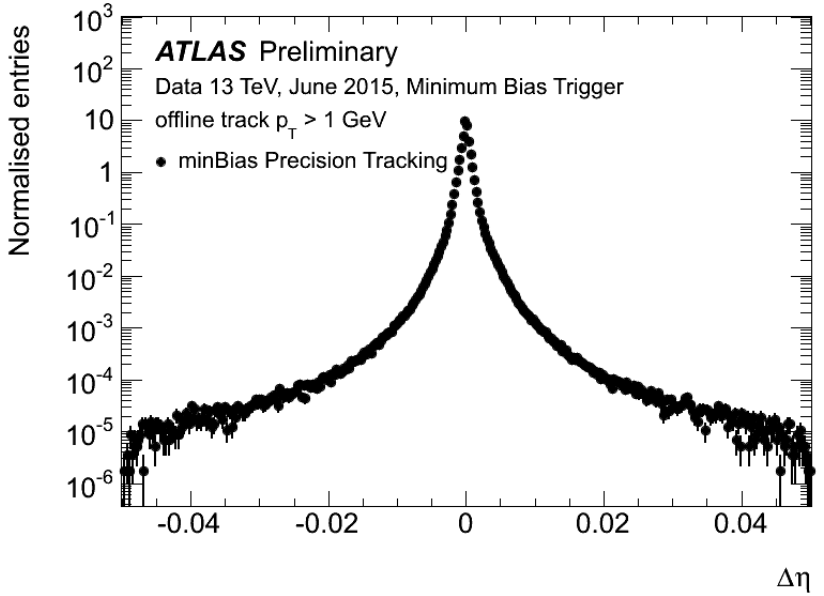
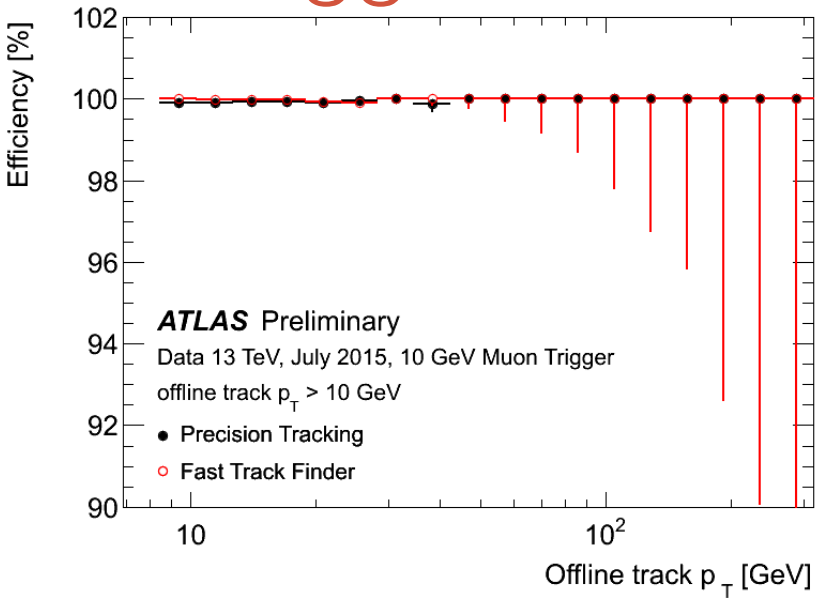
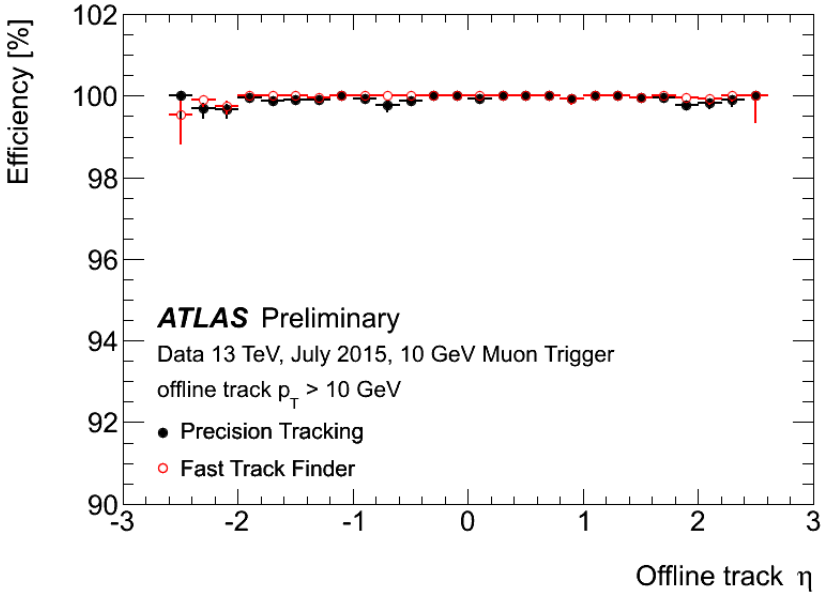
- Good η resolution



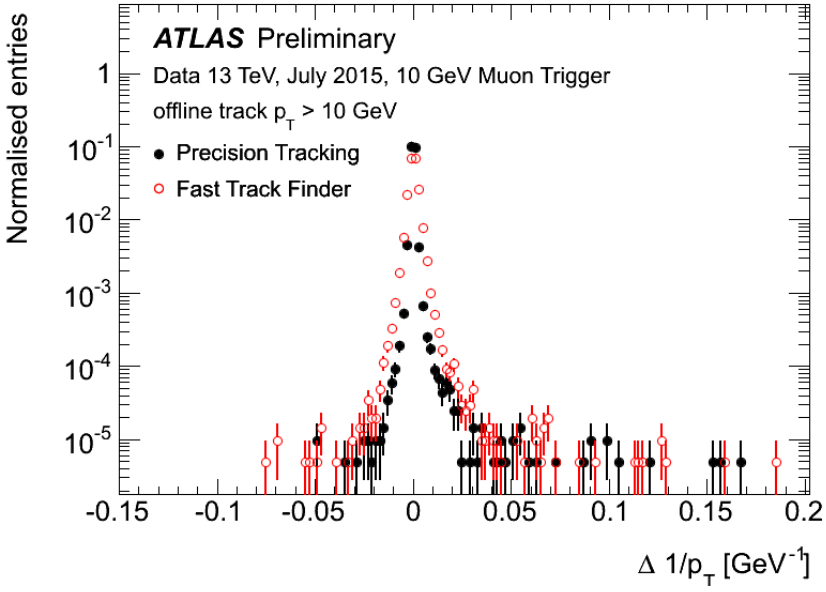
Muon trigger



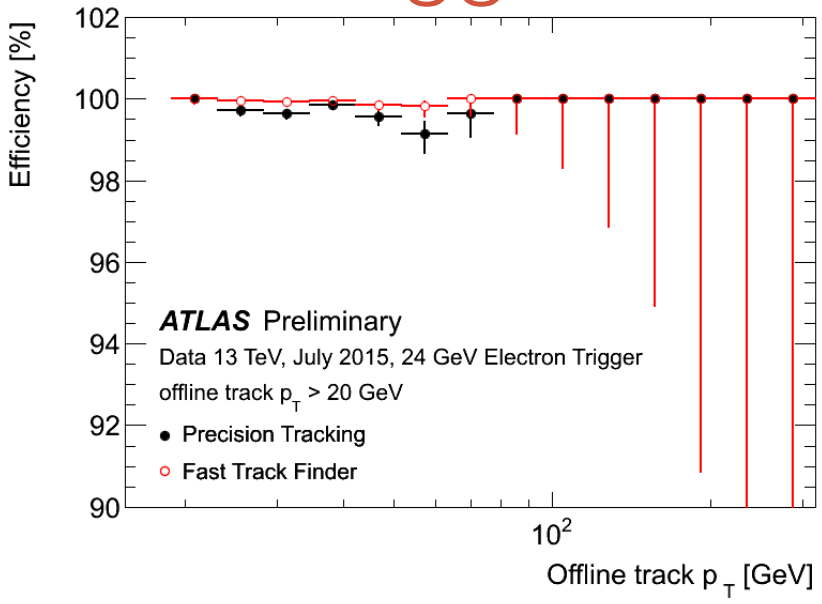


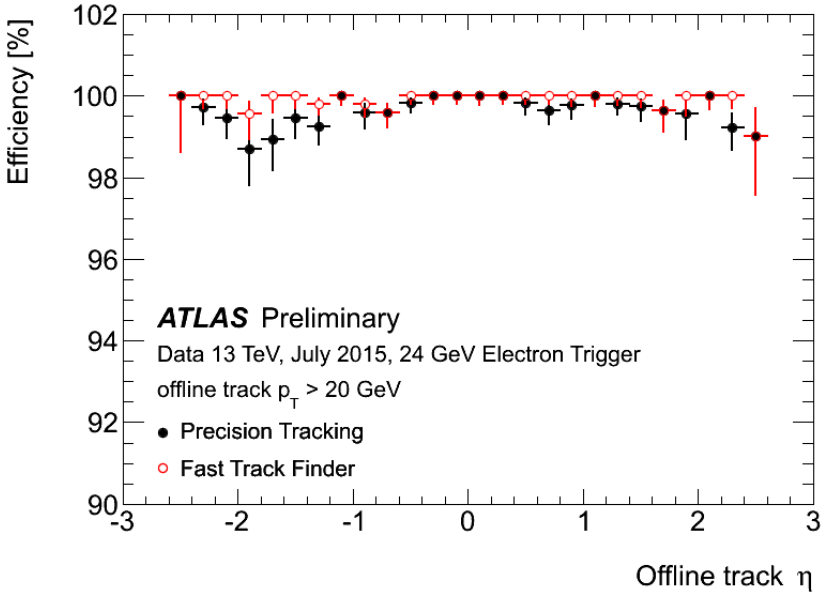
- Very high efficiencies
- Flat as a function of p_T and η

- $\Delta 1/p_T$ ~ resolution on the track curvature



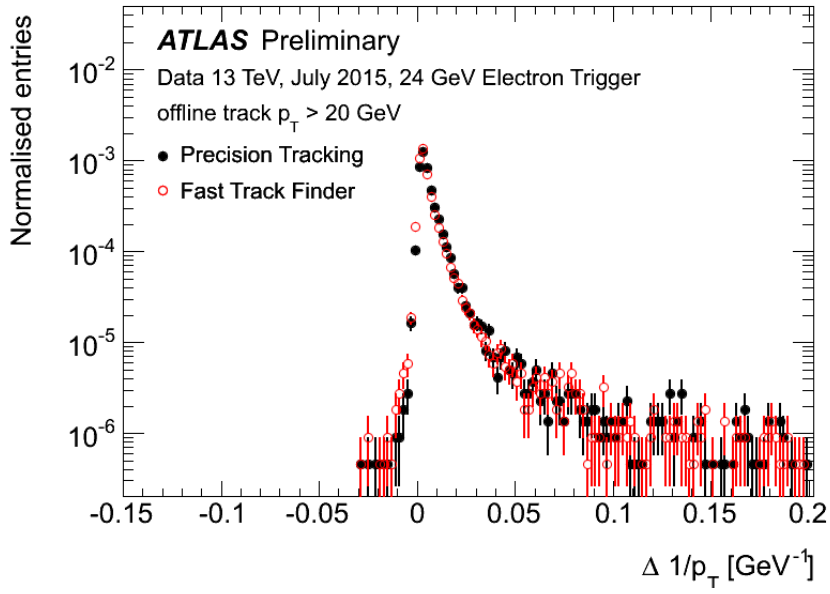
Electron trigger



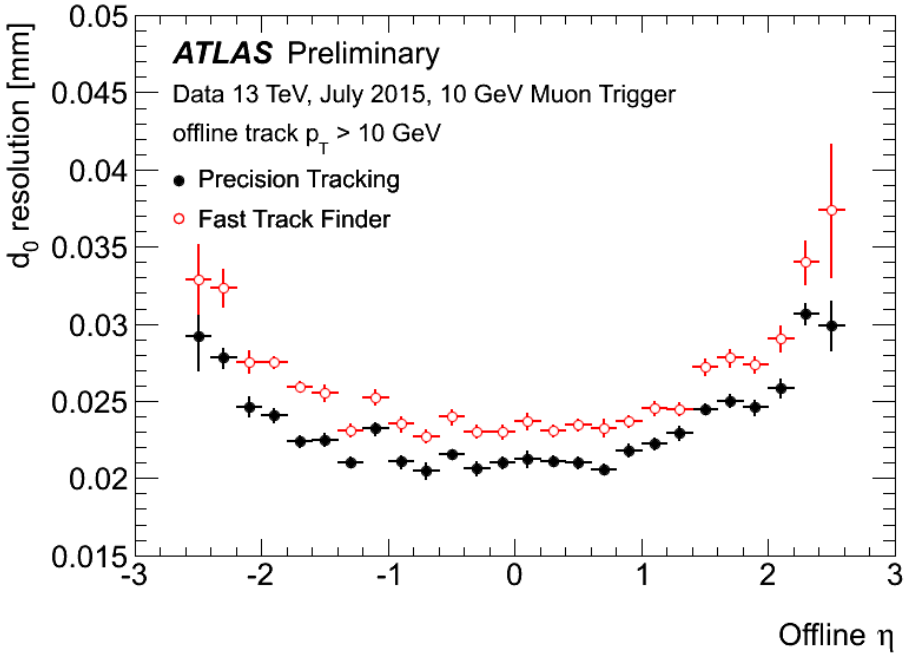


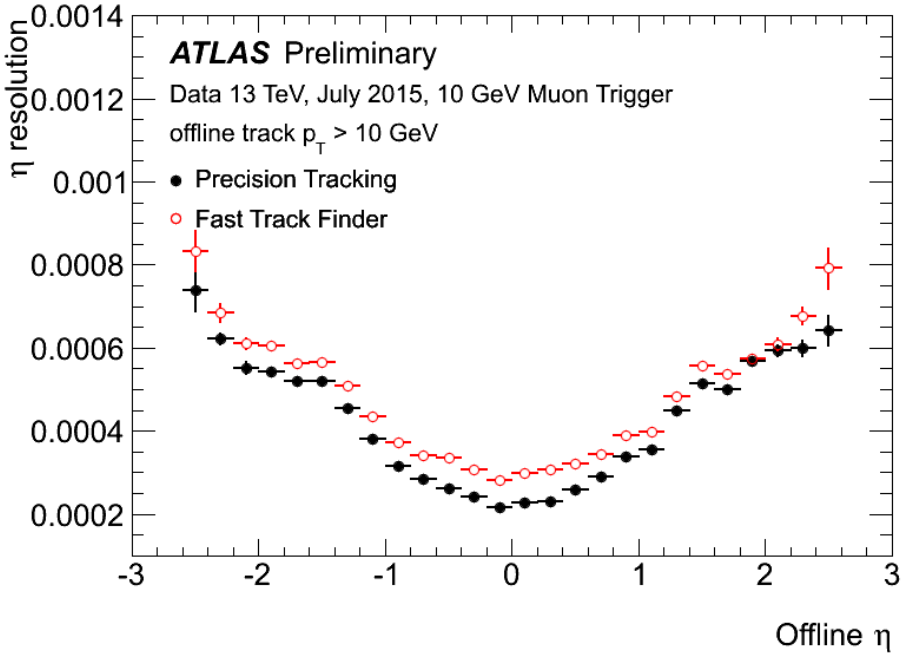
- Very high efficiencies
- Flat as a function of p_T and η

- Longer tail in $\Delta 1/p_T$ and lower efficiencies than muon trigger due to bremsstrahlung



Muon trigger resolution



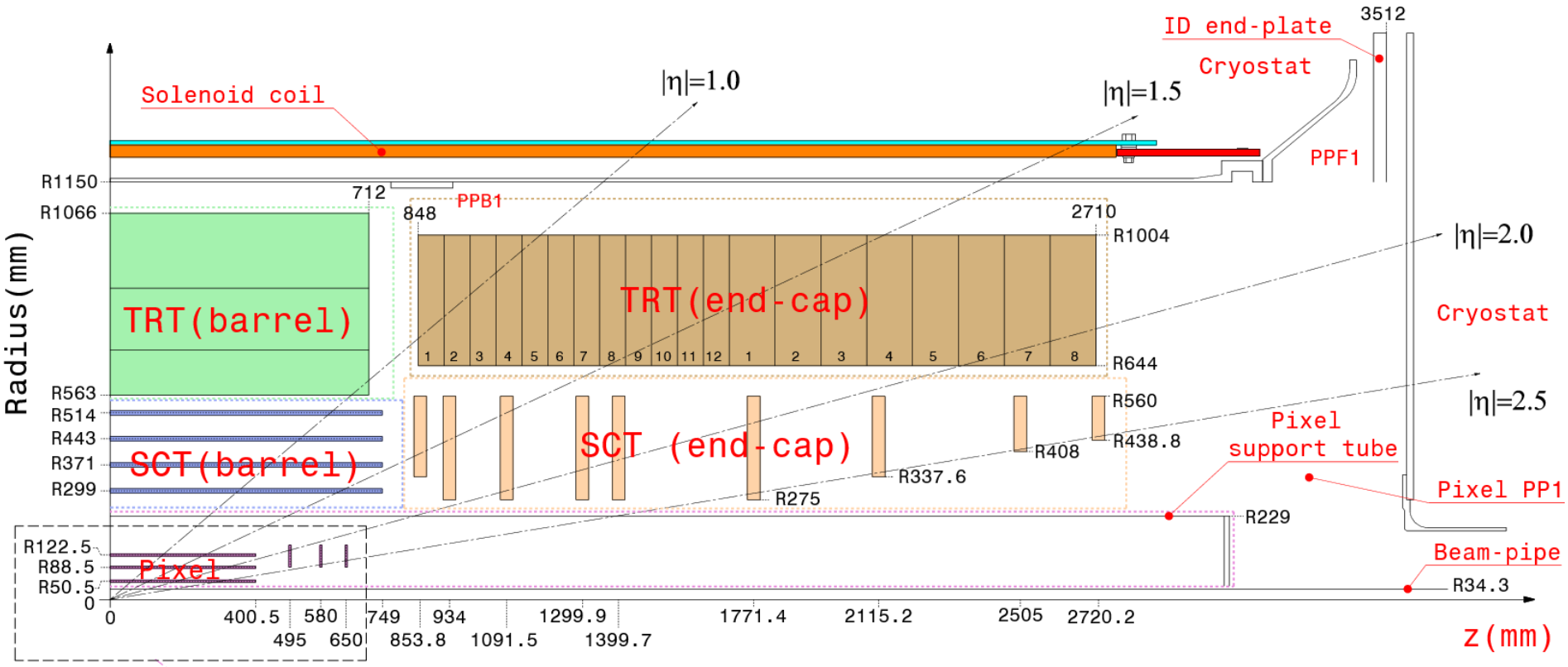


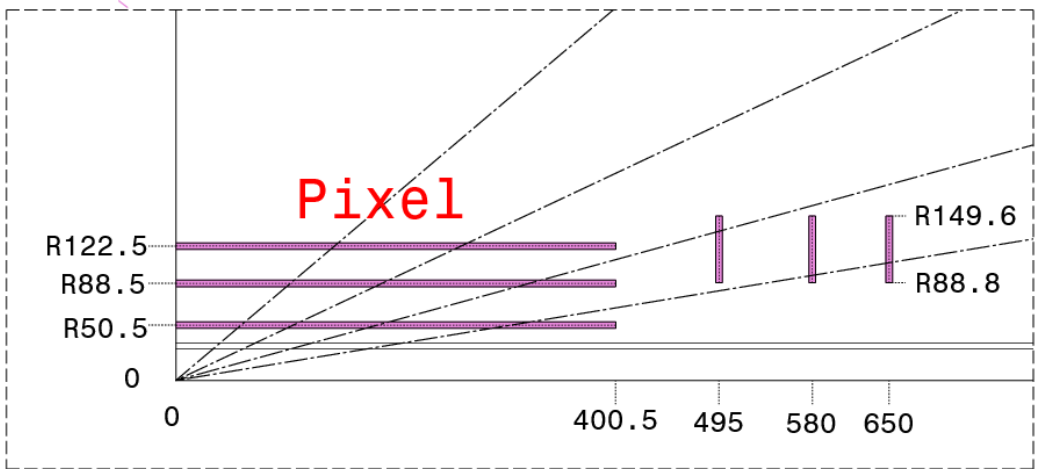
- Very good overall resolution
- Better resolution from Precision Tracking
- Lower resolution at high η due to detector geometry

Conclusion

- Single stage HLT in Run-II
- Dramatic time saving due to merged data preparation and track seeding
- Improvement in algorithm timing from profiling and optimisation
- A factor of 3 reduction in the average processing time for each event, operated at significantly higher input rates
- Good tracking performance
  - Close to 100% efficiency
  - Improved resolution

BACKUP



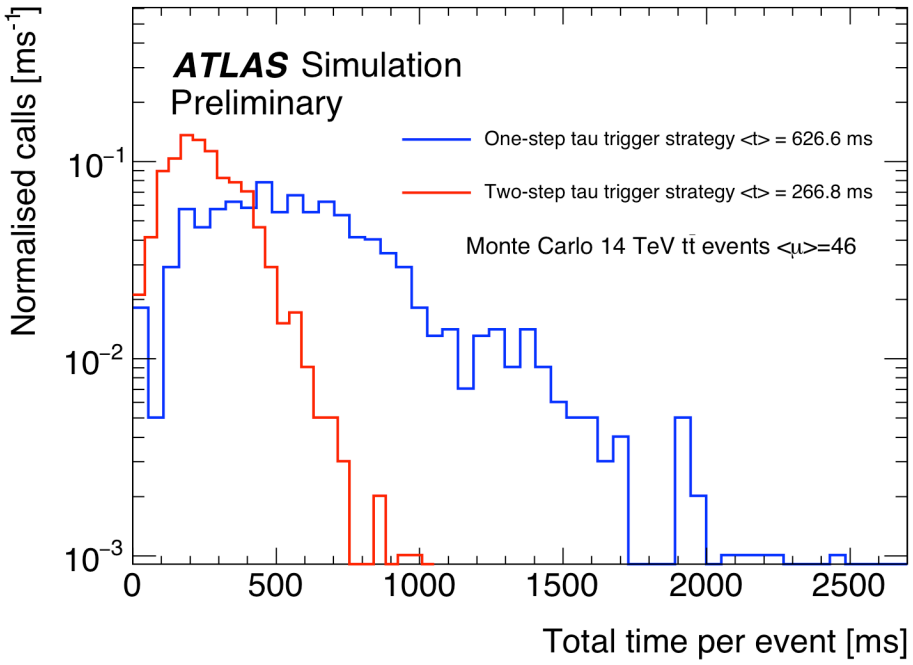


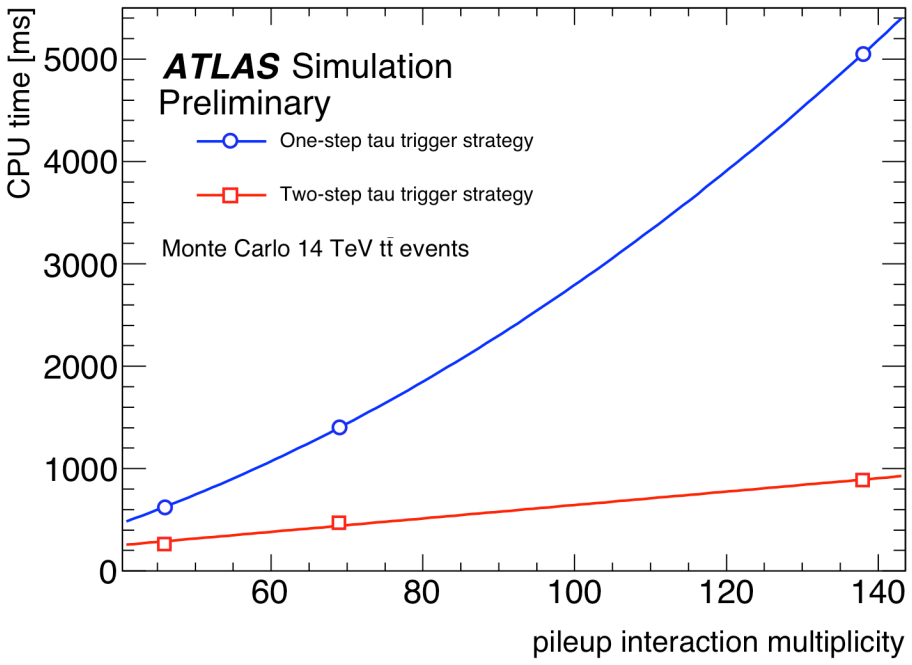
Envelopes

Pixel		45.5<R<242mm |z|<3092mm
SCT barrel		255<R<549mm |z|<805mm
SCT end-cap		251<R<610mm 810<|z|<2797mm
TRT barrel		554<R<1082mm |z|<780mm
TRT end-cap		617<R<1106mm 827<|z|<2744mm

Two-step tracking for tau/b-jets

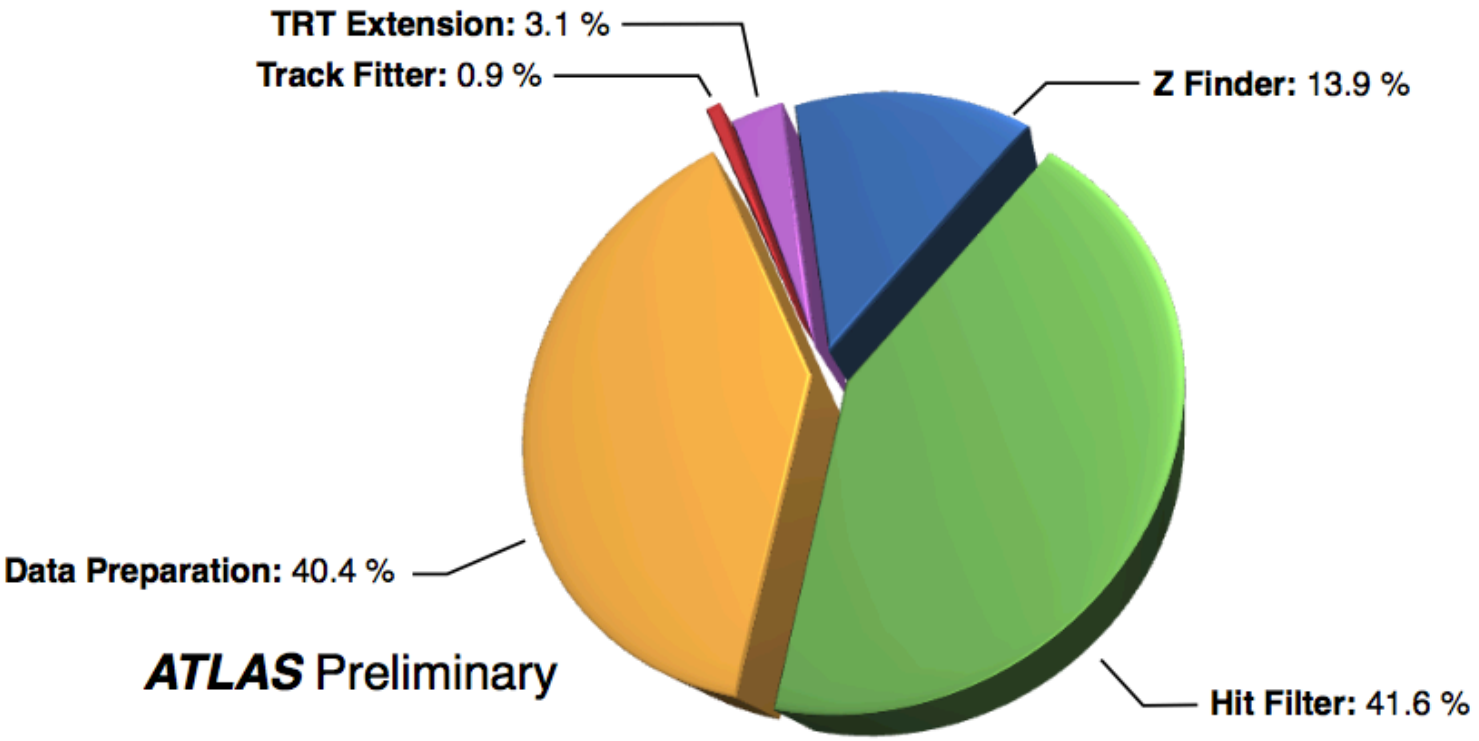
- In one-step tracking, CPU timing exhibits non-linear dependence on pile-up (i.e. number of spacepoints to be processed)
- Two-step tracking:
  - reject events without a high-p_T lead track in the RoI with $\Delta\eta \times \Delta\phi \times \Delta z = 0.1 \times 0.1 \times 0.225$ with respect to the central RoI coordinates
  - find additional tracks in $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ RoI within $\Delta z = 10$ mm of lead track



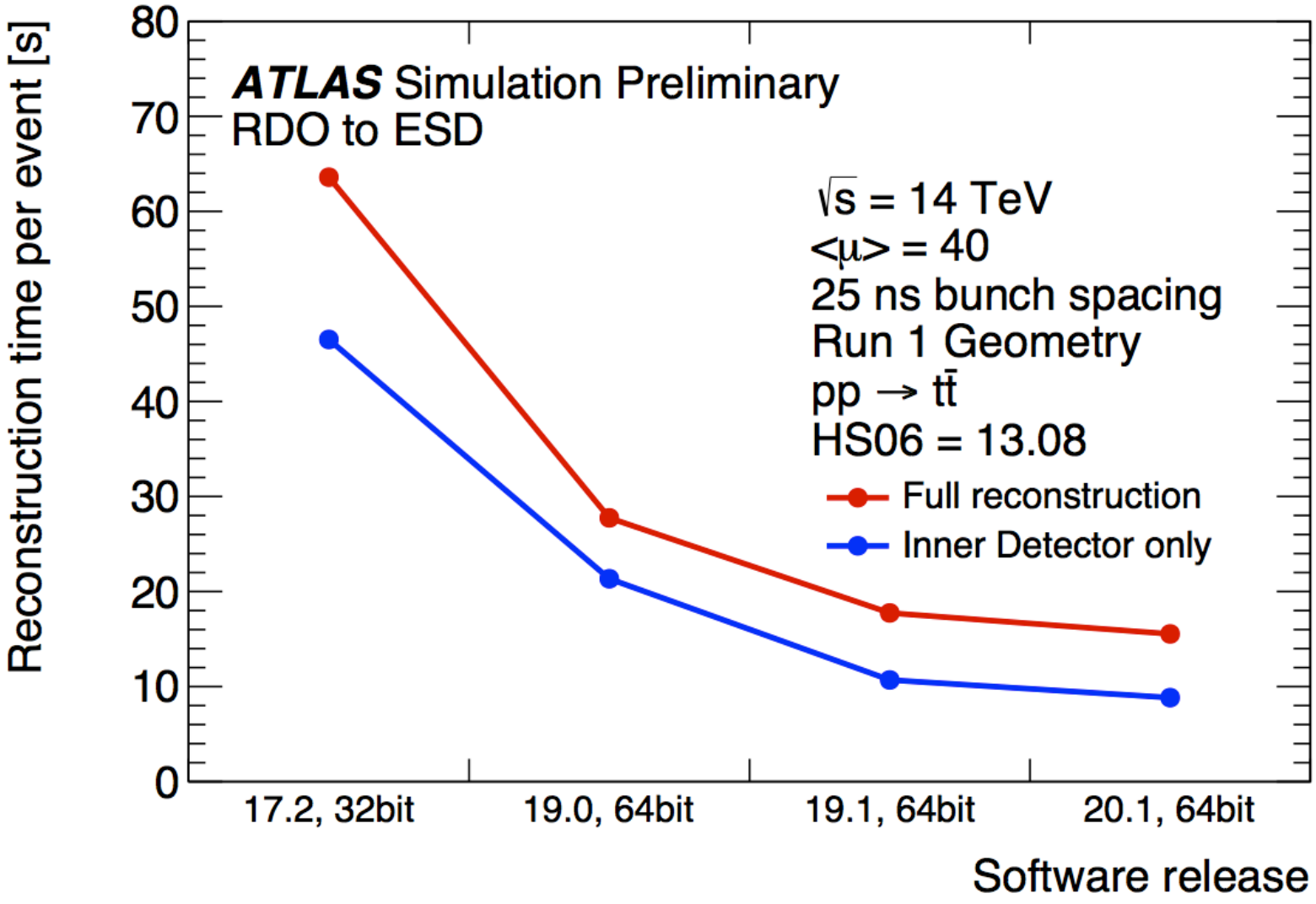


Profiling and optimisation

- Run-II algorithm built from Run-I blocks
- Investigation on improvement in speed and memory usage
- Various tools used for profiling
  - GOoDA
  - perf
  - Callgrind



Improvement from software release



IBL – improved resolution

- Showing here *offline* tracking resolution
- Data 2015 collected using minimum bias trigger
- Data 2012 derived from a mixture of jet, tau and missing E_T triggers